REPORT

Health of Canadians in a Changing Climate

ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Health Canada is the federal department responsible for helping the people of Canada maintain and improve their health. Health Canada is committed to improving the lives of all of Canada's people and to making this country's population among the healthiest in the world as measured by longevity, lifestyle and effective use of the public health care system.

This Report was developed with understanding and acknowledgement that Canada was built on the original homelands of many culturally diverse and historically distinct First Nations people and Inuit. Canada also is part of the ancestral homelands of The Métis. We respectfully acknowledge all Indigenous Peoples on whose traditional lands we live and work.

Également disponible en français sous le titre :

La santé des Canadiens et des Canadiennes dans un climat en changement : faire progresser nos connaissances pour agir

To obtain additional information, please contact:

Health Canada

Address Locator 0900C2

Ottawa, ON K1A 0K9

Tel.: 613-957-2991

Toll free: 1-866-225-0709

Fax: 613-941-5366

TTY: 1-800-465-7735

E-mail: hc.publications-publications.sc@canada.ca

Publication date: February 2022

Cat.: H129-121/2022E-PDF

ISBN: 978-0-660-41525-3

Pub.: 210509

Health of Canadians in a Changing Climate: Advancing our Knowledge for Action

Edited by

Peter Berry, Health Canada

Rebekka Schnitter, Health Canada

Suggested Citation

Berry, P., & Schnitter, R. (Eds.). (2022). *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action.* Ottawa, ON: Government of Canada.

Authors

Peter Berry, Health Canada

Phil Blagden, Health Canada

Céline Campagna, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Marika Egyed, Health Canada

Paddy Enright, Health Canada and University of Waterloo

Pierre Gosselin, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Sherilee Harper, University of Alberta

Katie Hayes, Health Canada and University of Toronto

National Collaborating Centre for Indigenous Health with contributions from Donna Atkinson, Roberta Stout, Regine Halseth, and Margo Greenwood

Nicholas Ogden, Public Health Agency of Canada

Rebekka Schnitter, Health Canada

Tim K. Takaro, Simon Fraser University

Contributors

Lewis Archer, National Reconciliation Program at Save the Children

Donna Atkinson, National Collaborating Centre for Indigenous Health

Jura Augustinavicius, McGill University

Amber Bedard, University of Calgary

Peter Berry, Health Canada

Catherine Bouchard, Public Health Agency of Canada

Gabrielle Brankston, University of Guelph

Elizabeth Brown, Public Health Ontario

Jordan Brubacher, Simon Fraser University

Chris Buse, University of Northern British Columbia and University of British Columbia

Céline Campagna, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Susan Clayton, College of Wooster

Christina Cook, University of British Columbia

Tricia Corrin, Public Health Agency of Canada

Ashlee Cunsolo, Memorial University

David Demers-Bouffard, Institut national de santé publique du Québec

Antonia Dibernardo, Public Health Agency of Canada

Shawn Donaldson, Health Canada and Carleton University

Michael A. Drebot, Public Health Agency of Canada

Gemma Dunn, Uisce (Ishka) Consulting International

Betty Edwards, Health Canada

Susan Elliott, University of Waterloo

Paddy Enright, Health Canada and University of Waterloo

Aamir Fazil, Public Health Agency of Canada

David N. Fisman, University of Toronto

Mike Flannigan, University of Alberta

Manon Fleury, Public Health Agency of Canada

James Ford, University of Leeds

Eleni Galanis, BC Centre for Disease Control and University of British Columbia

Lindsay Galway, Lakehead University

Pierre Gosselin, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Amy Greer, University of Guelph

Regine Halseth, National Collaborating Centre for Indigenous Health

Carla Hilario, University of Alberta

Emily Jenkins, University of Saskatchewan

Daniel Jubas-Malz, University Health Network

Nia King, Queen's University

Tom Kosatsky, British Columbia Centre for Disease Control

Julianne Kus, University of Toronto

Eric Lavigne, Health Canada

Patrick A. Leighton, Université de Montréal and CIUSSS du Centre-Sud-de-l'Île-de-Montréal

Alexandra Lesnikowski, Concordia University

L. Robbin Lindsay, Public Health Agency of Canada

Benny Ling, Health Canada

Diana Valencia Lopez, Health Canada

Ann-Marie Lowe, Public Health Agency of Canada

Antoinette Ludwig, Public Health Agency of Canada

Catherine Macdonald, Alliance for Healthier Communities

Morgan MacNeill, Health Canada

Paul Makar, Environment and Climate Change Canada

Maria Malik, Canadian Food Inspection Agency

Carlyn Matz, Health Canada

Deborah McGregor, York University

Lorraine McIntyre, British Columbia Centre for Disease Control

Ericha Moores, Natural Resources Canada

Shaun K. Morris, University of Toronto

Tyrone Munroe, Four Arrows Regional Health Authority

Hannah Tait Neufeld, University of Waterloo

Victoria Ng, Public Health Agency of Canada

Jolly Noor, University of Waterloo

Jaclyn Paterson, Health Canada

Radenko Pavlovic, Environment and Climate Change Canada

Melissa Perri, University of Toronto

David Plummer, Environment and Climate Change Canada

Sami Qutob, Health Canada

Jacinthe Racine, Environment and Climate Change Canada

Pierre Raymond, Health Canada

Jérôme Ribesse, Synergie Santé Environnement

Gabrielle Richards, University of Ottawa

Robyn Rittmaster, Health Canada

Rebekka Schnitter, Health Canada

Shanaya Singh, Health Canada

Ben Smith, Public Health Agency of Canada

Roberta Stout, National Collaborating Centre for Indigenous Health

Rebecca Stranberg, Health Canada

Denise Thomson, University of Alberta

Linda Varangu, Canadian Coalition for Green Health Care

Marielle Verret, Health Canada

Linda Vrbova, Public Health Agency of Canada

Lisa Waddell, Public Health Agency of Canada

Shannon Waters, Vancouver Coastal Health

Aaron Wilson, Health Canada

Heidi Wood, Public Health Agency of Canada

Guoliang Xi, Health Canada

Acknowledgements

The Climate Change and Innovation Bureau at Health Canada gratefully acknowledges the contribution of the following people in assisting in the development of assessment chapters.

Amreen Babujee, Katharine Neale, Alexandra Sawatzky, Francesca Cardwell, Robyn Hocking

Carolyn Brown is gratefully acknowledged for contributions to technical writing and editing that made this publication possible.

Reviewers

The Climate Change and Health Innovation Bureau at Health Canada gratefully acknowledges the contribution of the following people in providing guidance, reviewing chapters and providing written comments.

Bryan Adlard, Abdul Afghan, Christina Ameni, Eric Aubin, Helen Berry, Sonya Billiard, Barrie Bonsal, Elizabeth Bush, Tia Caprino, Anne Castelino, Keith Chau, Jade Craig-Payette, Ashlee Cunsolo, Angie Daze, Rob de loe, Chris Derksen, Warren Dodd, Patricia D'Onghia, Helen Doyle, Monica Dutt, Kristie L. Ebi, Elizabeth Elliott, Neville Ellis, Marjorie Emmanuel, Neal Fann, Victor Gallant, Frank Geraghty, Zoe Gillespie, Nela Gojevic, Michelle Hooper, Courtney Howard, Kristen Howe, Dave Hutton, Cheryl Khoury, Richard King, Megan Kirchmerier-Young, Christina Lee-Fuller, Sarah Levitt, Johanna MacDonald, Carlyn Matz, Stephanie McFayden, Deborah McGregor, Jeremy McNeil, Natasha Mohammed, Asish Mohapatra, Andy Morse, Pemma Muzumdar, Erin Myers, Meghan Myles, Chad Nelson, Simon Otto, Claudel Pétrin-Desrosiers, Bruno Pilote, David Plummer, Dominique Poulin, Kim Raine, François-Nicolas Robinne, Pablo Romero-Barrios, Daniel Rosenbaum, Rainer Sauerborn, Ryan Schwartz, Tina Sheppard, Raquel Silva, Kelly Skinner, Victoria Tunstall, David Turcotte, Eduardo Vides, Sonia Wesche, Kyle Whyte, Kara Williamson, Britt Wray, and Xuebin Zhang.

Secretariat and Peer Review Coordination

Rebekka Schnitter, Peter Berry, Jolly Noor, and Brianna Dukeshire

About the National Climate Change and Health Assessment

Why This Assessment Is Needed

The rapid rate of global climate change and the diminishing opportunity to keep warming below 1.5°C (IPCC, 2018) has increased awareness of the urgent need to prepare for climate change impacts on health and to mitigate climate change (WHO, 2018). Near-term reductions in greenhouse gases (GHGs) will not prevent further warming of the globe in the next few decades; increased efforts are needed to adapt to protect all Canadians from the associated health impacts (WHO, 2013; Smith et al., 2014; Watts et al., 2018). In many important areas, progress has been made globally to prepare individuals and health systems for climate change impacts, but a significant adaptation gap exists in many countries (Martinez & Berry, 2018).

Health authorities, researchers, and individual Canadians are seeking information about the way climate change is currently affecting health and is projected to do so in the future. Many local health units have undertaken assessments of climate change, health vulnerability, and adaptation and have begun taking measures to protect health. The number of decision makers requiring the latest scientific evidence of health threats from climate change is expanding, with new programs at local to national levels to support efforts to prepare for impacts. An example is Health Canada's climate change and health capacity-building program, HealthADAPT, launched in 2018 (Government of Canada, 2019).

At the same time, attribution studies have forged a causal link between climate change and health effects associated with specific events, and the urgency of efforts to better understand climate change impacts has increased, with international studies suggesting that even modest increases in temperature, expected in the next few decades, are associated with significant health impacts (IPCC, 2018). Scientists have also cautioned about possible limits to health adaptation (Watts et al., 2015; IPCC, 2018) under current rates of warming.

This assessment, *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*, is the first comprehensive study of current and projected risks from climate change to the health of Canadians since 2008. It was developed by a team of more than 80 subject matter experts from regional and federal health authorities and academic institutions across Canada. It addresses the evolving knowledge needs of government decision makers, civil society organizations, and individual Canadians by providing evidence-based and, where possible, quantitative information to help people understand how Canada's climate is changing, and the effects on health and health systems, including implications for those most at risk in society. For key risks to health, it also examines current efforts to prepare for climate change, from individual to national levels, and explores what further efforts are needed. The potential for very large co-benefits to health of well-designed measures to reduce GHGs are also explored in the report.

As part of the national assessment process, *Canada in a Changing Climate* (Natural Resources Canada, 2020), this study contributes to broaden understanding of climate change impacts and adaptation by the Government of Canada, including a focus on Canada's changing climate (Bush & Lemmen, 2019), national issues, regional perspectives, and impacts on First Nations, Métis, and Inuit peoples and communities. The national assessment process is based on a broad partnership of subject-matter experts and assessment users from all orders of government, Indigenous organizations, universities, professional and non-governmental groups, and the private sector. It includes engagement through a National Advisory Committee and the Adaptation Platform and engages the public through meetings, conferences, and online engagement tools.

Report Format

The chapters in this report discuss relevant findings from the scientific literature on priority health risks related to climate change and on adaptation options for protecting health. Where information is available, chapters include quantitative projections of future health risks from climate change (see Chapter 5: Air Quality; Chapter 6: Infectious Diseases; Chapter 7: Water Quality, Quantity, and Security). The report includes analysis of the interplay between climate change and important determinants of health, which can affect adaptive capacity and health equity to influence vulnerability to health impacts (see Chapter 9: Climate Change Impacts on Health Equity). The assessment includes a separate chapter on climate change impacts on Indigenous Peoples' health and includes information on these impacts throughout the full report (see Chapter 2: Climate Change on Indigenous Peoples' Health in Canada). All chapters include illustrative case studies of actions being undertaken by health authorities to reduce risks to Canadians from climate change.

The report is structured as follows:

Chapter 1: Climate Change and Health Linkages – provides information on how Canada's climate is changing and is projected to continue to change, to support the understanding of growing threats to health. It identifies the complex pathways through which climate change affects health and the key health risks facing Canadians.

Chapter 2: Climate Change and Indigenous Peoples' Health in Canada – explores current impacts of climate change on the health of First Nations, Inuit, and Métis peoples and communities. It highlights the role of current and legacy impacts of colonialism, racism, and discrimination in contributing to these impacts and highlights, through a number of case studies, the strengths and resilience of Indigenous Peoples in planning for the impacts.

Chapter 3: Natural Hazards – reviews evidence of how natural hazards are affected by climate change and their impacts on the mental, social, and physical health of Canadians. It then provides information about effective adaptation strategies for reducing risks and the co-benefits of undertaking these measures. It proposes research directions to address key knowledge gaps in this field.

Chapter 4: Mental Health and Well-Being – discusses current evidence of the mental health impacts of climate variability and change on Canadians, including regions and populations at higher risk for such impacts. It highlights important factors that support psychosocial well-being and adaptation options for preparing for climate change and limiting impacts from current hazards.

Chapter 5: Air Quality – examines the linkages between climate change and air quality in Canada, including how the health of populations could be affected by changes in air quality under various climate scenarios. The chapter also discusses the health co-benefits associated with efforts to mitigate GHG emissions and adaptation options for protecting Canadians from climate change impacts.

Chapter 6: Infectious Diseases – highlights the impacts of climate change on risks from infectious diseases of importance for public health in Canada, including those that are current, known disease risks (e.g., Lyme disease, West Nile virus) and new risks that may emerge. It then discusses adaptation to reduce climate-related infectious diseases, including their importance for populations at increased risk and the capacity of health systems to take needed actions. Existing research gaps are highlighted for the reader.

Chapter 7: Water Quality, Quantity, and Security – describes the relationship between climate change and the water cycle in Canada and attendant risks to the health of Canadians from impacts on water contamination, safety, and security. The vulnerability of drinking water systems, private wells, and Indigenous water systems is examined, and projected health risks from climate change are discussed. The chapter presents possible adaptations to reduce risks and important knowledge gaps in efforts to take actions.

Chapter 8: Food Safety and Security – presents existing evidence on the impacts of climate change on health through effects on food safety and security. It describes the nexus among climate change, the food system, and human health, as well as key drivers of poor health outcomes in Canada. Populations and regions at higher risk from impacts are discussed, along with options for adapting to future impacts.

Chapter 9: Climate Change and Health Equity – examines how important factors and trends at the individual, community, and health system levels can increase or decrease climate change risks to the health of Canadians. The implications of climate change for health equity are explored, along with measures to empower specific population groups to adapt. The chapter also provides tools and resources that support the integration of health equity considerations into climate change and health activities, such as vulnerability and adaptation assessments, and the adaptation design and evaluation process.

Chapter 10: Adaptation and Health System Resilience – provides an overview of adaptation as the key response to climate change impacts on the health of Canadians and discusses the importance of mainstreaming climate information into existing policies and planning, adaptation to future climate change conditions, and measures to address adaptation challenges. The status of health adaptation in Canada is investigated, along with evidence of climate change impacts on health systems, trends in health system vulnerability, and new tools that health authorities can use to build resilience.

Headline Statements

- **Climate change is already negatively impacting the health of Canadians.**

  Climate change has been a driver of recent health effects related to rising temperatures and extreme heat, wildfires, and the expansion of zoonotic diseases into Canada, such as Lyme disease (see Chapter 3: Natural Hazards; Chapter 5: Air Quality; Chapter 6: Infectious Diseases).

- **Health risks will increase as warming continues, and the greater the warming, the greater the threats to health.**

  Projected increases in the frequency and severity of intense precipitation events, urban flood risk, droughts, extreme heat, wildfires, and storms will directly affect health by causing more illness, injuries, and deaths, without greater adaptation efforts. The current burden of mental ill health in Canada is likely to rise as a result of climate change. Disruptions to food systems and water resources; worsening of air pollution; the emergence and re-emergence of climate sensitive infectious diseases; and increasing demands on health systems will continue to threaten Canadians' health (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada; Chapter 3: Natural Hazards; Chapter 4: Mental Health and Well-Being; Chapter 5: Air Quality; Chapter 6: Infectious Diseases; Chapter 7: Water Quality, Quantity, and Security; Chapter 8: Food Safety and Security).

- **Some Canadians are affected more severely by climate change, as exposure and sensitivity to hazards and the ability to take protective measures varies across and within populations and communities.**

  Growing climate change impacts worsen socio-economic conditions harmful to health, such as poverty, and amplify health inequities. Combined with increasing rates of chronic diseases, social isolation and an aging population, climate change augments impacts on health. People disproportionately affected by climate change include children; pregnant people; First Nations, Inuit, and Métis peoples; people with chronic illnesses; outdoor workers; low income individuals; and people with disabilities (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada; Chapter 3: Natural Hazards; Chapter 9: Climate Change and Health Equity).

- **The effects of climate change on health systems in Canada — for example, damage to health facilities and disruptions to health services and operations — are already evident and will increase in the absence of strong adaptation measures.**

  Health infrastructure, operations, health financing, health care, public health programming, supply chains, and the health workforce can be impacted by extreme weather events and by chronic stresses from longer-term warming, reducing access to and quality of care to Canadians. Health facilities and services in rural and remote areas, and health systems that have not assessed and managed risks, face the greatest threats. Compounding climate change hazards that can arise — for example, when extreme heat occurs with drought and a wildfire — pose severe risks to individuals and the health systems they rely on (see Chapter 10: Adaptation and Health System Resilience).

- **Efforts to prepare for climate change are known to reduce risks and protect health. We must take action now.**

  Many health authorities are working with decision makers in other sectors, such as emergency management, to take actions to protect people, communities, and health systems. This is called adaptation. Adaptation measures must be scaled up rapidly and substantially if current and future health impacts are to be reduced (see Chapter 10: Adaptation and Health System Resilience).

- **The health impacts of climate change on First Nations, Inuit, and Métis peoples are far-reaching, with disproportionate impacts on their communities, including food and water security and safety, air quality, infrastructure, personal safety, mental health and wellness, livelihoods, culture, and identity.**

  Indigenous Peoples have been adapting to changing environments since time immemorial. Indigenous knowledge systems and practices are equal to Western scientific knowledge and contribute to Indigenous Peoples' survival, adaptation, and resilience. Preparing for climate change requires addressing determinants of health and ongoing health inequities. It also requires that Indigenous Peoples' rights and responsibilities over their lands, natural resources, and ways of life are respected, protected, and advanced through Indigenous-led climate change mitigation, adaptation, policy, and research (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada).

- **To successfully protect all Canadians from the health impacts of climate change, decision makers must pursue adaptation actions that are inclusive and equitable and consider the needs of racialized, marginalized, and low income populations.**

  Existing health inequities could be made worse unless future adaptation and greenhouse gas mitigation efforts are designed to address them. Redressing inequities and strengthening determinants of good health, such as improving access to health care and housing quality, can help reduce the impacts of climate change on individual health (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada; Chapter 9: Climate Change and Health Equity).

- **Increased efforts to reduce greenhouse gas emissions are required to help protect the health of Canadians.**

  The continued emission of greenhouse gases into the atmosphere will impose limits on our ability to adapt and lead to more severe impacts on health. The health sector can show leadership in reducing its carbon footprint and improving environmental sustainability while building resilience to future climate change impacts (see Chapter 10: Adaptation and Health System Resilience).

- **Reducing greenhouse gas emissions can provide very large and immediate health co-benefits to Canadians.**

  The economic value of the health co-benefits can help to offset the implementation costs of measures. Health co-benefits of taking actions on air pollution are estimated to include thousands of avoided premature deaths annually in Canada by the middle of the century (see Chapter 5: Air Quality; Chapter 10: Adaptation and Health System Resilience).

Guide to the Report

This assessment builds on previous scientific studies and reports on risks to the health of Canadians so that government decision makers, health practitioners, researchers, and individual Canadians can take effective measures to protect health now and to prepare for future impacts. The Executive Summary provides an overview of key findings from each chapter of the report to help readers to easily access information most relevant to their efforts to prepare for climate change.

Assessment Approach and Methods

Beginning in 2017, Health Canada led focus groups and bilateral meetings with health sector decision makers, civil society organizations, researchers, National Indigenous Organizations, and youth to receive input on conducting the assessment. Advice was provided on key health issues to be addressed in the report, effective engagement processes during the assessment, and communicating the final results. The discussions revealed a strong interest in gaining a greater understanding of emerging issues related to climate change impacts on mental health, health equity, and Canada's health systems. In addition, partners highlighted the need for a strong focus on climate change impacts on the health of First Nations, Inuit, and Métis peoples and their communities; the importance of Indigenous knowledge systems for adapting; and the requirement for full and meaningful engagement, inclusion, and leadership of First Nations, Inuit, and Métis peoples to address climate change impacts. Partners also highlighted the strong desire to have this report include discussion of reducing GHG emissions as the key preventive approach to protecting health from climate change and of capturing the large health co-benefits of well-designed policies and measures.

The assessment builds on knowledge from the previous Government of Canada report, *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (Chapter 7: Human Health; Berry et al., 2014), as well as the previous comprehensive national climate change assessment, *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity* (Séguin, 2008). The report draws from a large body of scientific peer-reviewed research and other publicly available sources and is an evidence-based, mixed-methods study of the health and health system impacts from climate change in Canada. Authors compiled and assessed research to summarize the current state of science on priority health risks facing Canadians. The sources that informed this assessment included peer reviewed and grey literature in both English and French. There was no set cut-off period for the literature, although precedence was given to recent peer-reviewed literature and to seminal literature on the topic area published since the previous national climate change and health assessment, released in 2014.

While the geographic focus of this assessment is Canada, the authors draw upon the increasing number of studies at the local or regional levels in Canada and from analysis in other countries that are relevant for understanding impacts and adaptation options in Canada. The report was extensively reviewed by Canadian and international experts and federal health-portfolio partner departments; and a public review of the chapters was also undertaken.

Intersecting Factors that Increase Climate Change Vulnerability

Identifying intersecting factors that increase vulnerability to climate change impacts on health was a key objective of this assessment. Knowledge of these factors allows for the development of targeted adaptation measures that address challenges for individuals or health sector decision makers in protecting health from climate change. Each chapter includes discussion of factors that increase the risk of climate-related health impacts, and a full chapter is dedicated to this topic (see Chapter 9: Climate Change and Health Equity).

Uncertainty in the Analysis

Studies of climate change impacts on health are challenged by complex pathways and determinants — for example, factors related to personal behaviours, socio-economic conditions, and health system capacity. Through these pathways and determinants, individuals are exposed to climate hazards, respond to the threats, and experience effects on health. Exposures may be short-term and direct, as in the case of extreme heat events, or occur over longer time scales and be mediated by indirect factors related to physiological sensitivity and adaptive capacity. Analysis in this and previous Canadian assessments was hampered by Canada's large geography and diverse population centres, including smaller populations in remote and Northern communities, and limitations associated with the completeness, comparability, and usability of available health and climate data (Seguin, 2008; Berry et al., 2014). Understanding the potentially severe health impacts of compounding, cascading, or cumulative climate change impacts (for example, the floods and wildfires that struck parts of British Columbia in quick succession in 2017) is a larger and even more complex challenge and was beyond the scope of this report.

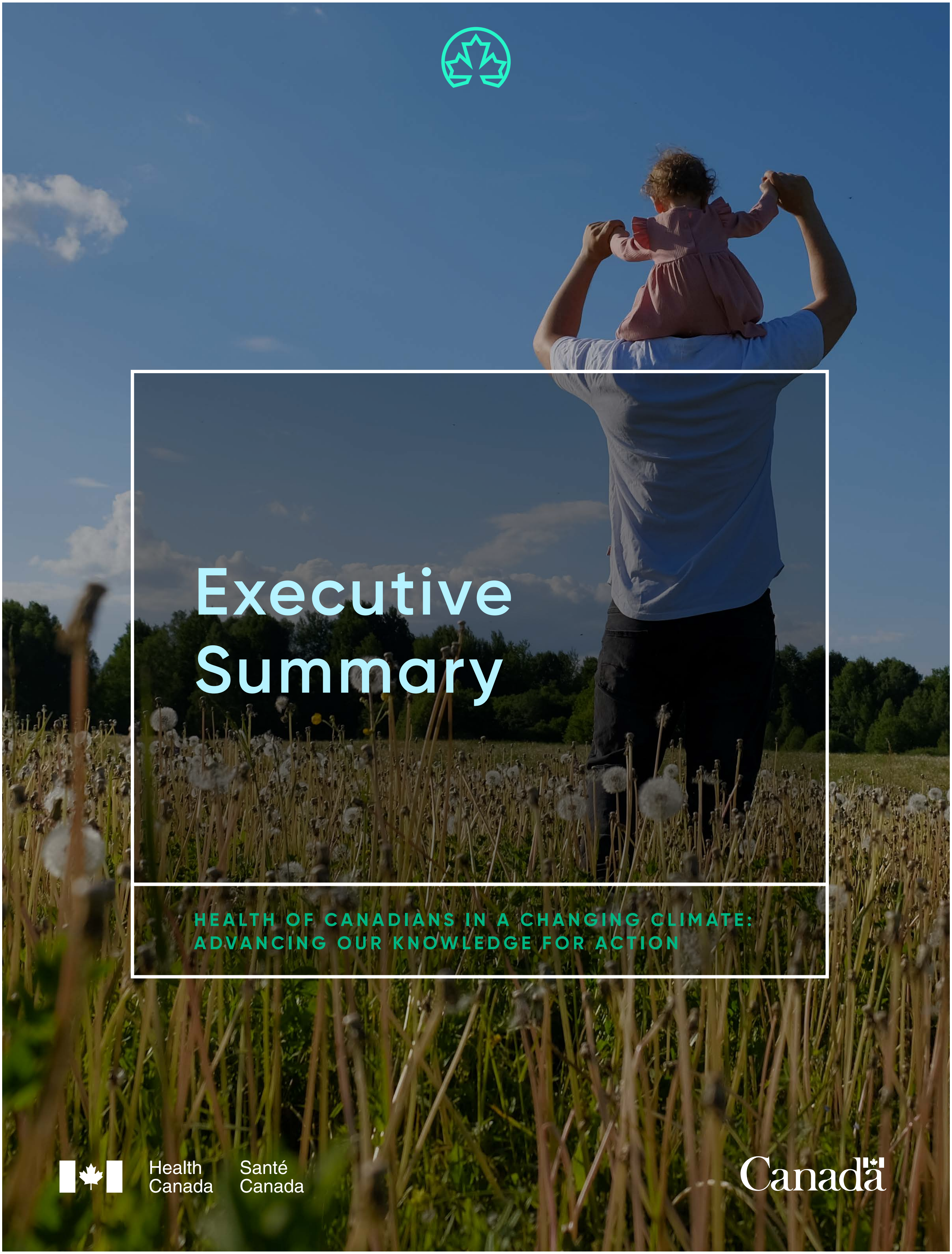
The number of studies that project risks to the health of Canadians from climate-related hazards, such as wildfires, extreme heat, air pollution, infectious diseases, and water-borne diseases, have increased in the last decade. However, some health outcomes related to climate change, including impacts on mental health, health equity, health systems, and food insecurity, remain difficult to model because of complex and dynamic drivers or data limitations. Studies of projected health risks from climate change reported in this assessment often included new analysis or existing studies of future health outcomes based on low Representative Concentration Pathway (RCP 2.6), medium (RCP 4.5), and/or high (RCP 8.5) emissions scenarios. Projections from the Coupled Model Intercomparison Project 5 (CMIP5) using the RCPs 2.6, 4.5, and 8.5 are widely used and have undergone robust evaluation by the science community. Where possible, authors drew upon results of climate scenarios, models, and projections reported in *Canada's Changing Climate Report* (Bush & Lemmen, 2019).

Economic estimates of climate change impacts on the health of populations and health systems, and of the costs of needed adaptation measures, are required for cost-benefit and cost-effectiveness analysis of measures to address climate change. This includes measures to adapt to health impacts and actions to prevent future climate change through GHG mitigation that may result in health co-benefits. A paucity of data still precludes rigorous economic analysis along the spectrum of health concerns facing Canadians from climate change. Selected examples and case studies of economic impacts (Chapter 5: Air Quality; Chapter 10: Adaptation and Health System Resilience) are included in this assessment report.

Assessment of confidence and uncertainty are critical elements of climate change and health scientific assessments. Uncertainty arose from data limitations related to a lack of spatial or temporal fit between climate and health information. It also arose from limitations or lack of models of relationships between climate and health (e.g., future mental health impacts), and lack of data integrated across disciplines and from projections of human behaviour (e.g., future adaptation actions by individuals). In this report, authors used standard language to communicate their confidence in the results, and the level of certainty or uncertainty. This was generally based on the amount of existing evidence to support a statement (e.g., number of studies), the quality of the evidence (e.g., based on an assessment of the credibility of the source authors and literature), and the relationships between observed and projected trends.

Research Needs

The assessment revealed that significant knowledge gaps remain about climate change impacts on health, vulnerabilities, and needed adaptations to reduce current impacts and avoid much more severe impacts in the future. Each chapter provides information on research needed to build the integrated knowledge base to inform future policy decisions by local, regional, provincial, territorial, and national governments as they prepare for climate change.



Executive Summary

HEALTH OF CANADIANS IN A CHANGING CLIMATE:
ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Summary

Climate change is already affecting the health of Canadians and, without taking concerted action, will continue to result in injury, illness, and death — with greater warming comes greater health risks. Many of these health impacts can be prevented if Canada rapidly and substantially scales up efforts now to adapt to growing threats to health. With increased awareness of the issue and collaboration among partners, health decision makers and communities should seize this window of opportunity to adopt strong adaptation measures and make health systems and facilities environmentally sustainable and resilient to climate change. Otherwise, climate change will continue to stress health systems, through longer-term impacts and by increasing disasters and emergencies that threaten to overwhelm their ability to protect Canadians and their communities.

How to use this report

The report *Health of Canadians in a Changing Climate: Advancing Our Knowledge for Action* assesses the latest research and knowledge to inform Canadians about the effects of climate change on health and health systems, populations most at risk of these effects, and the adaptation measures being taken in Canada.

The report is designed to help decision makers plan for the health effects of climate change and take action to reduce risks as well as to empower individuals to protect themselves and their loved ones. Public health officials can learn from promising practices to mainstream consideration of climate change and health into their plans and activities.

Information presented in the report and the accompanying infographics, policy briefs, and presentations may be used by local and regional health authorities, and provincial and territorial governments to undertake climate change and health vulnerability and adaptation assessments, and engage and mobilize partners in adaptation efforts. It can also be used to raise awareness among all Canadians of the need to take concerted efforts to address the climate change challenge and of the many health benefits of doing so.

Climate Change Impacts on Health

Research shows that the health of Canadians has been affected by climate variability and change in recent years — both directly, when extreme heat and other natural hazards result from climate change, and indirectly, through a range of social, environmental, cultural, and economic pathways that have effects on health. Recent health effects related to rising temperatures and extreme heat, wildfire events, and the expansion of zoonotic diseases into Canada, such as Lyme disease, are linked to a warming climate.

All Canadians can be affected by climate change; however, the distribution of these impacts and related health risks are not uniform. Seniors, children, racialized populations, low-income individuals, individuals with chronic health conditions, and First Nations, Inuit, and Métis peoples often experience greater health impacts of climate change. Existing health inequities and variations in the status of determinants of health can drive this increased risk, as can an individual's sensitivity (such as pre-existing health conditions) and exposure (such as geographic location) to climate hazards.

Natural Hazards

A range of natural hazards, including extreme weather events, routinely affect the health of Canadians, but sometimes effects on communities can be catastrophic. The number of days when the maximum temperature climbs over 30°C has increased in Canada, by about one to three days annually from 1948 to 2016 {3.4.1.2}. Such extreme heat increases deaths in Canadian cities by 2% to 13%, according to one study {3.4.2.1}. It is estimated that recent extreme heat events ("heat waves") in Quebec have led to a significant number of deaths: 291 in a 2010 extreme heat event and 86 in a 2018 extreme heat event. A severe extreme heat event in British Columbia in 2021 resulted in the death of 740 people {3.4.2.2}. Extreme heat can also increase hospitalization for cardiovascular problems {3.4.2.4} and pregnancy complications, including premature birth, early delivery, miscarriage, and congenital abnormalities such as neural tube defects {3.4.2.6}. While some risks, such as injury and death from cold, may decrease, the increase in death due to heat is expected to outpace the reduced rates of death due to cold {3.6.3.2}.

Drought increases fine dust in the air, which affects cardiovascular and respiratory health function. During droughts, winds spread pollen, fungi, mould, and bacteria, causing allergies and diseases. When rain falls after drought, pathogens can be carried into water bodies and drinking water systems, causing water-borne disease. Crop failures due to drought have many ripple effects on food security and food prices, as well as on the mental health of farmers and others in agricultural communities {3.7.2.4}.

Rainstorms and freezing rain result in pedestrian and motor vehicle-related injuries and other health risks due to infrastructure failure (such as power outages). Wind can also lead to accidents, especially if it reaches speeds of more than 70 km/h. Storms can lift massive amounts of pollen into the air, causing asthma outbreaks. In addition to washing viruses, bacteria, and parasites into surface and groundwater, leading to acute gastrointestinal illness, storms can spread the bacteria in airborne particles that cause legionellosis {3.9.2.5}.

Flooding can result in injuries, drowning, hypothermia, and electrocution. Because floodwaters can become contaminated from various sources, including sewage overflow, they can cause gastrointestinal and skin disease as well as infect wounds. Flooded homes can become unsafe because of mould, fungi, and bacteria. If power outages result from storms or floods, these can lead to accidents due to darkness, hypothermia from lack of heat, and carbon monoxide poisoning from using barbecues, camp stoves, and outdoor heaters indoors {3.9.2.6; 3.10.2.5}. Flooding can result in the evacuation of communities and cause long-term displacement, including from traditional territories, which can cause significant impacts on the health and well-being of affected Indigenous Peoples {2.4.1}. Studies show that flood victims can suffer mental health problems and cardiac events after a flood {3.10.2}.

Climate projections show increased extreme heat events in communities across Canada, and less precipitation in the summer throughout Southern Canada, with more droughts and water shortages in the summer in the Southern Prairies and the British Columbia Interior throughout the rest of this century {3.7.1}. While summer rain will decrease in Southern Canada, paradoxically, overall annual precipitation is increasing, especially in Northern Canada. More extreme precipitation events (unusually heavy rainfalls) are expected in the future {3.9.1}, leading to increased urban flood risk. Rising sea levels on the east coast of Canada are expected to submerge and erode coastlines.

With changing rainfall, snowfall, and temperatures, landslides are expected to become more common; the effect on avalanches has not yet been determined {3.11.1}. These hazards are rare in Canada but pose a risk of injury and death when they do happen. Avalanches are a risk for back-country skiers and snowmobilers, and landslides threaten homes and other infrastructure on hillsides {3.11.3}.

A growing threat to health in Northern communities is permafrost melting. Permafrost currently covers 40% of Canada's landmass, but this area is expected to decrease by between 16% to 20% by 2090, compared with 1990 {3.11.1}. Thawing threatens the stability of buildings, roads, and communities in Northern Canada, with concomitant effects on transportation and access {2.4.1}. As it melts, permafrost may release infectious diseases from frozen wildlife carcasses and heavy metals such as mercury that can threaten health {3.11.2.3}.

Air Quality

Exposure to air pollution causes a range of adverse health effects, including respiratory symptoms, development of heart and lung diseases including cancer, and premature death. Three major outdoor air pollutants — fine particulate matter, ground-level ozone, and nitrogen dioxide — together cause about 15,300 premature deaths in Canada annually, with an economic cost of $114 billion {5.3}. Climate change and air quality are closely linked. Key air pollutants are produced from fossil fuel combustion, which is also a primary source of greenhouse gases (GHGs) {5.4}, and from wildfires, which are increasing as a result of climate change. Some air pollutants, such as methane and soot, worsen climate change, whereas some scatter solar radiation, cooling the planet. Climate change affects air quality, as higher temperatures can increase pollutants in smog, such as ground-level ozone. Large, slow-moving high-pressure weather systems, which are expected to become more common with climate change, also worsen air pollution {5.4.3 and Figure 5.1}.

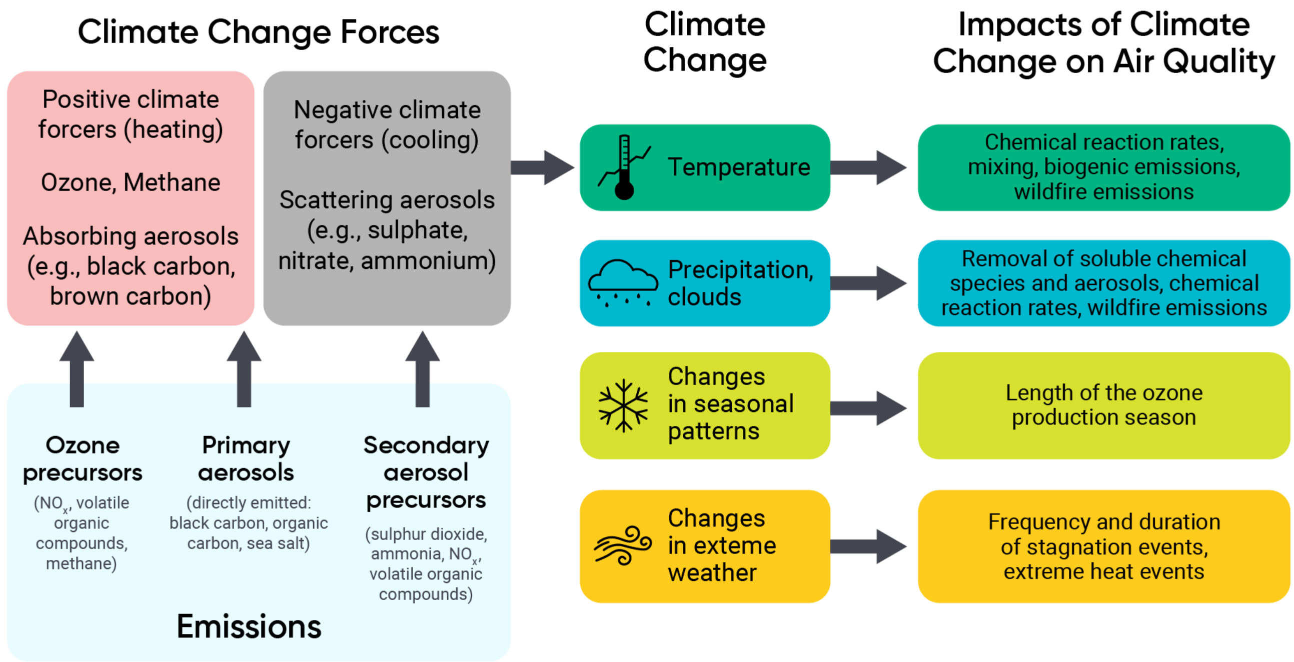


Figure 5.1 Linkages between air quality and climate change.

The area burned by wildfires in Canada is increasing, doubling from the 1970s to the 2000s. Western Canada, in particular, has seen significant increases in the number of fires and area burned from 1959 to 2015 {3.8.1}. In addition to residents and firefighters injured and killed by wildfire, smoke from wildfires, which can travel in plumes in the atmosphere up to several thousand kilometres, has adverse effects on health. Wildfire smoke contains many different air pollutants including fine particulate matter that can penetrate deep into lungs {5.3.1}. Exposure to wildfire smoke is associated with an increase in all-cause mortality as well as exacerbations of asthma and chronic obstructive pulmonary disease and increased respiratory infections. In Canada, the health burden of air pollution from wildfire smoke varies from year to year and between regions. Over five recent years, it is estimated that 54 to 240 premature deaths due to short-term exposure and 570 to 2500 premature deaths due to long-term exposure per year were attributable to fine particulate matter from wildfires as well as many non-fatal cardiorespiratory health outcomes. Studies project increases in these effects in North America throughout the century, including thousands of deaths, depending on the climate change scenario {5.6.4}. Wildfires in Canada causes property loss, evacuations, and environmental degradation, leading to increased mental health impacts in affected communities, such as depression, anxiety, and post-traumatic symptoms, even in young children {3.8.2.4; 3.8.3.3}.

Climate change can also affect indoor air quality, such as when elevated levels of outdoor air pollutants (including wildfire smoke) infiltrate buildings or when mould is produced after floods. Changes in the climate are also affecting airborne allergens by expanding the geographic distribution of plant species, extending pollen seasons and increasing pollen counts, which can affect the health of individuals with asthma and allergies.

Infectious Diseases

Risk from infectious diseases is affected by three factors: presence of the disease, protective behaviours by individuals, and people's sensitivity to the pathogen (which may be affected by their overall health and underlying health issues). Climate change is expected to affect all three of these factors directly or indirectly.

In 2008, a previous science assessment report projected that climate change would increase the prevalence of Lyme disease, as blacklegged tick vectors (Ixodes scapularis) and the infectious agents they carry (Borrelia burgdorferi) expand their range further into Canada from the United States, as a result of warming temperatures. Surveillance now provides strong evidence that Lyme disease emerged in Canada and spread northward as a result of climate change, causing a dramatic increase in human cases from 2009 to 2017 {6.3.1.5; Figure 6.5}.

Like Lyme disease, many other diseases will emerge or spread within Canada as our climate warms. These include viruses transmitted to humans by mosquitoes that are already found in regions of the United States bordering Canada, including La Crosse encephalitis virus. Like West Nile virus, which was probably imported to North America by infected mosquitoes on an airplane, other exotic viruses could reach Canada and spread if their reservoir hosts and vectors are found here. New species of mosquitoes and ticks may expand their range into Canada or arrive on human transportation, bringing both the vectors and the diseases they transmit. For example, a species of mosquito new to Canada that transmits chikungunya, dengue, and Zika viruses in other countries has become established in an area of Southern Ontario {Box 6.2}.

In addition to West Nile virus, Canada already has several diseases that can be transmitted by mosquitoes — eastern equine encephalitis virus, snowshoe hare virus, and Jamestown Canyon virus {6.3.1.3} — and one carried by fleas — Yersinia pestis, which causes pneumonic or bubonic plague {6.3.1.4}. Infections with these diseases are fortunately rare, and mainly result in mild or asymptomatic illness, but climate change could change the range and abundance of host animals and vectors, and lead to disease outbreaks {6.3.1.3}. Researchers are also watching other illnesses transmitted by blacklegged ticks (anaplasmosis, babesiosis, Powassan virus, and Borrelia miyamotoi), which are expected to spread in Canada with the expanding range of these ticks {Box 6.3}.

Climate change may have effects on diseases transmitted to humans directly by animals. Of concern is rabies in Arctic foxes, since the Arctic is warming more quickly than Southern Canada, affecting Arctic fox ecology. Hantavirus pulmonary syndrome, carried by mice, is a climate-sensitive disease, but it is not yet clear how climate change will affect it in Canada {6.3.2.1}. Roundworms and other parasites carried by domestic dogs, coyotes, foxes, or raccoons may expand their range in Canada {6.3.2.2}.

Weather and climate affect diseases transmitted from human to human. For instance, respiratory infections are often more prevalent in the winter. With climate change, milder and shorter winters may decrease incidence in that season, but research shows that warmer winters can lead to more widespread influenza the following year {6.3.3.1}.

Some infections acquired from the environment may also be sensitive to aspects of climate. *Cryptococcus gattii* {6.3.4.2}, blastomycosis {6.3.4.3}, and coccidioidomycosis {6.3.4.5} are fungal infections found in Canada, and risks from these are likely to change with expected changes in temperature and rainfall.

Water Quality

Climate change can affect the quality of drinking water, which is critical to health, and the safety and availability of water can have cascading effects on some other health risks discussed in this report. First, climate change can affect the sources of drinking water. Extreme rain events and rapid spring snowmelts can wash disease-causing bacteria and chemicals into oceans, lakes, and rivers. Heavy rainfalls can also lead to sewage overflows, which can contaminate bodies of water {7.3.2.3}. Conversely, droughts and low river flows can concentrate harmful substances and pathogens, causing health risks {7.3}. Rising temperatures can lead to outbreaks of toxic algae and cyanobacteria (together referred to as “harmful algal blooms”) in oceans and lakes, which can contaminate surface water and fish and shellfish.

Contaminated water can reach consumers directly if they use private surface or groundwater sources. Contaminated stormwater and wastewater can reach drinking water systems, which must be treated effectively to prevent illness in consumers. Fifteen per cent of Canadians get their drinking water from small non-municipal systems, and most water-borne acute gastrointestinal illnesses have been linked to such systems {7.3.2.1}. But even large municipal drinking water systems can be overwhelmed by extreme precipitation {7.3.3.2}. Stormwater can stir up sediments, making water more turbid and thus difficult to treat. If storms batter treatment facilities, water treatment systems can become ineffective or inoperative {7.3.2.1.1}.

Heavy rainfalls have been increasing in most regions of Canada under a changing climate. Such heavy rainfall was a contributing factor in the Walkerton, Ontario, tragedy in 2000, when bacteria entered the drinking water system, killing seven people and making hundreds ill. A single heavy rainfall was also involved in the worst outbreak of illness from drinking water in North America to date, in Milwaukee, Wisconsin, in 1993 {7.3.2.1}. Climate change driven sea-level rise also threatens to intensify water quality issues in coastal areas reliant on groundwater, with salt water intrusion of aquifers and private wells already challenging some coastal regions (such as British Columbia’s Gulf Islands and Atlantic Canada) {7.3.2.2}.

Access to safe drinking water is a particular problem for many Indigenous communities across Canada {2.4.5}. For example, 61 First Nations communities had been under a drinking water advisory for more than a year as of February 15, 2020. Such communities may use a variety of water systems, including wells, trucked water stored in tanks, and piped water, and may have few or no household water services. Lack of water can lead to dehydration and unhygienic conditions, and breakdowns in water safety can lead to gastrointestinal illness. Water insecurity may also lead community members to use “gathered water” from the environment, which may be unsafe.

Risks to Food Safety and Security

Climate change is an increasing threat to food safety and security in Canada. Storms and heavy precipitation can cause sewage overflow, carrying pathogens from the ground and sewage into water bodies, and contaminating crops in fields. If water treatment systems do not treat contamination effectively, food can become contaminated during production and processing, which require large amounts of clean water {7.3.3}.

Rising temperatures, changes in precipitation patterns, and extreme weather events can also contaminate food directly (Figure 8.4). Higher temperatures in fields and farms can mean that disease-causing pathogens grow more successfully in manure and soil. If food is not kept cold throughout its journey to the plate, warm temperatures can allow dangerous bacteria and other pathogens to grow. These pathways can lead to contaminated food, which is a particular problem for food eaten raw, such as leafy greens.

Health depends on food security — eating sufficient nutritious food. Food security, in turn, depends on the ability of the food system to support food availability, accessibility, and use (Figure 8.1). These are interconnected and affected by steps in the food system and social determinants of food security, such as income and cultural food traditions. If climate change affects the food system or determinants of food security, it can have cascading effects on health. Household food insecurity is associated with many adverse physical and mental health outcomes, including nutritional deficiencies, cardiovascular disease, diabetes, oral health issues, and depression. Furthermore, malnutrition can make people more susceptible to disease {8.4.2}.

Climate change is projected to affect global food availability, as rising temperatures, changing precipitation patterns, extreme weather, droughts, and sea level rise (saltwater flooding of coastlines) could all directly damage crops and decrease yields {Table 8.2}. These factors could also increase pests, invasive species, and diseases affecting food supplies. We are already seeing impacts on crops due to shifting climate patterns, such as the loss of the strawberry crop in Ontario in 2012 because of unusual spring temperatures {8.4.3.1}. As a storm in St. John's, Newfoundland and Labrador, demonstrated, food security can be affected when people cannot reach grocery stores for long periods {8.4.3.1}.

Rising carbon dioxide levels in the atmosphere may affect the nutritional content of food. Experiments have found that growing crops such as wheat, rice, and legumes in controlled environments with high atmospheric concentrations of carbon dioxide reduces zinc, iron, and protein concentrations by 3% to 15% {8.4.3.3.1}. Furthermore, pesticides and herbicides are less effective as carbon dioxide increases, which might lead to greater use and more health risks from these products {8.5.2.1.1}.

Climate change will also affect food accessibility. Research has shown disruptions to the global food system and supply chain from natural hazards, and climate-related lower crop yields have already been linked with increased food prices in Canada and may push them higher. These prices could make it more difficult for low-income Canadians to obtain essential foods they need to stay healthy.

Food insecurity can also result in changes in how people use food. This is particularly evident in Indigenous communities, where climate change is affecting the distribution, quality, and quantity of traditional food sources. In the absence of stable sources for traditional foods, Indigenous Peoples may rely more heavily on store-bought food, which can contribute to diets high in calories, salt, sugar, and saturated fat, and low in whole grains, nuts, seeds, legumes, fruits, and vegetables {2.4.4}. Such diets are a leading risk factor for death and disability in Canada {8.4.3.3.3}.

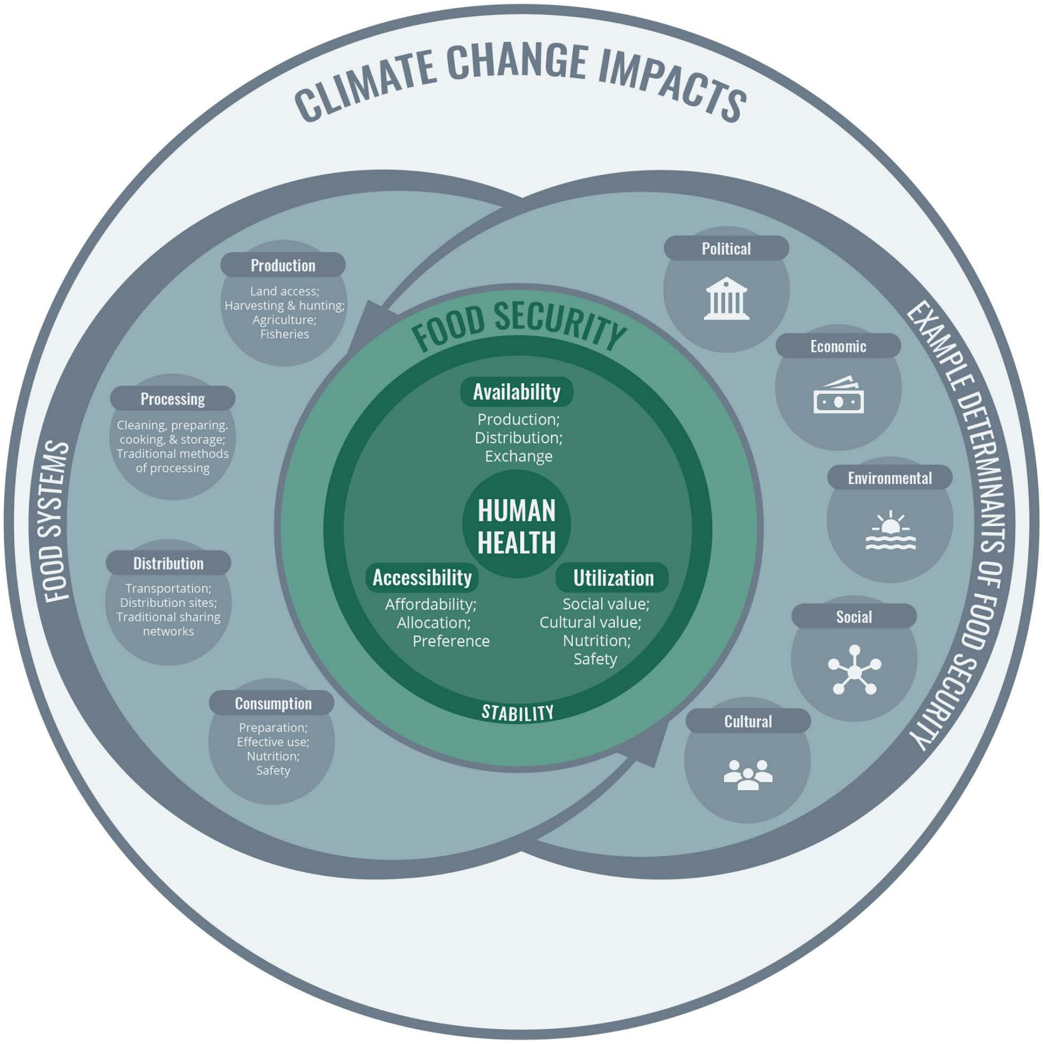


Figure 8.1 Conceptual framework outlining the relationships among food security, food safety, and health in a changing climate.

Mental Health

According to the Mental Health Commission of Canada, 7.5 million people in Canada experience mental health problems every year. While there are no known Canadian studies that project the mental health impacts of climate change, the current burden of mental ill health in Canada is likely to rise as a result of climate change. Costs of mental ill health borne by Canadians and health systems are expected to increase in the absence of further adaptation measures.

Climate change increases the risks of mental health impacts:

- worsening of existing mental illness such as psychosis;
- new-onset mental illness such as post-traumatic stress disorder;
- mental health stressors such as grief, worry, anxiety, and vicarious trauma; and,
- a lost sense of place, which refers to perceived or actual detachment from community, environment, or homeland.

Impacts can also include disruptions to psychosocial well-being and resilience, disruptions to a sense of meaning in a person's life, and lack of community cohesion. All of these can result in distress, higher rates of hospital admissions, increased suicide ideation or suicide, and increased substance misuse, violence, and aggression. Studies are also showing that people can become distressed about climate change itself, resulting in increased anxiety (often termed eco- or climate anxiety), grief (often termed eco-grief or climate grief), worry, anger, hopelessness, and fear.

Climate-related disasters are associated with mental health outcomes. For example, flooding, the most frequent form of disaster globally, can lead to increased levels of PTSD, general distress, depression, and anxiety among flood survivors {4.4.3.1}. Even people who are indirectly exposed to climate-related hazards can experience poor mental health outcomes, including vicarious trauma, secondary stress, and/or compassion fatigue for those whose lives have been disrupted by extreme events {4.4.3}.

Economic insecurity, displacement, and food and water insecurity after a disaster can also lead to mental health problems such as stress, anxiety, and depression {Chapter 4}. Research also shows that extreme heat can increase aggression and suicide rates, as well as increase social isolation for people who must stay inside {3.4.2.8}. Further, extreme heat can put people with mental illness at disproportionate risk because some mental illnesses, and some medications that treat mental illness, can affect the body's ability to cool down {4.4.3.2}. In addition, people with mental illness may face greater challenges in adapting to extreme heat because of cognitive impairment (for example, they do not seek shade) and/or socio-economic barriers, which disproportionately affect people with mental illness {4.4.3.2}.

Vulnerability to the Health Effects of Climate Change

As many sectors of Canadian society work together to mitigate and adapt to climate change, they must focus on the Canadians who are most at risk of the impacts. While climate change can affect any Canadian's health, an individual's sensitivity to climate change, exposure to its effects, and capacity to take protective measures and adapt (Figure 9.1) can increase or decrease vulnerability and their risk of being harmed.

The conditions and factors that affect a person's health, such as income, education, employment, and working and living conditions, are known as determinants of health. These determinants can increase or decrease an individual's exposure or sensitivity to climate-related health hazards and can create barriers that limit their ability to take protective measures. Existing health inequities (avoidable and unjust differences in health) and determinants of poor health (such as low income, substandard housing, food insecurity) can compound climate change vulnerability and create barriers to adaptation. Structural systems of oppression that result in health inequities are underlying drivers of vulnerability to climate change. Such systems of oppression include racism, heteronormativity, and colonialism. Redressing inequities and strengthening determinants of good health is required to increase climate change resilience {9.4.3}.

Increased risk can also be linked to certain locations, such as Canada's North, which is undergoing more rapid climate change than Southern areas; rural and remote areas, where access to health care may pose problems {9.4.3.3}; and urban heat islands in cities, where dark, paved surfaces and lack of green space can cause temperatures to exceed those in surrounding areas, endangering residents during extreme heat events.

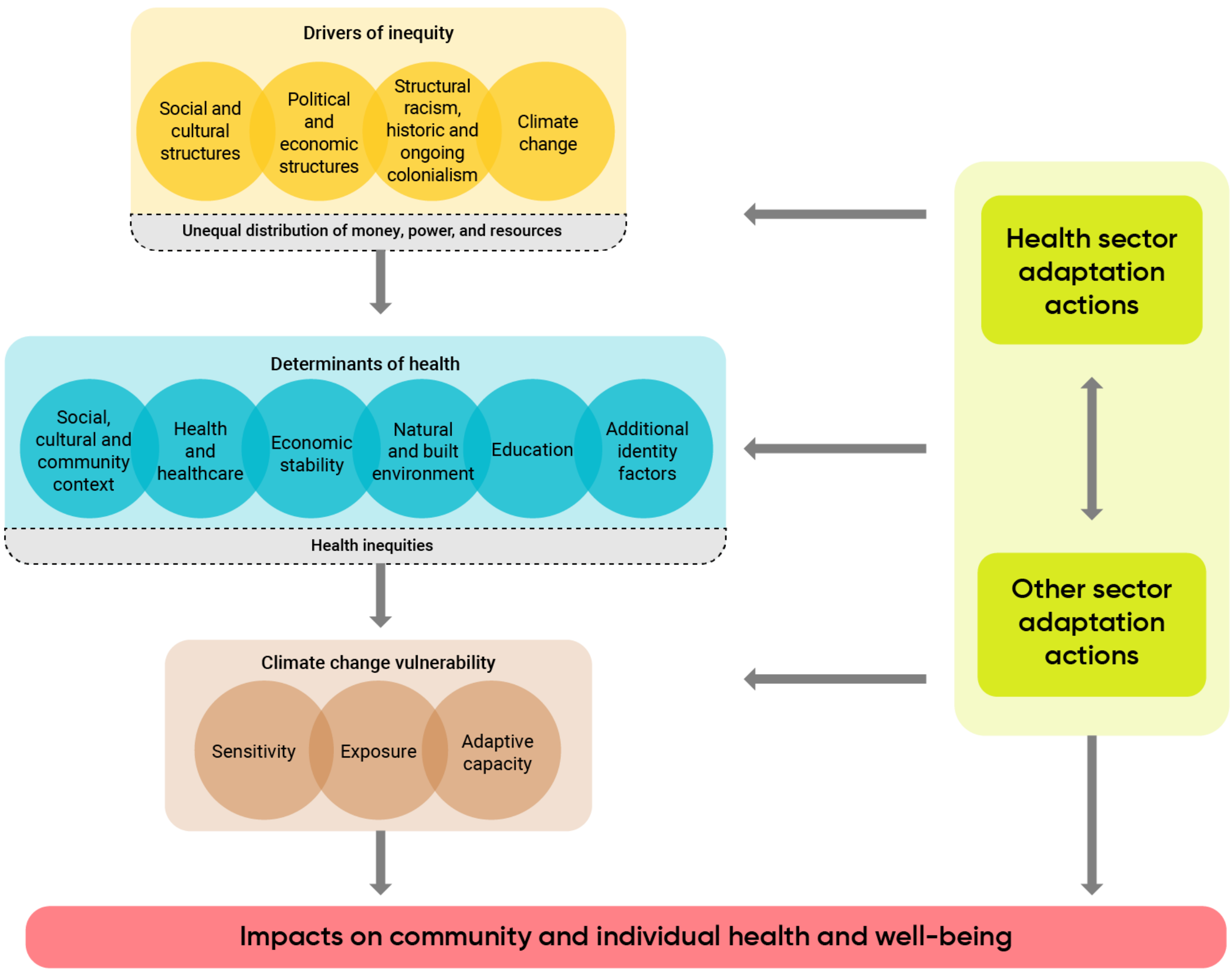


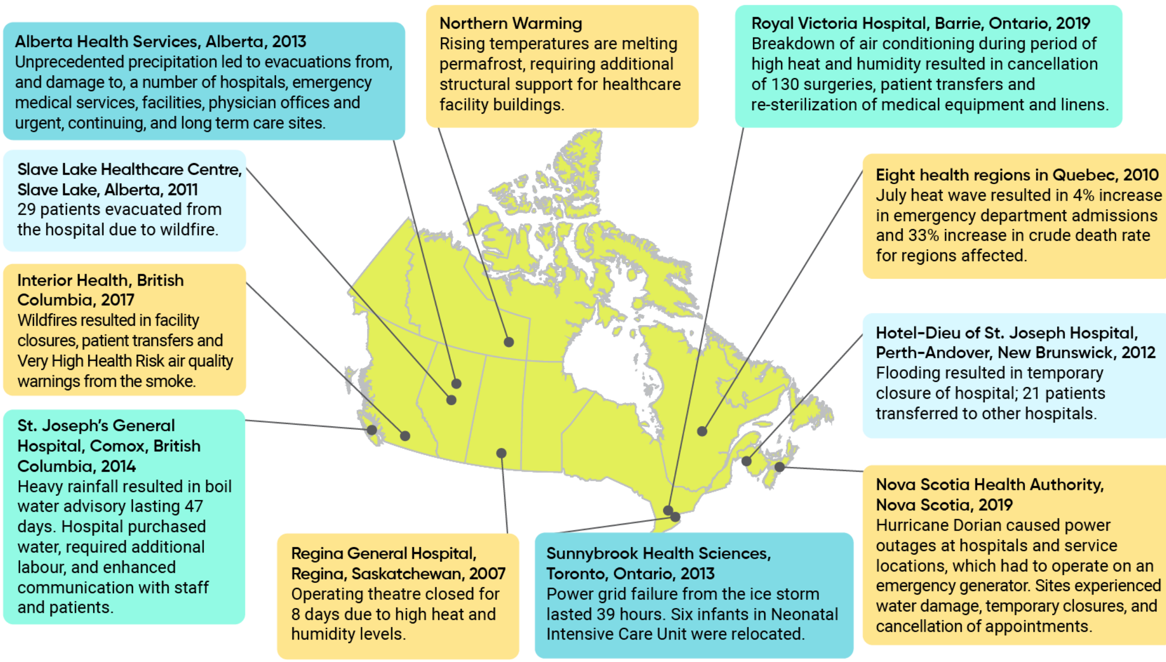
Figure 9.1 Climate change and health equity framework.

Research shows that the populations most affected by many climate change hazards are seniors, children, racialized populations, low-income individuals, individuals with chronic health conditions, and First Nations, Inuit, and Métis peoples {Chapter 2, Chapter 3, Chapter 9}. However, each individual within these broad population groups has a wide range of intersecting factors and characteristics that can increase or decrease resilience. Evidence shows that individual characteristics and resources should be taken into account when considering vulnerability and developing measures to empower people to adapt and to assist those disproportionately affected. In the absence of careful planning and accounting for existing health inequities, adaptation measures may benefit only part of the population and inadvertently worsen existing inequities {9.5.1}.

Many Indigenous communities, while experiencing disproportionate impacts of climate change and increased risk, draw on Indigenous knowledges that have enabled them to adapt and be resilient to climate over the millennia {2.5.1}. Thanks to strong community ties, for example, in Indigenous communities in the Arctic, people help each other cope with hazards and threats to health and safety {9.4.3.4}. There are gaps in current research of how some social groups, such as gender-diverse and 2SLGBTQQIA+ people, experience the health effects of climate change {9.2}.

Current Impacts on the Health System

When climate-related emergencies and disasters strike, health facilities and services are among those affected. The report lists many examples of storms, floods, and wildfires that forced health care centres and hospitals in Canada to close temporarily, evacuate patients, and/or cancel operations and other services {Table 10.5}. But it is precisely during these disasters that Canadians need emergency services, and health care disruptions can have major effects on health and well-being. Even if health facilities and services remain operational during a climate-related disaster, they can be pushed beyond their capacity to respond because of injuries, illnesses, and patient transfers due to the disaster {10.4.1}. Combined effects of climate change that overlap and interact could lead to cascading effects on several health outcomes simultaneously.



Climate variability and change impacts on Canadian health facilities (Chapter 10, Table 5).

Adaptation and Preparedness

Canada can reduce the health risks — and thus the injuries, illnesses, and deaths — from climate change by taking steps to prepare for risks and adapt to climate change. To stay ahead of the climate change curve of increasing impacts, health officials must increase current efforts, in collaboration with those in other fields, to understand, assess, prepare for, and help prevent the health impacts of climate change {10.3.1}.

Many actions are already being taken to protect Canadians, and these provide a foundation for learning and expanding such efforts. For example, heat alert and response systems are increasing in Canada. They allow residents facing impending hot weather to take necessary precautions, such as staying hydrated, seeking cool areas, and helping family members and friends who may need assistance. Since an extreme heat event in 2010, the province of Quebec has had an early warning system, which may have helped alleviate the effects of an extreme heat event in 2018 {3.4.4.2}. Tests of a telephone alert system for seniors and those with chronic diseases in case of extreme heat in the Montérégie region of Quebec showed that it resulted in fewer medical appointments {Box 3.3}.

To reduce risks from air pollution, Environment and Climate Change Canada forecasts an Air Quality Health Index across the country (except in Quebec, which has its own system), which provides a risk rating, health messages, and health protection advice, the latter two aimed at specific groups that may be at increased risk to the health impacts of poor air quality {5.7.1}. Further, the department has implemented Canada's Wildfire Smoke Prediction System (FireWork) to forecast fine particulate concentrations due to wildfire across Canada over the coming 48 hours {3.8.4.2; 5.7.2}.

Another common adaptation is "greening" of spaces in cities through planting trees and shrubs and creating parks. Several provinces and cities in Canada have actively adopted this measure, to combat urban heat islands. The soil in green spaces can also soak up excess water during heavy rainfalls and floods. However, greening of urban spaces has to be carefully planned and accompanied with public health guidance and messaging to avoid increasing risks from infectious diseases such as Lyme disease, and impacts of pollen on allergies.

Adaptation to infectious diseases that may emerge or increase with climate change requires a "One Health" approach that integrates our knowledge of disease in humans, the role of animal disease reservoirs, and the role of the environment, including climate. This integrated approach is needed to design and undertake systematic assessments of where disease risks may emerge, conduct surveillance for emerging diseases, and develop prevention and control responses (ranging from public alerts to vaccination programs) to protect Canadians from infectious diseases driven by climate change.

Generally, health authorities are lagging in climate change and health actions needed to keep up with growing risks to Canadians. For example, many do not have a climate change and health program or dedicated resources to support the development of adaptation measures. Research also shows that many health facilities — a critical component of health systems in efforts to reduce climate change impacts — are not taking needed actions to prepare for current risks and future warming {10.4.1}.

Many sectors must come together to address climate change impacts, as adaptation efforts related to land-use planning, infrastructure development, emergency preparedness, environmental management, and transportation planning can all affect health {Chapter 10}. Climate change adaptation plans, from local to national levels, can reduce health outcomes if they "mainstream" consideration of health in these plans and routinely evaluate their effectiveness as the country continues to warm.

While adaptation carries costs, these are offset by mitigating the escalating costs of health care due to climate change. Recent research in Quebec suggests that the projected costs of the increase in ragweed allergies due to climate change are $360 million for governments in that province and $475 million for society as a whole. For extreme heat, the study estimated increased costs of $370 million for governments in Quebec. In addition, increases of Lyme disease due to climate change are projected to cost governments in Quebec $60 million to $95 million {10.4.2}.

Making Adaptation Inclusive and Equitable

Research suggests that vulnerability and adaptation assessments (V&As) for climate change and health can be helpful in identifying the root causes of vulnerability, such as food insecurity, inadequate income, and social exclusion {Box 9.3}. They can also be used to identify unintended — negative or positive — health impacts of a planned policy, program, or initiative on marginalized populations {9.4.4}.

Adaptation planning should involve communities and those most affected by climate change. Participation of marginalized individuals and communities that already experience a disproportionate burden of illness and health inequities, such as Indigenous Peoples and racialized populations, is particularly important {Chapter 9}. Health adaptation planning can also include partnering with populations at highest risk, including women, persons with disabilities, seniors, immigrants, low-income residents, non-English/non-French speakers, outdoor workers, people exposed to environmental pollution, people with existing illnesses, people without access to insurance, public housing residents, newcomers to Canada, lone-parent households, students, transient and homeless populations, and parents with young children {10.3.2}.

A number of frameworks familiar to public health authorities are available to help decision makers engage with communities. To increase the representation and participation of groups that have often been excluded, decision makers and researchers need to recognize, acknowledge, and remove barriers to participation (such as financial burdens, travel requirements, language, child care, etc.). Investing time and resources in relationship-building and cultivating trust is key to this process {9.5.3}.

Adaptations affecting Indigenous communities should be Indigenous-led. There are many examples of adaptation projects that have improved health and were led by the community: a project to develop climate-resilient, healthy, and culturally appropriate housing in Nain, Nunatsiavut, Newfoundland and Labrador {9.5.2}; and a project to map flooding hazards and its effects in the Cree community of Kashechewan, in Northern Ontario {2.4.1; Box 2.2}.

Tailoring actions to protect health to specific communities and locations is one of the ways to avoid "maladaptation" — inadvertently causing other health risks when implementing adaptation measures. For example, greening in a city by planting pollen-producing trees can cause health problems for allergy sufferers {10.3.3; Table 2}. Or creating an urban green space can backfire if it leads to gentrification and displaces low-income people the park was designed to benefit. Adaptation needs to be carefully considered to avoid such missteps {10.3.3; Table 10.2}.

Adaptation of the Health System

The health system needs to be included in adaptation. Adaptation can help the health system prepare for climate-related effects on health and protect it from future effects on infrastructure, staff, and services. The adaptation framework for health systems {10.3.2} includes, among other areas of focus, analyzing health facility resilience, a first step in ensuring that health services remain functional. To support such an analysis, the Canadian Coalition for Green Health Care, in partnership with Health Canada, has developed a Health Care Facility Climate Change Resilience Checklist that can find gaps in resilience. More facilities need to assess their readiness for climate change impacts. In a recent survey, only 9% of health care facility staff respondents reported having completed resilience assessments, while only 4% have completed vulnerability assessments {10.4.1}.

Adaptation measures taken for health care facilities can include a range of actions in areas such as workforce training, food and medical supplies procurement, emergency preparedness, and design and engineering changes or upgrades to cope with heat, flooding, and power outages. As an example, the Nanaimo Regional General Hospital in British Columbia completed renovations in 2012 designed to lower risks in case of an extreme-weather emergency and to lower energy costs {Box 10.6}.

Health Co-Benefits of Climate Change Mitigation and Adaptation Actions

Measures taken in many sectors to mitigate climate change (by reducing GHGs or sequestering carbon) or to adapt to climate change can also have very large benefits for health — immediately or in the long term. These "co-benefits" of climate change mitigation and adaptation add to the value of action taken and can avoid poor health outcomes and economic costs to health systems and society {10.6}. Economic savings from such actions can also help to offset the costs to society of reducing GHGs.

As some examples, reducing fossil fuel use can improve air quality through reductions in fine particulates including soot and ground-level ozone. Better air quality has multiple co-benefits, including reductions in cardiovascular and respiratory diseases, and deaths. Greening communities to cool them can also have multiple knock-on health benefits, such as reductions in chronic diseases and improvements to mental health. Measures to make communities more liveable, such as installation of walking and biking paths, can improve exercise levels and mental health in residents. Such measures can also have positive impacts by reducing social isolation and crime {10.6}. Analysis in this assessment estimated that reductions in Canadian GHG and air pollutant emissions consistent with an RCP 6.0 pathway could result in 5200 avoided deaths for a single summer in 2050.

Several successful GHG mitigation and adaptation projects in Canada have had major co-benefits. To mention one, the University Health Network (UHN) in Toronto, Ontario, has reduced GHGs from its on-site natural gas use and consumption of purchased electricity, heat, or steam by 19% from 2010 to 2019. Much of this reduction came out of 214 energy projects completed between 2013 and 2018, saving UHN $18.9 million in utility costs. For cooling, UHN has also replaced traditional chillers with Deep Lake Water Cooling Technology at some of its facilities; this technology uses water cooled by Lake Ontario, improving the capacity, resilience, and reliability of UHN's chilled water system, and saves more than $22 million over 20 years. Such projects improve air quality, by removing sources of fossil fuel use, and water availability, by foregoing the use of water in cooling (in this case, 67 million litres per year) {Box 10.8}.

Scaling-Up Efforts to Protect Canadians

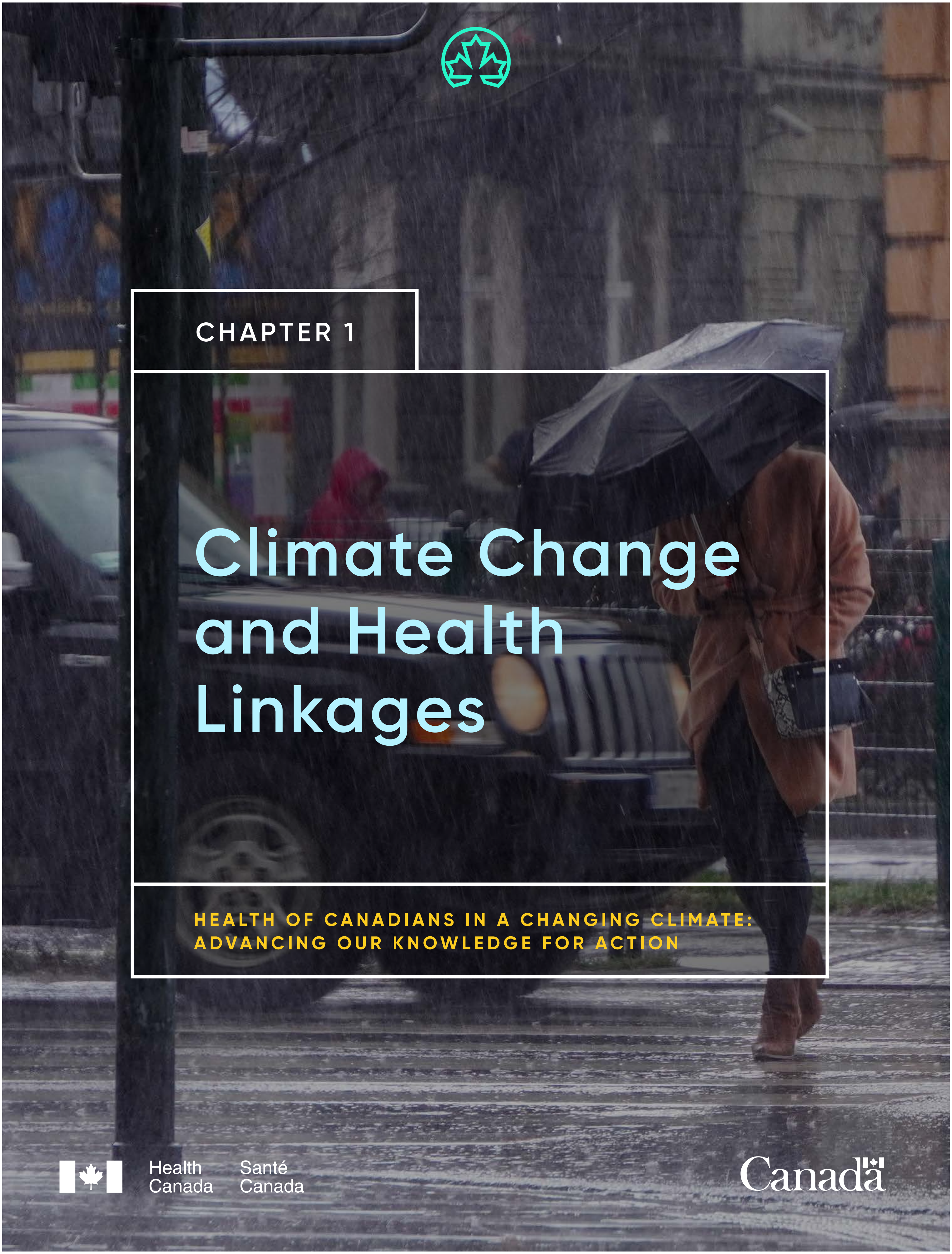
The health of Canadians can be protected from climate change. Canada has a historic opportunity to avoid many of its health effects. Decision makers in the health sector are recognizing the need to take adaptation measures to prepare for the health impacts of climate change. Levels of inequity, social cohesion, and technological innovation will influence how greatly the health of Canadians and their communities are affected by climate change and should be taken into account in all adaptation plans and processes. The resilience of health systems and the willingness and capacity of decision makers to take needed adaptive actions, in close collaboration with other sectors, will determine how the health system responds to climate change and helps Canadians affected by it. Reducing health risks to First Nations, Inuit, and Métis peoples requires respect for rights and responsibilities over their lands, natural resources, and ways of life, and advancing these rights through distinctions-based, Indigenous-led, climate change adaptation, policy, and research {Chapter 2}.

A number of health authorities, from local to national levels, in Canada are taking adaptation actions to reduce health risks. These experiences can be shared to mobilize further efforts to protect health. Such efforts must be scaled up rapidly and focused on health and health systems to take advantage of this opportunity to prevent and prepare for the health impacts of climate change.

The health of Canadians and their communities cannot be protected if warming continues unabated. Increased efforts to reduce GHGs can have very large health co-benefits, building individual and health system resilience and countering the effects of a warming climate. The health sector has the opportunity to show leadership in reducing its carbon footprint and preparing for climate change. The future health of Canadians will rely on such efforts from our decision makers.

Source:

Berry, P., & Schnitter, R. (Eds.). (2022). *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.



CHAPTER 1

Climate Change and Health Linkages

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Authors

Peter Berry, Health Canada

Rebekka Schnitter, Health Canada

Jolly Noor, University of Waterloo

Suggested Citation

Berry, P., Schnitter, R., & Noor, J. (2022). Climate Change and Health Linkages. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

1.1 Introduction

A broad range of risks to the health and well-being of Canadians from climate change were identified over two decades ago by scientists (Royal Society of Canada, 1995; Koshida & Avis, 1998; Health Canada, 1999). Subsequent science assessments and related studies, from national to local levels, have suggested that health risks are increasing, that they are posing serious threats to populations, and that impacts on some individuals and communities from current climate variability are significant (Séguin, 2008; Gosselin, 2010; Berry et al., 2014a; Berry et al., 2014b; Levison et al., 2018). An increase in some diseases, such as Lyme disease, due in part to a changing climate (Hoegh-Guldberg et al., 2018); the observed increase in the frequency and severity of extreme weather events and disasters such as extreme heat events and wildfires; and the expected increases in extreme precipitation with a warmer climate and associated flood risks in some areas, all call for a better understanding of the populations and regions at higher risk to impacts on health. New information about growing risks, key vulnerability factors, and promising adaptation options is needed to support efforts to increase the resilience of Canadians, their communities, and their health systems.

Canadians are concerned about climate change impacts on health. In 2017, 93% of Canadians who accept the reality of climate change indicated that it is either a health risk now (53%), or will be in the future (40%), and over half (55%) felt personally vulnerable to its impacts (Environics, 2017). In addition, health authorities and medical organizations in and outside of Canada have called for concerted efforts to reduce risks and increase the climate resilience of health systems (WHO, 2015; Health Care without Harm, 2017; Medical Society Consortium on Climate & Health, 2017; Howard, 2018; WMA, 2018; Claudel et al., 2020; Global Climate and Health Alliance, 2020). Adaptation actions based on robust evidence of risks to health can be effective in protecting people, including those that experience disproportionate impacts, from the effects of climate change (Ebi & Burton, 2008; WHO, 2015). However, important limits to adaptation may exist as warming increases (Ebi et al., 2021).

1.2 Canada's Changing Climate

Greenhouse gases (GHGs) that cause warming of the globe continue to increase rapidly. In 2019, globally averaged atmospheric concentrations of carbon dioxide (CO_2), the main driver of long-term climate change, reached a record high of 409.8 parts per million (ppm), up from 400.1 ppm in 2015 (WMO, 2018a; Lindsey, 2020). Such levels of CO_2 are unprecedented; similar levels only existed 3 to 5 million years ago, when the Earth was 2°C to 3°C warmer and sea level was 10 m to 20 m higher (WMO, 2018b). Global CO_2 emissions rose by 1.7% in 2018 (IEA, 2019). Atmospheric concentrations of the other two important long-lived GHGs, methane (CH_4) and nitrous oxide (N_2O), also continue to increase rapidly. In 2018, CH_4 reached 259% and N_2O reached 123% of pre-industrial (1750) levels (WMO, 2020).

Due to global anthropogenic emissions of GHGs, Canada's climate has changed and is projected to continue to do so over the coming decades. On average, Canada is warming at approximately twice the rate of the global average, and the Northern region is warming even faster (Bush & Lemmen, 2019). Since 1948, annual average temperatures over the Canadian landmass have increased by 1.7°C, while the North has warmed on average by 2.3°C over the same time period. In addition, extreme warm temperatures have become hotter while extreme cold temperatures have become less cold (Bush & Lemmen, 2019).

Climate models project that temperatures across Canada will continue to increase, with the largest warming occurring in the winter. The continued warming is "virtually certain" (Zhang et al., 2019), but the magnitude will vary, depending on the future rate of GHG emissions. Under a low global emissions scenario (RCP2.6), an additional annual warming of about 2°C is projected for most of this century compared to the 1986 to 2005 base period, whereas, under the high emissions scenario (RCP8.5), additional warming of over 6°C is projected for the country as a whole by late century, with even larger changes projected in the North (Figure 1.1).

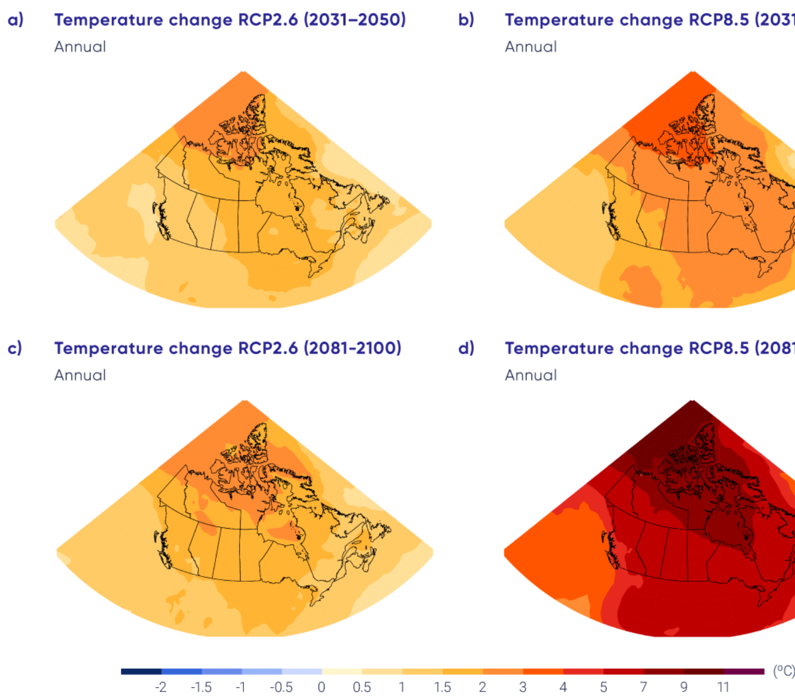


Figure 1.1 Projected change in annual mean temperature across Canada. The figure shows projected annual temperature change for Canada under a low emissions scenario (RCP2.6) (left panel) and a high emissions scenario (RCP8.5) (right panel) for the near term (top row) and the late century (bottom row). Projections are represented by the median of the Coupled Model Intercomparison Project (CMIP5) multi-model ensemble. Changes are relative to the 1986 to 2005 period. Source: Zhang et al., 2019.

In many parts of Canada, there has been an increase in precipitation and a shift toward less snowfall and more rainfall. There has been no observed increase, for Canada as a whole, of extreme precipitation (accumulated amounts over a day or less); however, in the future, daily extreme precipitation is projected to increase (Zhang et al., 2019). Continued warming means that total precipitation is expected to increase for much of Canada (Figure 1.2), while some areas might experience decreases in the summer, particularly in Southern Canada under a high emission scenario and toward late century (Zhang et al., 2019). The availability of freshwater may be reduced as warming continues, increasing risks of summer water supply shortages in some regions (Bonsal et al., 2019; Bush & Lemmen, 2019).

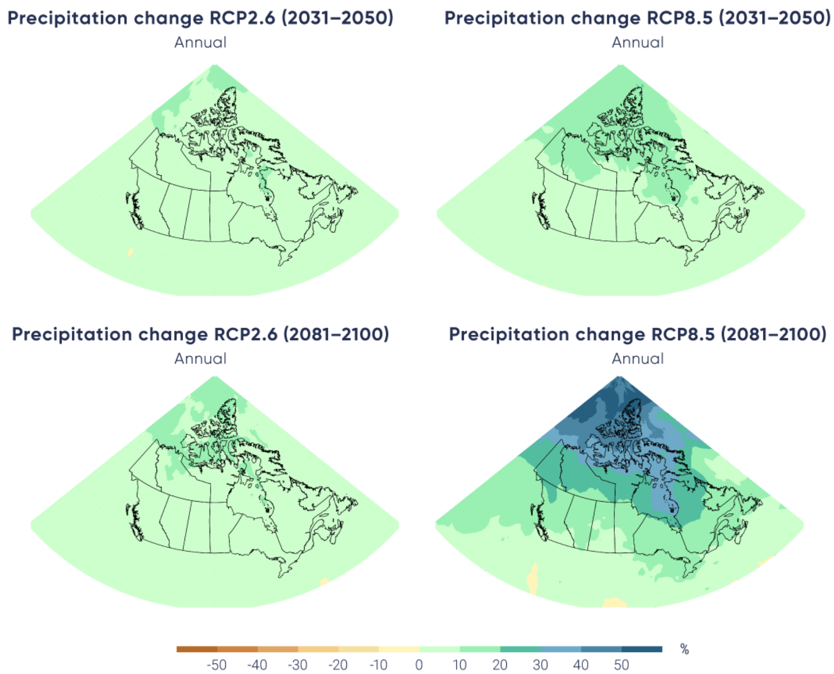


Figure 1.2 Projected annual precipitation changes across Canada. The figure shows projected annual precipitation changes for Canada under a low emissions scenario (RCP2.6) (left panel) and under a high emissions scenario (RCP8.5) (right panel) for the near term (top row) and the late century (bottom row). Maps and time series of projected annual mean precipitation change (%) as represented by the median of the fifth phase of the Coupled Model Intercomparison Project (CMIP5) multi-model ensemble. Changes are relative to the 1986 to 2005 period. Source: Zhang et al., 2019.

Daily extreme precipitation is projected to increase and the return periods — the time between events — for given extreme precipitation events are projected to decrease. Under a high GHG emissions scenario, a current once in 20-year rainfall extreme will become a once in 10-year event by mid-century (a two-fold increase in frequency) (Zhang et al., 2019). Urban areas will therefore need to manage increased flood risks and attendant health threats (e.g., contaminated water supplies) due to more severe rainfalls. Local sea level is projected to rise along much of the Canadian coastline, which will increase the frequency and magnitude of extreme high water level events and increase coastal flooding (Greenan et al., 2019).

Given that some additional warming is unavoidable, many current trends in climate change impacts relevant for health will continue, including (Bush & Lemmen, 2019):

- more frequent and intense extreme hot temperatures;

- increased severity of extreme heat events;
- less extreme cold;
- increased risk of drought;
- increased risk of wildfires;
- increasing length of the growing season;
- reduced seasonal lake ice cover across the Arctic;
- reduced sea ice extent;
- thinning of glaciers; and
- warming and melting of permafrost.

Increased variability in weather and climate is more challenging for people to adapt to. Profound effects on the Canadian climate are expected, should global GHGs continue to increase this century. Limiting warming globally, and in Canada, requires global action to reduce GHG emissions to near zero within a few decades (Bush & Lemmen, 2019).

1.3 Climate Change and Health

Evidence of the risks to health from climate change and the pathways through which people are affected has grown with publication of reports from the Intergovernmental Panel on Climate Change (IPCC) (Confalonieri et al., 2007; Smith et al., 2014; WHO, 2014; WHO, 2018) and related studies (Watts et al., 2015; Crimmins et al., 2016; Watts et al., 2018). Climate drivers of poor health that need to be understood to adapt are complex and mediated by a range of determinants of health and other situational, behavioural, and organizational factors (Figure 1.3). This makes the management of current risks to health, and of projected impacts, by public health officials challenging and requires close partnerships with officials within and outside the health sector.

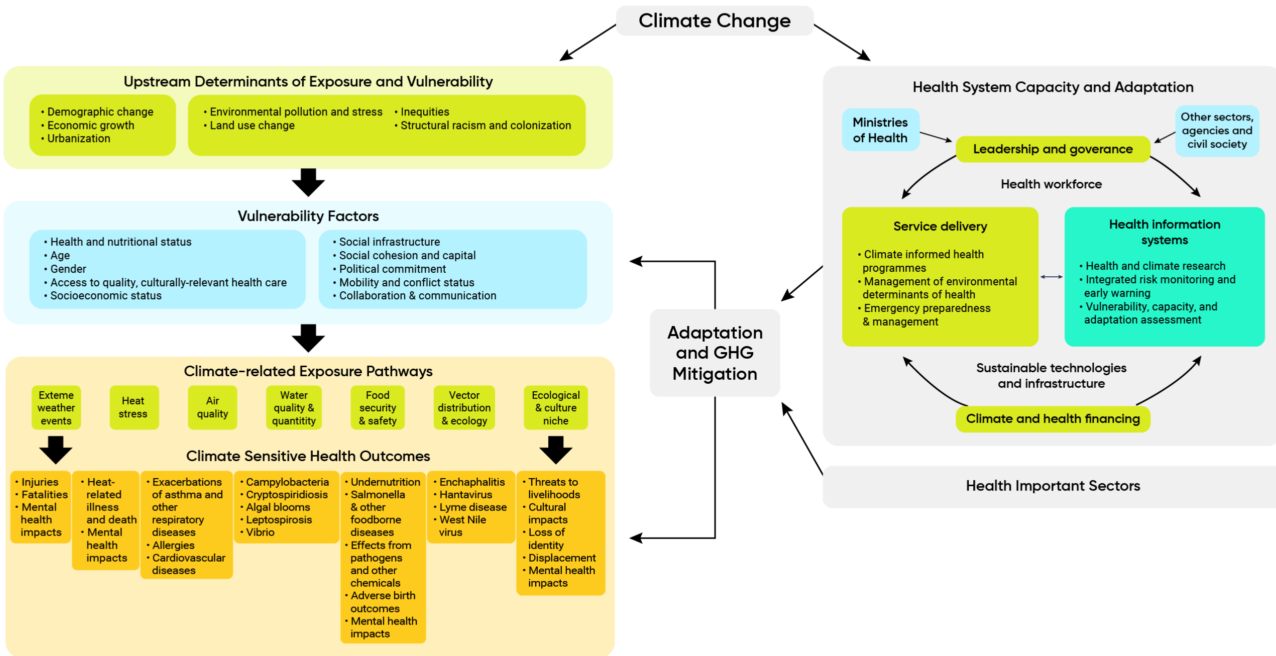


Figure 1.3 Pathways through which climate change affects the health of Canadians. Source: Adapted from WHO, 2022, Working paper on measuring climate resilience of health systems; Haines & Ebi, 2019.

Upstream drivers related to trends such as population growth, economic growth, urbanization, colonialism, and racism can put pressures on a range of factors that can increase or decrease vulnerability to the health impacts of climate change. Health can be affected by climate change directly or indirectly, through a range of exposure pathways, as temperatures continue to rise, precipitation patterns change, and the frequency and severity of extreme weather events increase, resulting in more natural disasters (IPCC, 2012; Smith et al., 2014; Watts et al., 2015; Hoegh-Guldberg et al., 2018).

Direct impacts on health can include non-communicable diseases (e.g., respiratory and cardiovascular diseases, mental health impacts) and injuries and deaths associated with extreme weather events such as wildfires, storms, extreme heat events, floods, and droughts. Less obvious effects of climate change on health arise from changes to ecosystems that support the spread of disease, pathogens, or contaminants to people, for example, the expansion of vector-borne diseases in new geographical regions, more water and air pollution due to warmer temperatures, or greater risks to food insecurity. Climate change is increasing vulnerability to multiple simultaneous hazards that threaten health (Mora et al., 2018), and continued global warming beyond 1.5°C increases risks of exceeding critical thresholds that would lead to more severe damage of natural systems and human societies (Haines & Ebi, 2019).

Health and social services play an important role in protecting Canadians from climate change impacts. They are the first lines of defence, whether through primary prevention (e.g., reducing GHG emissions in health care and reducing the urban heat island effect), secondary prevention (e.g., warning systems and public education campaigns), or tertiary prevention (e.g., treating injuries and illnesses associated with climate-related hazards) (see Chapter 10: Adaptation and Health System Resilience). The failure of such services during an extreme event, or the diminished capacity to provide services over time, would have direct impacts on health and well-being. There is increasing recognition of the impacts that climate change can have on health systems (WHO, 2015; Balbus et al., 2016; Haines & Ebi, 2019), as evidenced by recent disasters such as Hurricanes Katrina and Sandy in the United States (Health Care without Harm, 2018) and catastrophic wildfires in Alberta and British Columbia (Purdy, 2016; Toews, 2018).

Certain populations in and outside Canada bear a disproportionate burden of the health impacts from climate change (Berry et al., 2014; Hoegh-Guldberg et al., 2018; Shultz et al., 2020) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada; Chapter 9: Climate Change and Health Equity). Globally, it has been estimated that children bear 88% of the burden of disease from climate change (WHO & UNEP, 2010). Climate change is a threat to the health of people in all countries. Some dynamics that drive risks, such as infectious diseases, effects on water and food systems, or supply chain disruptions, can transcend borders (Balbus et al., 2016; Friel, 2019), thereby affecting Canadians.

Climate change is increasing the risk of humanitarian crises (Jochum et al., 2018) and threatening the global health gains achieved over the past century (Smith et al., 2014). From 2014 to 2017, climate shocks were partly responsible for the increase in food-insecure people in the world to more than 800 million — a growth of between 37 million and 122 million (GCA, 2019). Globally, it has been estimated that 200 million people every year by 2050 could need international humanitarian aid because of the impacts of climate change, which is almost double the number of people (108 million) that required assistance in 2018 to recover from floods, storms, and wildfires (IFRCRCS, 2019). Possible linkages exist between climate-related hazards and human migration (UNHCR, 2015; Haines & Ebi, 2019; McLeman, 2020) — for example, the 2018 droughts in Central America coincided with international migration patterns (CRED, 2019). Impacts have also been linked with conflict (Schleussner et al., 2016; Werrell & Femia, 2017) — for example, droughts in Ethiopia have been indirectly linked to decreased food security and areas of conflict (WHO, 2018) and the 2006 drought in Syria contributed to the deterioration of economic conditions and subsequent conflict (Gleick, 2014; Kelley et al., 2015).

Climate change is considered a “threat multiplier” (Hallegatte et al., 2015) and is expected to lead to increased poverty, dislocation, and forced migration among many populations (Hoegh-Guldberg et al., 2018). It is also recognized as an increasingly important national health security issue, given the potential interplay between climate change and infectious diseases (Hawa, 2017) (see Chapter 6: Infectious Diseases). However, the way in which climate change shocks and stresses can compound other drivers of conflict and migration is complex, as are implications for human health, and research in these areas is still emerging (Hsiang, 2013; Bowles et al., 2015).

Impacts on the health of populations and communities may be immediate or may last years (e.g., non-communicable diseases such as mental health; see Chapter 4: Mental Health and Well-Being); they may also be long-lived, multi-generational, or irreversible, such as impacts on or the loss of cultures (WHO, 2018) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). In addition, researchers are starting to link specific events that have affected health directly to climate change. For instance, specific extreme weather events, including the hot and dry conditions that contributed to record wildfires in British Columbia in 2016, or the record heat wave in that province in June 2021 have been attributed to climate change (Herring et al., 2018; World Weather Attribution, 2021), allowing researchers to also make linkages to the health impacts of such events (Ebi et al., 2017; Hoegh-Guldberg et al., 2018). In addition, Vicedo-Cabrera et al. (2021) estimate that, between 1991 and 2018, 38.5% of heat-related mortality in 25 census metropolitan areas in Canada could be attributed to human-induced climate change.

Scientists are also learning more about the very large short-term and longer-term health co-benefits of well-designed GHG mitigation measures and of proactive adaptation actions in other sectors. Actions to address climate change in the agriculture, water and sanitation, infrastructure, energy, urban design, and transportation sectors, for example, can reduce environmental pollution and support healthy lifestyles and communities (Haines et al., 2009; Smith et al., 2014; Martinez et al., 2018). The potential benefits of reduced deaths from air pollution, are so large that the Lancet Commission on Climate and Health has called climate change the "greatest global health opportunity of the 21st century" (Watts et al., 2015, p.1) (see Chapter 5: Air Quality). Research suggests that, for a range of future scenarios, the value of the benefits to health resulting from policies and activities in line with meeting the United Nations Framework Convention on Climate Change Paris Agreement targets could exceed their costs (Markandya et al., 2018). Canada is a signatory to the Paris Agreement and has pledged to reduce its GHG emissions to 511 Mt CO_2 equivalent by 2030[1] and to achieve a net-zero-emissions economy by 2050 (Government of Canada, 2021).

Health system infrastructure and services in Canada are being affected by climate-related hazards; reduced pressures and costs to health systems from improved population health through such measures can free up resources to build climate-resilient health systems and recover from the unavoidable impacts (Martinez et al., 2018). Greater understanding of how to gauge the climate resilience of health systems (e.g., indicators), tools to facilitate needed adaptation, and roles and responsibilities of key actors and partnership opportunities will support preparedness efforts (see Chapter 10: Adaptation and Health System Resilience).

1.4 Growing Knowledge of Climate Change Impacts on the Health of Canadians

Over two decades ago, the first national assessment of climate change impacts on Canadians that included information on human health and well-being was conducted (Koshida & Avis, 1998). Since that time, two national-level climate change and health assessments, led by Health Canada, were completed (Séguin, 2008; Berry et al., 2014), contributing to a growing foundation of scientific knowledge. The 2014 study provided updated knowledge about climate change-related health concerns included in previous reports (e.g., air pollution, infectious diseases, water and food-borne diseases, and climate-related natural hazards), populations that experience disproportionate impacts, and adaptation options.

The 2014 assessment also provided new information about health challenges faced by people living in specific communities and regions — urban, rural, coastal and Northern — and included a list of key research

1 Canada's GHG emissions were 729 Mt CO_2 eq in 2018 (Government of Canada, 2020).

gaps that require investigation to inform efforts to protect health. All people in Canada are at risk from the health impacts of climate change. However, the experience of impacts and the ability to adapt are not uniform and vary across populations, communities, and regions. An individual's sensitivity to climate change impacts, exposure to climate change hazards, and ability to take protective measures all contribute to climate change vulnerability. Upstream drivers of inequity (e.g., colonialism, racism, social and economic inequities) interact with and shape determinants of health. Health inequities and determinants of poor health compound vulnerability, and thus, some individuals and population groups face disproportionate health risks and challenges with adapting. In addition, the COVID-19 pandemic has intensified pre-existing inequities in Canadian society (Statistics Canada, 2020a).

Efforts to protect health from climate change through adaptation and GHG mitigation measures can inadvertently exacerbate population vulnerability, or present opportunities to strengthen health equity and reduce disproportionate health risks in society (see Chapter 9: Climate Change and Health Equity). Broad population groups that are commonly at higher risk to the health impacts of climate change in Canada include seniors, children and youth, people that are socially and economically disadvantaged, Indigenous Peoples, people with chronic diseases and compromised immune systems, people with disabilities, emergency first responders and support workers, and residents of northern and remote communities (Berry et al., 2014a). There is much variation within and among these groups in Canada. Populations at higher risk, and those on the front lines of climate change have historically been labelled as "victims," when, in reality, many people have a long history of demonstrated adaptive capacity, despite existing health inequities and discrimination.

1.5 Demographic and Socio-Economic Trends in the Canadian Population

Most Canadians enjoy good health, which increases resilience to the impacts of climate change. Specific demographic, social, and economic trends are important for understanding current and future health risks associated with climate change, as they can affect vulnerability and lead to inequitable health outcomes as risks increase (Balbus et al., 2016). For example, health and income disparities can increase the risk of some health impacts of climate change (Balbus et al., 2016; WHO, 2018). Trends in Canada relevant to the understanding of current and future impacts of climate change health risks are provided below.

1.5.1 Population Growth

- Canada's population is estimated to have increased by 23.7% from 2000 (30.7 million) to 2020 (38 million) (Statistics Canada, 2020b).

- Much of Canada's population is also aging. According to the 2016 Census, adults over the age of 65 years (5.9 million) now outnumber children under the age of 15 (5.8 million). The number of Canadians over the age of 85 years is growing rapidly — four times more quickly than the general population (PHAC, 2017).
- In contrast, younger Indigenous population cohorts are growing quickly, and Indigenous communities have proportionally more children than older adults (PHAC, 2017).

1.5.2 Social Capital and Networks

- Many more Canadians now are living alone. In 2016, 4 million Canadians were living alone, which is double the number in 1981 (Statistics Canada, 2019b).
- Social isolation is increasing in Canada. In 2017, 44% of Canadians visited friends at least a few times a week, while in 2003, 58% did so. In addition, visits to family also declined over that time period, from 38% to 26% (PHAC, 2017).
- In 2018, 86% of Canadians had access to high-speed broadband internet (CRTC, 2019).

1.5.3 Racial and Ethnic Diversity

- In 2011, almost one in five Canadians (19.1%) belonged to a visible minority group, which was up from 16.2% in 2006. In 2011, the South Asian (25% of the visible minority population), Chinese (21.1%), and Black populations (15.1%) were the three largest visible minority groups. By 2031, Statistics Canada estimates that visible minority groups will make up between 29% and 32% of the population (Statistics Canada, 2018).

1.5.4 Economic Disparity and Inequity

- The percentage of Canadians considered low-income after tax was 12.3% in 2018, which is just slightly lower than in 2000 (12.8%) (Statistics Canada, 2020c).
- A significant number of Canadians struggle with food and water insecurity, and levels vary across Canada, with higher rates in the North. It was estimated that, in 2017–2018, 12.7% of Canadian households experienced food insecurity at some point during the previous year, an increase from previous national estimates (Tarasuk & Mitchell, 2020). This is likely an underestimate, as not all populations were captured in the survey (e.g., on-reserve Indigenous Peoples and homeless people) and not all provinces and territories monitor rates of food insecurity (PHAC, 2017).
- In 2016, 1.7 million households were in core housing need; that is, their dwelling is considered unsuitable, inadequate, or unaffordable (Statistics Canada, 2016), and there were 22,190 Canadians living in 995 shelters (Statistics Canada, 2019c).

1.5.5 Health Status

- Life expectancy has continued to climb in Canada, with an increase of 5.3 years for men and 3.3 years for women from 1995 to 2019 (PAHO, 2019). From 2016 to 2017, for the first time, life expectancy did not increase, as a result of the opioid epidemic (Statistics Canada, 2019a).
- In 2016, 44% of all Canadians over 20 years of age had at least one chronic health condition, including hypertension (25%), mood and/or anxiety disorders (13%), diabetes (11%), asthma (11%), chronic obstructive pulmonary disease (10%), ischemic heart disease (8%), cancer (8%), and dementia (7%) (PHAC, 2019b).
- The number of Canadians who report they are obese, living with diabetes, or have a mood disorder has been increasing in Canada. Over the past three decades, the number of obese children has tripled (PHAC, 2019a), and the number of all Canadians who are obese rose from 23.1% in 2004 to 26.7% in 2015 (Statistics Canada, 2017). These conditions are linked to increased health risks related to cancer, cardiovascular disease, and respiratory disease (PHAC, 2017).
- There are important differences in health status between rural and urban populations. People living in urban areas tend to have lower mortality rates for injury, suicide, and motor vehicle accidents, as well as lower rates of smoking and being overweight or obese. However, urban populations tend to have higher rates of cancer, infectious disease and stress, as well as a weaker sense of community belonging. Fully 80% of Canadians live in urban or suburban areas, with almost 36% (12.5 million) living in Toronto, Montreal, or Vancouver (PHAC, 2017). In contrast, rural Canadians tend to be in poor or fair health, less stressed, and have a stronger sense of community belonging. In addition, they have the highest rates of mortality from all causes as well as from respiratory disease (PHAC, 2017).

1.6 Climate Change Impacts on Indigenous Peoples' Health

The health and well-being of Canada's Indigenous Peoples[2] continues to be affected by Canada's history of systemic racism, colonization, and discrimination. This has included forced displacement from traditional territories, residential school experiences of abuse and neglect, and the disruption of traditional culture, language, and practices (PHAC, 2020). Compared to non-Indigenous people, First Nations, Inuit, and Métis peoples face greater challenges from climate change impacts on health due to existing disparities, such as shorter lifespans, higher rates of chronic diseases, and greater food and water insecurity in many communities (PHSA, 2011; FNHA, 2018; PHAC, 2018). Sharp divisions in health status exist between some

2 The term Indigenous Peoples is used throughout this report to refer to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples, as defined under Section 35 of the *Constitution Act, 1982*.

Indigenous and non-Indigenous Canadians. Many serious health challenges face Indigenous Peoples living in remote communities because of less access to safe drinking water, health care, and quality housing, as well as challenges with food security and safety (PHAC, 2017). Several factors increase risks to First Nations, Inuit, and Métis peoples from climate change impacts, including (Furgal & Séguin, 2006; Furgal et al., 2008; Turner & Clifton, 2009):

- close cultural connection and dependence on the natural environment;
- historic and ongoing burdens of colonialism;
- vast distances between communities;
- small service centres;
- harsher climates;
- remoteness and isolation;
- limited social, educational, and employment opportunities;
- poorer transportation systems;
- infrastructure vulnerabilities (e.g., unstable housing, water, sewage);
- food costs;
- effects of industrial resource extraction; and
- the unique and relatively complex legal, governance, and service structures for First Nations, Inuit, and Métis peoples and communities.

Drawing on studies using Indigenous knowledge and Western science, this assessment includes an examination of how climate change is expected to exacerbate health risks among Indigenous Peoples living in Canada. For example, health may be affected through climate effects on food and water, or less directly through an erosion of diverse cultures, language, and traditional livelihoods. However, the cultural and social factors unique to First Nations, Inuit, and Métis peoples, including the inextricable connection to and reliance on land and water for food, medicines, identity, and spirituality and a holistic, interconnected view of health and well-being, may also convey important and unique adaptive capabilities that all Canadians can learn and benefit from (PHAC, 2017) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Consideration of the unique perspectives and disproportionate impacts experienced by Indigenous Peoples in Canada in this assessment can support efforts to further the recommendations in the *Truth and Reconciliation Commission of Canada: Calls to Action* (TRC, 2015) and the *United Nations Declaration on the Rights of Indigenous Peoples* as they relate to climate change action (UN, 2007).

1.7 References

Balbus, J., Crimmins, A., Gamble, J. L., Easterling, D. R., Kunkel, K. E., Saha, S., & Sarofim, M. C. (2016). Climate Change and Human Health. In A. Crimmins, J. Balbus, J. L. Gamble, C. B. Beard, J. E. Bell, D. Dodgen, R. J. Eisen, N. Fann, M. D. Hawkins, S. C. Herring, L. Jantarasami, D. M. Mills, S. Saha, M. C. Sarofim, J. Trtanj, & L. Ziska (Eds.), *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (pp. 25-42). Washington, DC: U.S. Global Change Research Program. <https://doi.org/10.7930/J0765C7V>

Berry, P., Clarke, K.-L., Fleury, M. D., & Parker, S. (2014a). Human health. In F. J. Warren & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 191-232). Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/pub?id=9.699408&sl=0>

Berry, P., Paterson, J., & Buse, C. (2014b). *Assessment of Vulnerability to the Health Impacts of Climate Change in Middlesex-London.* Report Prepared for the Middlesex-London Health Unit. London, United Kingdom. Retrieved from <https://www.healthunit.com/climate-change>

Bonsal, B. R., Peters, D. L., Seglenieks, F., Rivera, A., & Berg, A. (2019). Changes in freshwater availability across Canada. In E. Bush, & D. S. Lemmen (Eds.), *Canada's Changing Climate Report* (pp. 261-342). Ottawa, ON: Government of Canada.

Bowles, D. C., Butler, C. D., & Morisetti, N. (2015). Climate change, conflict and health. *Journal of the Royal Society of Medicine*, *108*(10), 390–395. <https://doi.org/10.1177/0141076815603234>

Bush, E., & Lemmen, D. (Eds.). (2019). *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/Climate-change/pdf/CCCR_ExecSumm-EN-040419-FINAL.pdf>

Canadian Radio, Television and Telecommunications Commission (CRTC). (2019). *Communications monitoring report.* Retrieved from <https://crtc.gc.ca/eng/publications/reports/policymonitoring/2019/>

Centre for Research on the Epidemiology of Disasters (CRED). (2019). Disasters 2018: Year in review. *CRED crunch*, Issue No. 54. Retrieved from <https://www.emdat.be/cred-crunch-54-disasters-2018-year-review>

Claudel, P-D., Hackett, F., McGregor, D., & Banasiak, K. (2020). *The Lancet Countdown on Health and Climate Change: Policy Brief for Canada.* Lancet Countdown Tracking Progress on Health and Climate Change and Canadian Medical Association. Retrieved from <https://policybase.cma.ca/en/viewer?file=%2fdocuments%2fPolicyPDF%2fPD21-01.pdf#search=setName%3a(%2bClimate%20change)&phrase=false>

Confalonieri, U., Menne, B., Akhtar, R., Ebi, K. L., Hauengue, M., Kovats, R. S., Revich, B., & Woodward, A. (2007). Human Health. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 391-431). Cambridge, United Kingdom: Cambridge University Press.

Crimmins, A., Balbus, J., Gamble, J. L., Beard, C. B., Bell, J. E., Dodgen, D., Eisen, R. J., Fann, N., Hawkins, M. D., Herring, S. C., Jantarasami, L., Mills, D. M., Saha, S., Sarofim, M. C., Trtanj, J., & Ziska, L. (Eds.). (2016). *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* Washington, DC: U.S. Global Research Program.

Ebi, K. L., Boyer, C., Ogden, N., Paz, S., Berry, P., Campbell-Lendrum, D., Hess, J. J., & Woodward, A. (2021). Burning embers: synthesis of the health risks of climate change. *Environmental Research Letters, 16*(4), 044042. Retrieved from <https://iopscience.iop.org/article/10.1088/1748-9326/abeadd/pdf>

Ebi, K. L., & Burton, I. (2008). Identifying practical adaptation options: an approach to address climate change-related health risks. *Environmental Science and Policy*, *11*(4), 359–369.

Ebi, K. L., Ogden, N. H., Semenza, J. C., & Woodward., A. (2017). Detecting and Attributing Health Burdens to Climate Change. *Environment Health Perspectives, 125*(8), 085004. doi: 10.1289/EHP1509.

Environics Research. (2017). *Public perceptions of climate change and health – Final report.* Ottawa, ON.

First Nations Health Authority (FNHA). (2018). *First Nations Health Status & Health Services Utilization: Summary of Key Findings 2008/09 - 2014-15*. West Vancouver, BC: First Nations Health Authority.

Friel, S. (2019). Climate change and the people's health (N. Krieger, Ed.). Oxford University Press. doi:10.1093/oso/9780190492731.001.0001

Furgal, C., Buell, M., Chan, L., Edge, V., Martin, D., & Ogden, N. (2008). Health impacts of climate change in Canada's north. In J. Séguin (Ed.), *Human Health in a Changing Climate: A Canadian assessment of vulnerabilities and adaptive capacity* (pp. 303-366). Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/pub?id=9.699408&sl=0>

Furgal, C., & Séguin, J. (2006). Climate change, health, and vulnerability in Canadian northern Aboriginal communities. *Environmental health perspectives*, *114*(12), 1964–1970. <https://doi.org/10.1289/ehp.8433>

Gleick, P. H. (2014). Water, Drought, Climate Change, and Conflict in Syria. *Weather, Climate, and Society*, *6(*3), 331-340. Retrieved from <https://journals.ametsoc.org/view/journals/wcas/6/3/wcas-d-13-00059_1.xml>

Global Climate and Health Alliance. (2020). *Health as a driver for action on climate change*. Retrieved from <http://climateandhealthalliance.org/climate-health/health-as-a-driver-for-action-on-climate-change/>

Global Commission on Adaptation (GCA). (2019). *Adapt now: A global call for leadership on climate resilience. Global Centre on Adaptation and World Resources Institutes*. Retrieved from <https://gca.org/wp-content/uploads/2019/09/GlobalCommission_Report_FINAL.pdf>

Gosselin, P. (2010). Health of populations. In C. DesJarlais, M. Allard, D. Bélanger, A. Blondlot, A. Bouffard, A. Bourque, D. Chaumont, P. Gosselin, D. Houle, C. Larrivée, N. Lease, A. T. Pham, R. Roy, J. P. Savard, R. Turcotte, & C. Villeneuve (Eds.), *Learning to Adapt to Climate Change* (pp. 64-75). Montreal, QC: Ouranos.

Government of Canada. (2020). *Greenhouse gas emission.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html>

Government of Canada. (2021). *Progress towards Canada's greenhouse gas emissions reduction target.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/progress-towards-canada-greenhouse-gas-emissions-reduction-target.html>

Greenan, B. J. W., James, T. S., Loder, J. W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R. C., Gilbert, D., Tremblay, J-E., Wang, X. L. & Perrie, W. (2019). Changes in oceans surrounding Canada. In E. Bush & D. Lemmen (Eds.), *Canada's Changing Climate Report* (p. 343-423). Ottawa, ON: Government of Canada.

Haines, A., & Ebi, K. (2019). The Imperative for Climate Action to Protect Health. *The New England journal of medicine*, *380*(3), 263–273. <https://doi.org/10.1056/NEJMra1807873>

Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D., Davies, M., Bruce, N., Tonne, C., Barrett, M., & Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: Overview and implications for policy makers. *Lancet (London, England)*, *374*(9707), 2104–2114. <https://doi.org/10.1016/S0140-6736(09)61759-1>

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2015). *Shock waves: managing the impacts of climate change on poverty*. Washington, DC: World Bank.

Hawa, K. (2017). Health and climate Security: Interconnected security challenges of climate change and infectious disease. In C.E. Werrell, & F. Femia (Eds.), *Epicenters of Climate and Security: The New Geostrategic Landscape of the Anthropocene*. The Center for Climate and Security. Retrieved from <https://climateandsecurity.files.wordpress.com/2017/06/epicenters-of-climate-and-security_the-new-geostrategic-landscape-of-the-anthropocene_2017_06_091.pdf>

Health Canada. (1999). CAPITALizing on Science: Report of a Workshop on Climate Change, Science and Health. *Canadian Journal of Public Health.*

Health Care without Harm. (2017). *Health Care Worldwide Calls for Action on Climate Change*. Retrieved from <https://noharm-global.org/articles/news/global/health-care-worldwide-calls-action-climate-change>

Health Care without Harm. (2018). *Safe haven in the storm: Protecting lives and margins with climate-smart health care*. Retrieved from <https://noharm-uscanada.org/documents/safe-haven-storm-protecting-lives-and-margins-climate-smart-health-care>

Herring, S. C., Christidis, N., Hoell, A., Kossin, J. P., Schreck, C. J., III, & Stott, P. A. (2018). Explaining Extreme Events of 2016 from a Climate Perspective. *Bulletin of the American Meteorological Society, 99*(1), 1-157. Retrieved from <https://journals.ametsoc.org/view/journals/bams/99/1/bams-explainingextremeevents2016.1.xml>

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., & Zhou, G. (2018). Impacts of 1.5ºC Global Warming on Natural and Human Systems. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C.* Cambridge, United Kingdom: Cambridge University Press. Retrieved from <https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Chapter3_Low_Res.pdf>

Howard, C. (2017). *Lancet countdown 2017 report: Briefing for Canadian policymakers*. Canadian Medical Association & Canadian Public Health Association. Retrieved from <https://www.cpha.ca/sites/default/files/uploads/advocacy/2017_lancet_canada_brief.pdf>

Howard, C. (2018). *Lancet countdown 2018 report: Briefing for Canadian policymakers.* Canadian Medical Association & Canadian Public Health Association. Retrieved from <https://cape.ca/wp-content/uploads/2018/11/2018-Lancet-Countdown-Policy-Brief-Canada.pdf>

Hsiang, S. M., Burke, M., & Miguel, E. (2013). Quantifying the influence of climate on human conflict. *Science,* 341, 1235367. <http://dx.doi.org/10.1126/science.1235367>

Intergovernmental Panel on Climate Change (IPCC). (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change* (C. B., Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, & P. M. Midgley, Eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved from <https://www.ipcc.ch/report/managing-the-risks-of-extreme-events-and-disasters-to-advance-climate-change-adaptation/>

International Energy Agency (IEA). (2019). *Global Energy & CO2 Status Report 2019*. Paris, France. Retrieved from <https://www.iea.org/reports/global-energy-co2-status-report-2019>

International Federation of Red Cross and Red Crescent Societies (IFRCRCS). (2019). *The cost of doing nothing: The humanitarian price of climate change and how it can be avoided*. Geneva, Switzerland.

Jochum, B., Devine, C., Calain, P., Guevara, M., Schwerdtle, P. N., Belliveau, L. B., Ali, S. I., Tremblay, L. L., McIver, L., Xue, K., Harczi, G., Lai, W., Lamb, S., Collet, O., & Tirima., S. (2018). *Climate Change and Health: an urgent new frontier for humanitarianism.* Lancet Countdown: Tracking Program on Health and Climate Change and Doctors without Borders. Retrieved from <https://www.doctorswithoutborders.ca/sites/default/files/2018-lancet-countdown-policy-brief-msf.pdf>

Kelley, C. P., Mohtadi, S., Cane, M. A., Seager, R., & Kushnir, Y. (2015). Climate change in the Fertile Crescent and implications of the recent Syrian drought. *PHAS*, *112*(11), 3241-3246.

Koshida, G., & Avis, W. (Eds.). (1998). Executive Summary. In *Canada Country Study*, Volume VII. Global Climate Change: National Sectoral Issue. Ottawa, ON: Government of Canada.

Levison, M., Butler, A., Rebellato, S., Armstrong, B., Whelan, M., & Gardner, C. (2018). Development of a Climate Change Vulnerability Assessment Using a Public Health Lens to Determine Local Health Vulnerabilities: An Ontario Health Unit Experience. *International Journal of Environmental Research and Public Health*, *15*(10), 2237. <http://dx.doi.org/10.3390/ijerph15102237>

Lindsey, R. (2020). *Climate Change: Atmospheric Carbon Dioxide.* Retrieved from <https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide>

Markandya, A., Sampedro, J., Smith, S. J., Dingenen, R. V., Pizarro-Irizar, C., Arto, I., & González-Eguino, M. (2018). Health co-benefits from air pollution and mitigation costs of the Paris Agreement: A modelling study. *The Lancet Planetary Health, 2*(3). doi:10.1016/s2542-5196(18)30029-9

Martinez, G.S., Berry, P., Balbus, J., Hodgson, T., Salazar, M., Sellers, S., & Hess, J. (2018). The Adaptation Health Gap: A Global Overview. The Adaptation Gap Health Report. Nairobi, Kenya: United Nations Environment Programme.

McLeman, R. (2020). *How will international migration policy and sustainable development affect future climate-related migration?* Transatlantic Council on Migration. Retrieved from <https://www.migrationpolicy.org/sites/default/files/publications/tcm-climate-migration-mcleman_final.pdf>

Medical Society Consortium on Climate & Health. (2017). *Medical Alert! Climate change is harming our health.* Retrieved from <https://medsocietiesforclimatehealth.org/wp-content/uploads/2017/03/gmu_medical_alert_updated_082417.pdf>

Mora, C., Spirandelli, D., Franklin, E. C., Lynham, J., Kantar, M. B., Miles, W., Smith, C. Z., Freel, K., Moy, J., Louis, L. V., Barba, E. W., Bettinger, K., Frazier, A. G., Colburn, J. F. IX., Hanasaki, N., Hawkins, E., Hirabayashi, Y., Knorr, W.,...Hunter, C. L. (2018). Broad threat to humanity from cumulative climate hazards intensified by greenhouse gas emissions. *Nature Climate Change, 8*(12), 1062–1071. <https://doi.org/10.1038/s41558-018-0315-6>

Pan American Health Organization (PAHO). (2019). *Core indicators 2019: Health trends in the Americas.* Washington, DC. Retrieved from <https://www.paho.org/hq/index.php?option=com_content&view=article&id=15499:core-indicators-2019-health-trends-in-the-americas&Itemid=1894&lang=en>

Provincial Health Services Authority (PHSA). (2011). *Towards reducing health inequities: A health system approach to chronic disease prevention. A discussion paper.* Vancouver, BC: Population & Public Health, Provincial Health Services Authority.

Public Health Agency of Canada (PHAC). (2017). *State of health report 2017.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/public-health/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living.html>

Public Health Agency of Canada (PHAC). (2018). *Key health inequalities in Canada: A national portrait – Executive summary.* Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/science-research/key-health-inequalities-canada-national-portrait-executive-summary/hir-executive-summary-eng.pdf>

Public Health Agency of Canada (PHAC). (2019a). *Childhood obesity*. Retrieved from <https://www.canada.ca/en/public-health/services/childhood-obesity/childhood-obesity.html>

Public Health Agency of Canada (PHAC). (2019b). *Prevalence of chronic diseases among Canadian adults.* Retrieved from <https://www.canada.ca/en/public-health/services/chronic-diseases/prevalence-canadian-adults-infographic-2019.html>

Public Health Agency of Canada (PHAC). (2020). *From risk to resilience: An equity approach to COVID-19: Chief Public Health Officer of Canada's report on the state of public health in Canada 2020.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/from-risk-resilience-equity-approach-covid-19.html#a2.1>

Purdy C. (2016). Fort McMurray residents plagued by sleepless nights, study finds. *Toronto Star*.

Royal Society of Canada. (1995). *Implications of global change for human health: Final report of the health issues panel of the Canadian Global Change Program*. Incidental Report No IR95-2.

Schleussner, C-F., Donges, J. F., Donner, R. V., Schellnhuber, H. J. (2016). Enhanced conflict risks by natural disasters. *Proceedings of the National Academy of Sciences, 113*(33), 9216-9221. <doi: 10.1073/pnas.1601611113>

Séguin, J. (Ed.). (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity*. Ottawa, ON: Health Canada. Retrieved from <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Shultz, J. M., Sands, D. E., Kossin, J. P., & Galea, S. (2020). Double environmental injustice – climate change, Hurricane Dorian, and the Bahamas. *New England Journal of Medicine*, *382*, 1-3. Retrieved from <https://www.nejm.org/doi/full/10.1056/NEJMp1912965>

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q.,... Sauerborn, R. (2014). Human health: Impacts, adaptation, and co-benefits. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 709-754). Cambridge, United Kingdom: Cambridge University Press. Retrieved from <https://www.ipcc.ch/report/ar5/wg2/>

Statistics Canada. (2016). *Core housing need: 2016 census of population*. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/en/catalogue/98-509-X>

Statistics Canada. (2017). *Measured body mass index, Canadian Community Health Survey – Nutrition, 2015*. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/daily-quotidien/170801/dq170801a-eng.htm>

Statistics Canada. (2018). Ethnic diversity and immigration. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/pub/11-402-x/2011000/chap/imm/imm-eng.htm>

Statistics Canada. (2019a). Changes in life expectancy by selected causes of death, 2017. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/daily-quotidien/190530/dq190530d-eng.htm>

Statistics Canada. (2019b). Insights on Canadian Society: Living Alone in Canada. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/pub/75-006-x/2019001/article/00003-eng.htm>

Statistics Canada. (2019c). The characteristics of shelter residents, Income Research Paper Series. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/pub/75f0002m/75f0002m2019004-eng.htm>

Statistics Canada. (2020a). *Experiences of discrimination during the COVID-19 pandemic.* Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/daily-quotidien/200917/dq200917a-eng.htm>

Statistics Canada. (2020b). *Table 17-10-0009-01 Population estimates, quarterly*. Ottawa, ON. Retrieved from <https://doi.org/10.25318/1710000901-eng>

Statistics Canada. (2020c). *Table 11-10-0135-02 Percentage of persons in low income by sex*. Ottawa, ON. Retrieved from <https://doi.org/10.25318/1110013501-eng>

Tarasuk, V., & Mitchell, A. (2020). *Household food insecurity in Canada, 2017-18*. Toronto, ON: Research to identify policy options to reduce food insecurity (PROOF). Retrieved from <https://proof.utoronto.ca/>

Toews, E. (2018). Canadian Healthcare Facilities: Winter 2017-2018. *Journal of Canadian Healthcare Engineering Society*, *38*(1), 28-30. Retrieved from <https://issuu.com/riccardo11/docs/chf_winter_2017-2018>

Truth and Reconciliation Commission of Canada (TRC). (2015). *Honouring the truth, reconciling for the future: Summary of the final report of the Truth and Reconciliation Commission of Canada*. Ottawa, ON: Government of Canada.

Turner, N. J., & Clifton, H. (2009). "It's so different today": Climate change and indigenous lifeways in British Columbia, Canada. *Global Environmental Change*, *19*(2), 180–190. <https://doi.org/10.1016/j.gloenvcha.2009.01.005>

United Nations (UN). (2007). *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP). New York, NY. Retrieved from <https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf>

United Nations High Commission for Refugees (UNHCR). (2015). *The environment and climate change*. Geneva. Retrieved from <https://www.unhcr.org/540854f49.pdf>

Vicedo-Cabrera, A. M., Scovronick, N., Sera, F., Royé, D., Schneider, R., Tobias, A., Astrom, C., Guo, Y., Honda, Y., Hondula, D. M., Abrutzky, R., Tong, S., de Sousa Zanotti Stagliorio Coelho, M., Nascimento Saldiva, P. H., Lavigne, E., Matus Correa, P., Valdes Ortega, N., Kan, H., Osorio, S., Kyselý, J., Urban, A., … Gasparrini, A. (2021). The burden of heat-related mortality attributable to recent human-induced climate change. *Nature Climate Change.* <https://doi.org/10.1038/s41558-021-01058-x>

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P. M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., Hamilton, I., … Costello, A. (2015). Health and climate change: policy responses to protect public health. *Lancet (London, England)*, *386*(10006), 1861–1914. <https://doi.org/10.1016/S0140-6736(15)60854-6>

Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J., Cox, P. M., Daly, M., Dasandi, N., Davies, M., Depledge, M., Depoux, A., Dominguez-Salas, P., Drummond, P., Ekins, P., Flahault, A., … Costello, A. (2018). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *Lancet (London, England)*, *391*(10120), 581–630. <https://doi.org/10.1016/S0140-6736(17)32464-9>

Werrell, C. E., & Femia, F. (Eds.). (2017). *Epicenters of climate and security: The new geostrategic landscape of the Anthropocene.* The Center for Climate and Security. Retrieved from <https://climateandsecurity.files.wordpress.com/2017/06/epicenters-of-climate-and-security_the-new-geostrategic-landscape-of-the-anthropocene_2017_06_091.pdf>

World Health Organization (WHO). (2014). *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s*. Geneva, Switzerland.

World Health Organization (WHO). (2015). *Operational framework for building climate resilient health systems.* Geneva, Switzerland. Retrieved from <http://www.who.int/globalchange/publications/building-climate-resilient-health-systems/en/>

World Health Organization (WHO). (2018). *COP 24 Special Report – Health and climate change.* Geneva, Switzerland. Retrieved from <https://www.who.int/publications/i/item/cop24-special-report-health-climate-change>

World Health Organization (WHO). (2019). *WHO Health and Climate Change Survey Report: Tracking Global Progress.* Geneva, Switzerland. Retrieved from <https://www.who.int/globalchange/publications/country-profiles-global-report-2019/en/>

World Health Organization (WHO) & United Nations Environment Programme (UNEP). (2010). *Healthy environments for healthy children: key messages for action*. Retrieved from <http://www.who.int/ceh/publications/hehc_booklet/en/>

World Medical Association (WMA). (2018). *Why doctors need to join the fight against climate change.* Retrieved from <https://www.wma.net/news-post/why-doctors-need-to-join-the-fight-against-climate-change>

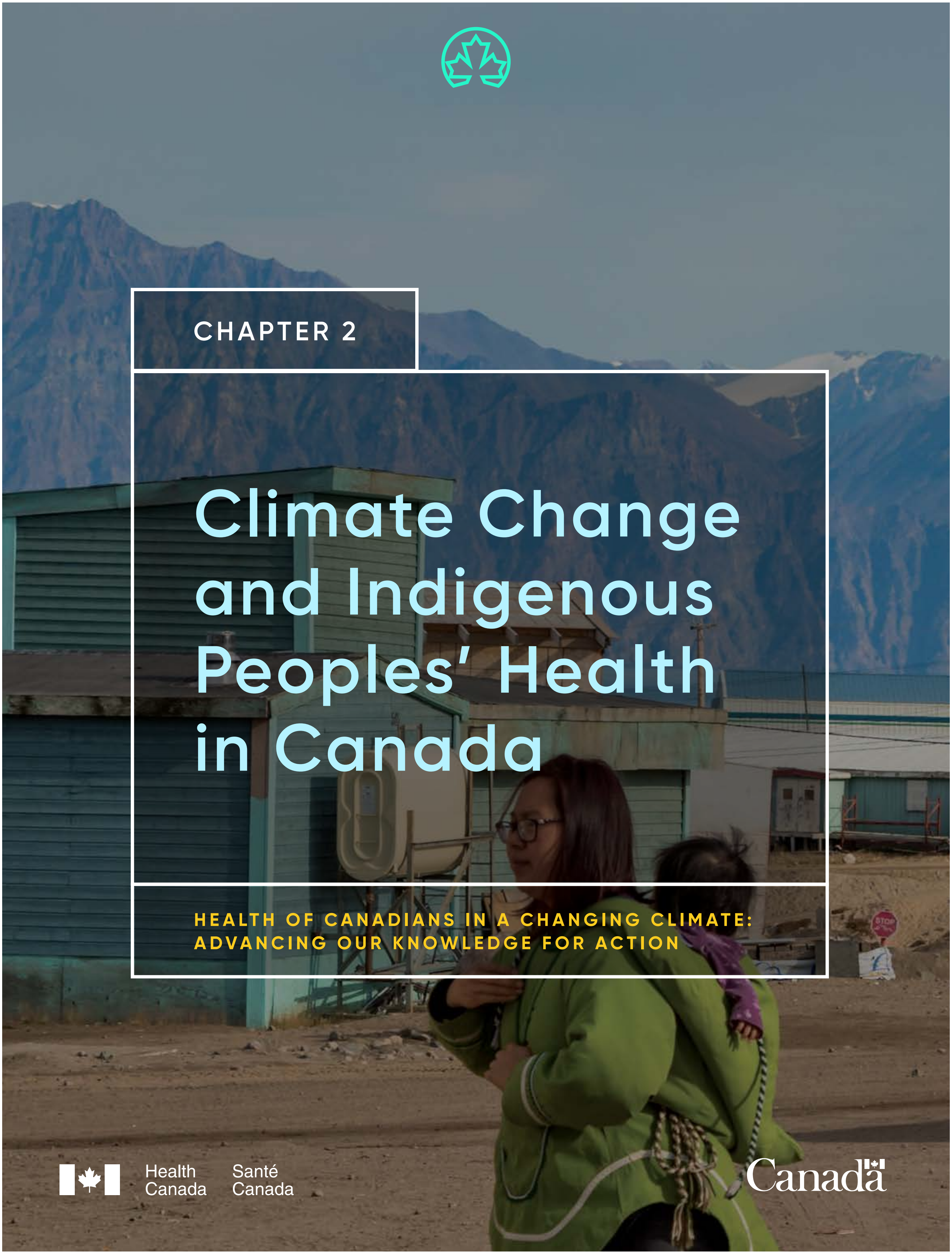
World Meteorological Association (WMO). (2018a). *WMO greenhouse gas bulletin (GHG Bulletin) - No. 14: The state of greenhouse gases in the atmosphere based on global observations through 2017.* Retrieved from <https://library.wmo.int/index.php?lvl=notice_display&id=20697#.XFycurCWx1s>

World Meteorological Association (WMO). (2018b). *WMO statement on the state of the global climate in 2017.* Retrieved from <https://library.wmo.int/index.php?lvl=notice_display&id=20220#.X5hF8DkUk2x>

World Meteorological Association (WMO). (2020). *WMO statement on the state of the global climate in 2019.* Retrieved from <https://library.wmo.int/doc_num.php?explnum_id=10211>

World Weather Attribution. (2021). Western North American extreme heat virtually impossible without human-caused climate change. <https://www.worldweatherattribution.org/western-north-american-extreme-heat-virtually-impossible-without-human-caused-climate-change/>

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., & Kharin, V. V. (2019). Changes in Temperature and Precipitation Across Canada. In E. Bush, & D.S. Lemmen, (Eds.), *Canada's Changing Climate Report* (pp. 112-193). Ottawa, ON: Government of Canada.



CHAPTER 2

Climate Change and Indigenous Peoples' Health in Canada

HEALTH OF CANADIANS IN A CHANGING CLIMATE:
ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Prepared by the National Collaborating Centre for Indigenous Health with contributions from Donna Atkinson, Roberta Stout, Regine Halseth, and Margo Greenwood

Suggested Citation

National Collaborating Centre for Indigenous Health (NCCIH). (2022). Climate Change and Indigenous Peoples' Health in Canada. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

Summary

First Nations, Inuit, and Métis peoples in Canada are uniquely sensitive to the impacts of climate change because they tend to live in geographic regions experiencing rapid climate change and because they have a close relationship to and depend on the environment and its natural resources. The direct and indirect impacts of climate change on the health and well-being of First Nations, Inuit, and Métis are interconnected and far-reaching.

The changing climate will exacerbate the health and socio-economic inequities already experienced by First Nations, Inuit, and Métis peoples, including respiratory, cardiovascular, water- and foodborne, chronic and infectious diseases, as well as financial hardship and food insecurity. Natural hazards, coupled with unpredictable and extreme weather events, can result in temporary or long-term evacuations from traditional territories, in addition to greater risk of injury and death from accidents while out on the land. Infrastructure damage or instability due to climate change, particularly in Northern and remote locations, may restrict access to health systems and supplies. Climate change threatens First Nations, Inuit, and Métis peoples' ways of life, resilience, cultural cohesion, and opportunities for the transmission of Indigenous knowledges and land skills, particularly among youth. Cross-cutting climate impacts will disrupt the livelihoods of First Nations, Inuit, and Métis peoples, families and communities, affecting their sense of identity and cultural continuity and compounding existing mental health issues. Indigenous knowledge systems and practices are key to First Nations, Inuit, and Métis peoples' ability to observe, respond, and adapt to climate and environmental changes.

Key Messages

- First Nations, Inuit, and Métis peoples in Canada are uniquely sensitive to the impacts of climate change, given their close relationships to land, waters, animals, plants, and natural resources; tendency to live in geographic areas undergoing rapid climate change, especially Northern Canada; and greater existing burden of health inequities and related determinants of health.
- The health impacts of climate change on First Nations, Inuit, and Métis peoples are interconnected and far-reaching. They result from direct and indirect impacts of climate change that exacerbate existing inequities, and affect food and water security, air quality, infrastructure, personal safety, mental well-being, livelihoods, and identity, as well as increase exposure to organisms causing disease.
- Health impacts are experienced differently within and between First Nations, Inuit, and Métis men, women, boys, girls, and gender-diverse people. Thus, research and adaptations must respect cultures, geography, local contexts, and the unique needs of these communities.

- First Nations, Inuit, and Métis peoples have been actively observing and adapting to changing environments in a diversity of ways since time immemorial. Indigenous knowledge systems and practices are equal to scientific knowledge and have been, and continue to be, critical to Indigenous Peoples' survival and resilience.
- Indigenous knowledge systems are increasingly recognized, both nationally and internationally, as important in adapting to climate change, monitoring impacts at the local and regional level, and informing climate change policy and research.
- First Nations, Inuit, and Métis peoples are rights holders. Preparing for the health impacts of climate change requires that Indigenous Peoples' rights and responsibilities over their lands, natural resources, and ways of life are respected, protected, and advanced through distinctions-based, Indigenous-led, climate change adaptation, policy, and research.

Overview of Climate Change Impacts on the Health and Well-Being of First Nations, Inuit, and Métis Peoples in Canada

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Impacts on First Nations, Inuit, and Métis peoples and communities	• Increased wildfire, drought, and flooding events • Instability and melting of permafrost and changes to ground snow cover, sea ice extent and thickness • Changes to sea levels and weather patterns • Higher exposure to climate risks in relation to natural and built environments (such as poor housing, water, sanitation, and environmental contaminants) • Decreased availability, quality, quantity, and safety of traditional food sources • Melting and damage to ice roads • Effects of warming and changes to precipitation patterns that affect survival and transmission of disease-causing organisms	• Exacerbation of health and socio-economic inequities • Air quality health impacts (such as respiratory and cardiovascular diseases) • Increased water and foodborne diseases • Mental health impacts (such as stress, anxiety, and post-traumatic stress disorder) • Exacerbation of chronic and infectious diseases • Increased injuries and deaths from accidents (e.g., natural hazards and extreme weather events) • Increased direct and indirect health impacts from permafrost-related infrastructure damage • Decreased opportunities for transmission of Indigenous knowledges and land skills, particularly among youth, affecting sense of identity, mental well-being, and cultures

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
		• Temporary or long-term evacuation or displacement of populations from traditional territories, disrupting lives, creating financial hardship and affecting mental well-being • Food and water insecurity due to decreased access to and quality of land, waters, plants, animals, and natural resources • Impacts on health and infrastructure (such as restricted or delayed travel for health and emergency services, access to medical supplies, and patient safety)

2.1 Introduction

"Sister of ocean and sand,
Can you see our glaciers groan with the weight of the world's heat?
I wait for you, here,
on the land of my ancestors,
heart heavy with a thirst for solutions
as I watch this land change
while the world remains silent" [1]

Indigenous[2] Peoples, in Canada and globally, are recognized as uniquely sensitive to the impacts of climate change because they often live in geographic regions already experiencing rapid change and because of their close relationships with and dependence on land, waters, animals, plants, and natural resources for their sustenance, livelihoods, cultures, identities, health, and well-being (Ford, 2012; ILO, 2017; Jones, 2019). Non-climate determinants of health exacerbate these sensitivities, including a greater existing burden of health inequities compared to non-Indigenous populations and the historic and ongoing effects of colonization and socio-economic and political marginalization (Ford et al., 2010a; Ford, 2012; ILO, 2017; Jones, 2019).

The health impacts of climate change on First Nations, Inuit, and Métis peoples are interconnected and far-reaching. Changing temperature and precipitation regimes will increase the frequency and intensity of extreme weather events (e.g., floods, storms, heat events, droughts), wildfires, sea level rise, and coastal erosion, with direct and indirect impacts on food and water security, air quality, infrastructure, personal safety, mental health and well-being, livelihoods, and identity (Ford et al., 2010a; Ford, 2012; Yusa et al., 2015). These impacts will be experienced differently within and among First Nations, Inuit, and Métis men, women, boys, girls, and gender-diverse people in communities from coast to coast to coast.

Although often portrayed as passive victims or harbingers of climate change impacts in international reporting (Ford et al., 2016b; Belfer et al., 2017), Indigenous Peoples in Canada and around the world have been actively observing and adapting to changing environments in a diversity of ways for millennia (Ford et al., 2020). Indigenous knowledge systems and practices have been critical to their survival and resilience and are increasingly recognized as valuable to understanding and responding to climate change (Ford et al., 2016b; Expert Panel on Climate Change Adaptation and Resilience, 2018; ILO, 2019). Mobilizing Indigenous knowledges and experiences in climate change adaptation, policy, and research in a consistent, collaborative, decolonial, and rights-based way, however, remains a significant challenge (IPCC, 2014; Ford et al., 2016b; Belfer et al., 2019; Huntington et al., 2019; Latulippe & Klenk, 2020).

1 Excerpt from *Rise* (Jetñil-Kijiner & Niviâna, n.d.).

2 The term Indigenous is used in this chapter to refer collectively to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples, as defined under Section 35 of the *Constitution Act, 1982*. Wherever possible, clear distinctions are made between these three distinct, constitutionally recognized groups. Indigenous Peoples outside of Canada are also referenced in some instances – particularly with respect to international climate policy, processes, and rights – and are identified as such.

This chapter provides an overview of climate change risks to Indigenous Peoples' health in Canada. It begins with a description of Indigenous health inequities, followed by climate change risks to health specific to natural hazards; mental health and well-being; air quality; food safety and security; water quality, quantity, and security; infectious diseases; and health systems. The role of Indigenous knowledges in climate change adaptation, monitoring, policy, and research is then discussed within the context of Indigenous Peoples' rights as well as national and international obligations. Existing knowledge gaps specific to First Nations, Inuit, and Métis peoples important for efforts to protect health are provided, along with considerations for moving forward.

2.1.1 First Nations, Inuit, and Métis Populations in Canada

First Nations, Inuit, and Métis peoples in Canada are a youthful and fast-growing population. In 2016, the Indigenous population reached 1,673,785 (4.9% of the total Canadian population), which represents an increase of 42.5% from the 2006 Census (Statistics Canada, 2017). From 2006 to 2016, the First Nations population grew by 39.3% to reach 977,230; the Inuit population grew by 29.1% to reach 65,025; while the Métis population grew by 51.2% to reach 587,545. The average age of the Indigenous population in 2016 was 32.1 years, which is almost a decade younger than the non-Indigenous population. Approximately 29.2% of First Nations, 33% of Inuit, and 22.3% of Métis people were 14 years of age or younger in 2016, compared to 16.4% of the non-Indigenous population (Statistics Canada, 2017). The proportion of Indigenous people over 65 years of age is also on the rise and accounted for 7.3% of First Nations, Inuit, and Métis populations in 2016 (Statistics Canada, 2017).

There are more than 600 First Nations communities in Canada, representing more than 60 Indigenous languages (Statistics Canada, 2017). The largest proportion of First Nations people live in Ontario (24.2%), followed by the western provinces of British Columbia (17.7%), Alberta (14.0%), Manitoba (13.4%), and Saskatchewan (11.7%) (Statistics Canada, 2017). In 2016, the majority of Inuit (72.8%) lived in the 53 communities of Inuit Nunangat (the traditional homelands of Inuit), with the largest proportion living in Nunavut (63.7%), followed by Nunavik (24.9%), Inuvialuit (6.6%), and Nunatsiavut (4.8%) (Statistics Canada, 2017). Inuktut is the term used for all Inuit languages; it includes 12 main dialects and nine different writing systems[3] (The Royal Canadian Geographical Society, 2018). The majority of the Métis population (80.3%) live in communities and settlements[4] in Ontario and the western provinces. Alberta has the largest Métis population (19.5%), followed by Manitoba (15.2%), British Columbia (15.2%), Quebec (11.8%), Saskatchewan (9.9%), and the Atlantic provinces (7.2%). Métis have their own unique language called Michif, a combination of French and Cree languages that also borrows from English and other Indigenous languages.

3 In September 2019, the Inuit Tapiriit Kanatami Board of Directors approved a unified orthography for Inuktut called Inuktut Qaliujaaqpait. This standardized writing system was developed by Inuit for Inuit to strengthen Inuktut across Inuit Nunangat for future generations (ITK, 2019a).

4 There are eight Métis settlements in Alberta: Paddle Prairie (or Keg River), Buffalo Lake (Caslan), East Prairie, Elizabeth, Fishing Lake (Packechawanis), Gift Lake (Ma-cha-cho-wi-se), Kikino (Goodfish Lake), Big Prairie (now Peavine). These settlements are the only government-recognized Métis land base in Canada (The Royal Canadian Geographical Society, 2018).

Recent Statistics Canada data suggest Indigenous Peoples are increasingly urbanized. Among First Nations with registered or treaty Indian status, 44.2% lived on reserve in 2016, while the remainder lived off reserve. Growth was noted for both on-reserve (+12.8%) and off-reserve (+49.1%) First Nations over the period 2006 to 2016 (Statistics Canada, 2017). While most Inuit lived in Inuit Nunangat in 2016, approximately 27.2% lived outside its borders; of those, 56.2% lived in a metropolitan area of at least 30,000 people, with the largest Inuit populations living in Ottawa-Gatineau, Edmonton, and Montreal (Statistics Canada, 2017). Of the three Indigenous groups, Métis are most likely to live in a city, with 62.6% living in a metropolitan area of at least 30,000 people. Winnipeg has the highest Métis population in Canada, followed by Edmonton, Vancouver, and Calgary (Statistics Canada, 2017).

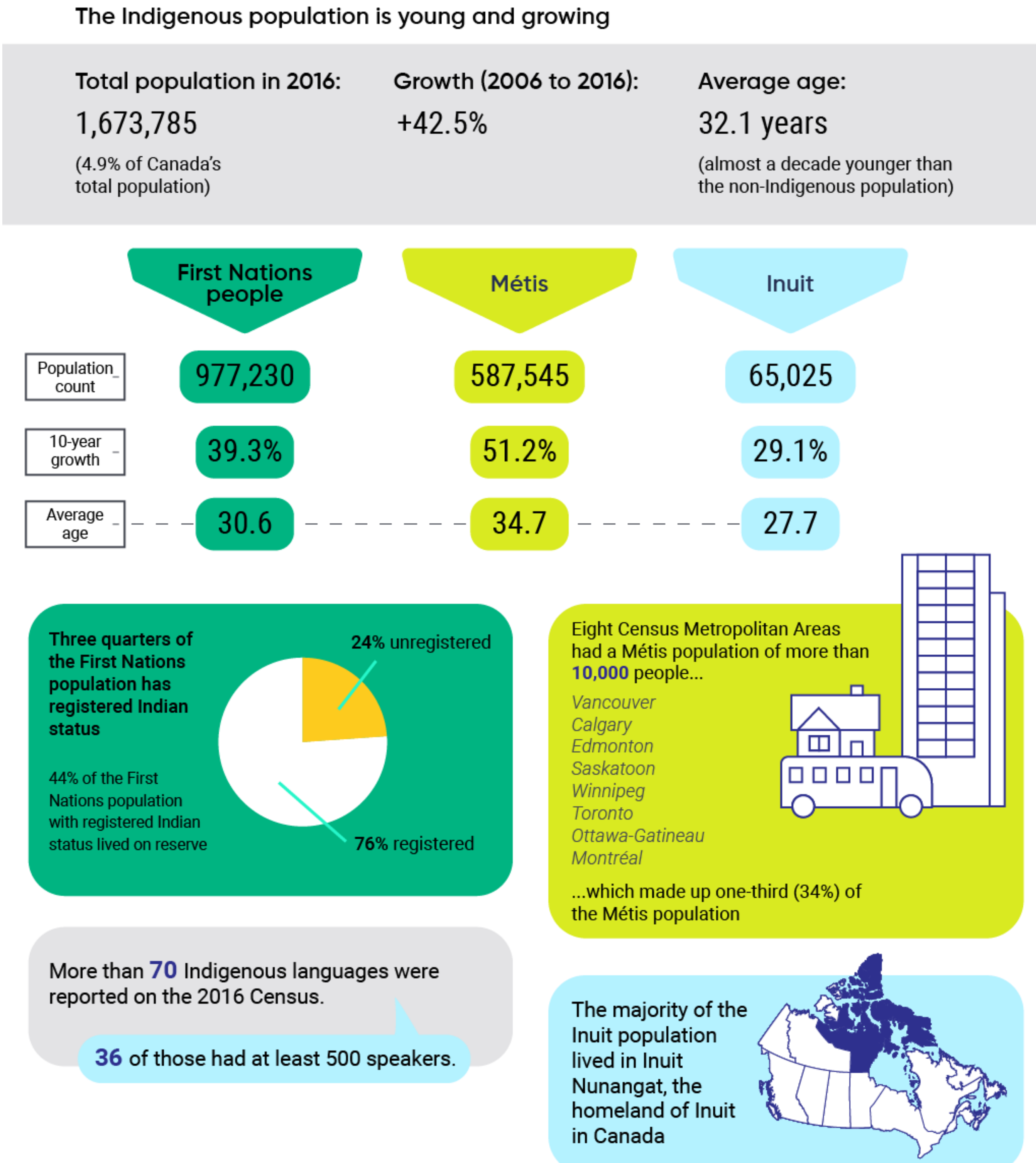


Figure 2.1 The Indigenous population in Canada. Source: Statistics Canada, 2016.

2.2 Methods and Approach

This chapter is a synthesis of publicly available peer-reviewed and grey literature, as well as alternative media sources (e.g., videos, news articles) focused on climate change risks to First Nations, Inuit, and Métis peoples' health in Canada and on the role of Indigenous knowledges in climate change adaptation, policy, and research efforts. It is important to note that this is the first time an Indigenous-specific chapter has been included as part of Canada's national climate change and health assessment. Emphasis was placed on literature specific to Canada published since the 2014 assessment on human health in *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (Berry et al., 2014), although older sources and international literature were included, as appropriate.

Sources were identified through a search of academic databases (e.g., BioMed Central, PubMed, and Science Direct), Google, and Google Scholar using the following search terms: "First Nations/Inuit/Métis/Indigenous" and "climate change" and "adaptation/infectious diseases/natural hazards/mental health/air quality/food security/water safety/water security/health services" and "Canada" and "traditional knowledge/traditional ecological knowledge/Indigenous knowledge." This search was supplemented with manual scanning of citations in key publications and a targeted search of relevant websites, including Indigenous and non-Indigenous government agencies and organizations (e.g., national Indigenous organizations, Indigenous Services Canada). Additional sources were included based on peer-review feedback of this chapter.

Of the relevant publications identified, the majority were peer-reviewed and focused on Inuit populations in the Arctic, with the remainder focused on First Nations or Indigenous populations generally in rural and Northern Canada. Specific populations are distinguished in this chapter, where possible, to highlight the diverse perspectives and experiences within and among First Nations, Inuit, and Métis peoples and communities. However, some generalizations are made depending on the number and nature of citations used (e.g., more than one Indigenous group is being referenced) and in instances where there are potentially shared experiences (e.g., health inequities and determinants).

Significant gaps identified from this review include literature related to climate change health risks affecting Indigenous populations in other regions of Canada (e.g., Prairies, Maritimes), Métis and urban Indigenous populations, and gendered perspectives on climate change (see section 2.7 Knowledge Gaps). The focus of research in the North is due to the more rapid warming in that region and the greater severity of current and projected impacts (Ford, et al., 2014; ITK, 2019b). The gaps also point to the limitations of Indigenous health research and data in Canada more generally (see Box 2.1).

Box 2.1 Indigenous health data and research in Canada

In assessing climate change risks to health, it is important to recognize the limitations and challenges of Indigenous health data and research as they currently exist in Canada. Relevant, high-quality data are challenged by a lack of disaggregated and longitudinal First Nations, Inuit, and Métis-specific data; the absence of relevant, consistent, and inclusive Indigenous identifiers in population health data sources; and a lack of strengths-based and community-driven health and wellness indicators (Smylie, 2010; Smylie & Firestone, 2015). Some geographic areas and populations are over-represented in core population health data sources (e.g., Status First Nations living on reserve or Inuit living in Inuit Nunangat), while others are severely under-represented (e.g., non-Status First Nations, Métis, or other Indigenous Peoples living in urban areas) (Young, 2003; Smylie, 2010; Kumar et al., 2012). This substandard health data result in generalizations across diverse First Nations, Inuit, and Métis populations and an under-estimation of the health inequities between Indigenous and non-Indigenous people (Smylie & Firestone, 2015). Working in partnership with First Nations, Inuit, and Métis peoples and their representative and governing organizations to govern and manage the data collected from them is critical to addressing these challenges (Smylie & Firestone, 2015).

Research on Indigenous health has, and continues to be, dominated by non-Indigenous researchers (Brown, 2018; Anderson, 2019) and by scientific knowledge paradigms that consider Indigenous methodologies, epistemologies, knowledges, and perspectives less rigorous than Western science (Saini, 2012; Hyett et al., 2018). It is also tainted by a history of unethical policies and practices, including the "misappropriation and abuse of Indigenous knowledge, property, culture and biological samples," as well as a "failure to share data and resulting benefits; and the dissemination of information that misrepresented or stigmatized entire communities" (Hyett et al., 2018, p. E616). Consequently, much of the health research conducted to date is not relevant to First Nations, Inuit, and Métis peoples' health needs or priorities (Young, 2003; Wilson & Young, 2008; Hyett et al., 2018). Although ethics guidelines and community-based and partnership approaches are improving the practice of health research involving First Nations, Inuit, and Métis peoples (Hyett et al., 2018), there is still considerable work to be done to ensure research is respectful, relevant, reciprocal, and responsible. Guidance on best practices for research with Indigenous Peoples and communities have been developed by non-governmental organizations, national Indigenous organizations, and government agencies, and complement resources developed by communities and other organizations (RCAP, 1996; NAHO, 2011; CIHR, 2013; First Nations Information Governance Centre, 2014; CIHR, NSERC, & SSHRC, 2018; Hyett et al., 2018; ITK, 2018; Kilian et al., 2019).

2.3 Health Inequalities and Indigenous Peoples' Health

"Rapid climate change is yet another layer of stress cast over our already stressed society" [5]

Although Indigenous Peoples are the most youthful and fastest-growing segment of Canada's population, they do not enjoy the same benefits of good health as other Canadians. First Nations, Inuit, and Métis individuals, families, and communities experience a disproportionate burden of ill health compared to non-Indigenous people, including significantly higher rates of infant and child mortality, unintentional injury and death, chronic and infectious diseases, suicide, exposure to environmental contaminants, malnutrition, and a reduced life expectancy (Gracey & King, 2009; Greenwood et al., 2018; PHAC, 2018a). Health disparities are influenced, in part, by the social determinants of health, or the conditions in which individuals are born, grow, live, work, and age (CSDH, 2008). Key social determinants of health include income and social status, employment and working conditions, education, early childhood development, physical environments, social supports and coping skills, health behaviours, access to health services, gender, culture, and race. These conditions are, in turn, the result of complex structures and systems operating at the local, national, and global levels that determine the distribution of money, power, and resources within and among countries (Marmot, 2007; CSDH, 2008; Reading, 2018). Together, the determinants of health and their structural drivers contribute to a social gradient of health, where the most socio-economically disadvantaged populations experience the greatest burden of ill health (Marmot, 2007) (see Chapter 9: Climate Change and Health Equity).

Indigenous-specific determinants of health are linked to past and contemporary colonial policies and practices, including dispossession of traditional lands; forced relocation to reserves or settlements; child apprehensions related to Indian residential schools, the Sixties Scoop,[6] and subsequent child welfare policies; forced relocation to tuberculosis sanatoria and Indian hospitals;[7] oppression through the Indian Act; and systemic discrimination (Gracey & King, 2009; Greenwood et al., 2018). These determinants serve to perpetuate structural inequities and systemic disadvantage across the lifespan and across generations. Such intergenerational impacts are evident in the disturbingly high rates of substandard or overcrowded housing, poverty, food and water insecurity, unemployment, child apprehension, incarceration, as well as lower rates of educational attainment and poorer access to quality health care (Reading & Wien, 2009; NCCAH,

5 Natan Obed, as quoted in ITK (2016, p. 28).

6 Indigenous Peoples continued to experience trauma, loss, and grief because of the rapid expansion of the child welfare system in the 1960s. During this period, commonly known as the "Sixties Scoop" (Sinclair, 2007), disproportionate numbers of Indigenous children were placed in foster care. By the end of the 1960s, "30% to 40% of the children who were legal wards of the state were Indigenous children – in stark contrast to the rate of 1% in 1959" (Fournier & Crey, 1997, as cited in Kirmayer et al., 2000, p. 609).

7 Indian hospitals were racially segregated institutions, originally serving as tuberculosis sanatoria, but later operating as general hospitals overseen by the Indian Health Service. They were poorly funded, understaffed, and overcrowded, and many Indigenous people experienced abuse, coercion, and medical experimentation in them (Lux, 2016; McCallum & Perry, 2018).

2012; NCCAH, 2017). In contrast, factors such as spending time out on the land, having a strong sense of Indigenous identity, cultural continuity, supportive kinship and community relationships, and expressions of self-government and self-determination can promote protective factors such as resilience, self-reliance, and self-confidence to facilitate more positive health outcomes (Chandler & Lalonde, 1998; Petrasek MacDonald et al., 2013a; Kielland & Simeone, 2014). Health determinants intersect and manifest differently among First Nations, Inuit, and Métis peoples, influencing risk and protective factors associated with health status in distinct ways across the lifespan (Reading & Wien, 2009).

Determinants of health frameworks, and perspectives of health and well-being generally, vary considerably within and among First Nations, Inuit, and Métis peoples. At a national level, some key documents articulating these perspectives include:

- *The First Nations Health Transformation Agenda by the Assembly of First Nations* (AFN, 2017)
- *Social Determinants of Inuit Health in Canada by Inuit Tapiriit Kanatami* (ITK, 2014)
- *Métis Life Promotion Framework©* (MLPF) (Martens et al., 2010).

The status of determinants of health can increase or decrease vulnerability to health risks associated with climate change (see Chapter 9: Climate Change and Health Equity). Existing health inequities and inequalities can compound vulnerability to climate-related health risks. This results in increased exposure and sensitivity to climate hazards and decreased ability to cope and adapt (Islam & Winkel, 2017).

2.3.1 Gender as a Determinant of Indigenous Peoples' Health

Before colonization, "Indigenous categorizations of gender emerged within other cultural and social practices, and were as diverse as Indigenous cultures themselves" (Hunt, 2016, p. 7). Historic and ongoing colonial processes imposed new social norms and legal rights that altered these often egalitarian and matrifocal gender roles and responsibilities, creating significant gender inequalities as well as discrimination against gender fluidity and homosexuality (Vinyeta, et al., 2015; Hunt, 2016). In the context of climate change, gender intersects with other determinants of health — such as education, race, income, and social status — to create unique climate change vulnerabilities, resiliencies, and lived experiences among First Nations, Inuit, and Métis women, men, boys, girls, and gender-diverse people (WHO, 2014; Vinyeta, et al., 2015; Williams et al., 2018). In Canada, the majority of gender and climate change research conducted with First Nations, Inuit, and Métis populations to date has focused on food security, mental health, unintentional injury, and deaths (Sellers, 2018); attitudes and behaviours toward climate change (Bunce, 2015; Bunce et al., 2016); and environmental governance (Natcher, 2013; Staples & Natcher, 2015a; Staples & Natcher, 2015b; Sellers, 2018).

Climate change impacts are experienced differently across genders due to cultural differences in gender-based responsibilities. In a study by Bunce (2015), activities such as picking berries, making clothing, and preparing and preserving food were identified as central to identity and the well-being of Inuit women. Changes in berry production, thickness and duration of sea ice, and the quality and quantity of furs and pelts can hinder fulfillment of these traditional roles and the transmission of these skills to younger generations

(Dowsley et al., 2010; Pauktuutit, 2011; Bunce, 2015; Bunce et al., 2016). For First Nations, Inuit, and Métis women, a key part of female identity is the special relationship to water and the responsibilities to care for and protect it (Anderson, 2010; McGregor, 2012; Szach, 2013; Powys Whyte, 2014). Climate change may affect the availability and quality of fresh water, which can significantly affect emotional, mental, and spiritual health and well-being (Longboat, 2013; Szach, 2013).

It is well recognized that warming temperatures are expected to increase the frequency and intensity of extreme heat events and the range and survival of vectors of infectious diseases, such as mosquitoes and ticks. Kovats and Hajat (2007) found that men are more likely to be active in hot weather, which makes them more vulnerable to heat stress. Pregnant women are at increased risk of poor health outcomes from placental abruption in full-term pregnancies (He et al., 2018) (see Chapter 3: Natural Hazards). Since First Nations, Inuit, and Métis men spend considerable time outdoors engaging in land-based activities (e.g., hunting, fishing, trapping), climate change can be expected to disproportionately place Indigenous men at increased risk of heat-related conditions and vector-borne diseases such as Lyme disease and West Nile virus (Vinyeta et al., 2016; Sellers, 2018).

However, at present, there is a lack of surveillance and reporting on these types of climate-related impacts. For example, despite the expanded range and frequency of vector-borne illnesses such as West Nile virus, Lyme disease, and Zika virus, and recognition of the importance of vector-borne disease surveillance and monitoring programs, including among First Nations communities (PHAC, 2018b), systematic vector surveillance does not occur in all provinces and territories (Awuor et al., 2019), and Indigenous status has not been identified in human case surveillance data. As a result, there are no publicly available data from surveillance programs that identify the prevalence of vector-borne illnesses among specific populations, including Indigenous populations.

Indigenous men may also be at greater risk of accidents as the environments in which they carry out their traditional activities become more hazardous (Vinyeta et al., 2016). Changes in weather and climate, including decreases in wildlife populations or safe access to hunting areas, can also limit the transmission of gender-based knowledge and skills to younger generations (Jacob et al., 2010; Downing & Cuerrier, 2011; Pauktuutit, 2011; Bunce, 2015; Bunce et al., 2016).

Emotional responses and coping strategies related to climate change effects may also be gendered. For example, Inuit women experienced stronger emotional reactions (e.g., fear, distress, helplessness, anger, sadness, and frustration) to climate change effects than Inuit men, while men were more likely to experience anxiety in response to climate change (Cunsolo Willox et al., 2012; Sellers, 2018). Inuit women are also more likely to share their feelings with others and manage stress in healthy ways, including becoming strong activists in climate change actions at global and local levels (Bunce, 2015; Williams et al., 2018; Hania, 2019; Santisteban, 2020). First Nations, Inuit, and Métis men may experience increased stress as a result of losing access to places and resources critical to masculine identities, especially those tied closely to livelihoods, which may exacerbate problems of substance abuse, suicide, and family violence that have been associated with colonization and cultural loss and are particularly prevalent in some First Nations and Inuit communities (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2015; Vinyeta et al., 2016).

2.4 Climate Change Risks to Indigenous Peoples' Health

"The respect that we need to show the land and its relatedness to us. We are the land. If the land is sick then it ain't going to be very long before we're going to get sick." [8]

The impacts of climate change on the land, and on Indigenous Peoples' relationships to the land, are already evident in communities from coast to coast to coast, not just in terms of effects on physical health, but also on the emotional, spiritual, psychological, and cultural well-being of Indigenous Peoples (ISC, 2019a). The dramatic, unprecedented rate of change has led some Indigenous communities and organizations to declare climate change states of emergency. In May 2019, the Vuntut Gwitchin First Nation (Old Crow, Yukon) was the first to issue a formal state of emergency, asserting that their traditional way of life was under threat from the rapidly changing landscape (Yeednoo Diinehdoo Ji'heezrit Nits'oo Ts'o' Nan He'aa Declaration, n.d.). Vuntut Gwitchin First Nation Chief, Dana Tizya-Tramm, noted, "It's going to be the blink of an eye before my great grandchild is living in a completely different territory, and if that's not an emergency, I don't know what is" (Avery, 2019, n.p.). The Assembly of First Nations (AFN) subsequently declared a global climate emergency at its July 2019 annual general meeting, along with calls to develop a First Nations–led climate strategy and to convene a national gathering to advance climate advocacy, which was held in March 2020, in Whitehorse, Yukon (AFN, 2019, AFN, 2020).

In Inuit Nunangat, which is warming at almost three times the global average (Bush & Lemmen, 2019), the Inuit Tapiriit Kanatami (ITK) has responded to this unprecedented rate of change and impacts by developing the *Inuit Priorities for Canada's Climate Strategy: A Canadian Inuit Vision for Our Common Future in Our Homelands* report (ITK, 2016) and the *National Inuit Climate Change Strategy* (ITK, 2019b).

In October 2016, the Métis National Council (MNC) passed a resolution on climate change and the environment at a special sitting of its general assembly. Couched in a nation-to-nation, government-to-government approach, the resolution supports meaningful Métis engagement and review of federal environmental legislation, policy, protection, management, and assessment processes (Métis National Council, 2016). The MNC has also conducted a national climate change and health vulnerability assessment (JF Consulting, 2020).

The health impacts of climate change on First Nations, Inuit, and Métis peoples are far-reaching, and have already been observed in many regions of Canada. The following section provides a broad overview of climate change risks to First Nations, Inuit, and Métis peoples' health and well-being associated with natural hazards, mental health, air quality, infectious diseases, food safety and security, water safety and security, and health systems. Risks are discussed in the context of existing First Nations, Inuit, and Métis peoples' health inequities and the unique sensitivities of Indigenous Peoples to climate change. Examples of Indigenous adaptation projects and initiatives from across Canada in response to climate change are also provided.

8 Batchewana Elder quoted in Tobias & Richmond (2014. p. 29).

2.4.1 Natural Hazards

"The sea ice has really changed. I used to travel both by dog team and skidoo to and from Pond Inlet. In my recent trip, the snow has changed. The snow on top and snow condition on top has changed. Normally, in the spring, the snow on the top will freeze at night. This process is called qiqqsuqqaqtuq. This frozen layer can be seen when the day just starts getting daylight; it is sparkling because of the recent freeze up on top. I noticed it wasn't like that anymore. This process, the freezing, isn't happening anymore."[9]

First Nations, Inuit, and Métis peoples are uniquely sensitive to the health impacts of climate-related events, given their close reliance on the environment for their sustenance, livelihoods, and cultural practices (Ford, 2012; Kipp et al., 2019b). The related health impacts are experienced both directly and indirectly. In the Arctic, rising temperatures are affecting permafrost stability, ground snow cover, sea ice extent and thickness, sea levels, and weather patterns (Ford et al., 2014; Durkalec et al., 2015; ITK, 2016). These changes are exacerbating the loss of knowledge and land skills related to weather prediction, transportation to hunting grounds, and wildlife patterns, leading to increased risk of injuries and fatalities, more search and rescue missions, and reduced access to country foods[10] (Lemelin et al., 2010; Andrachuk & Smit, 2012; Pearce et al., 2012; Sheedy, 2018). For example, the rate of unintentional injuries was more than three times higher than the Canadian average among Inuit land-users in Nunavut over the period 2006 to 2015, and the number of search and rescue operations has more than doubled over the past decade due to changes in temperature and ice (Clark et al., 2016a; Clark et al., 2016b). The loss of knowledge and land skills also threatens Inuit identity and well-being by decreasing opportunities for land- and sea-based activities and for sharing and teaching knowledge and skills, particularly for youth (ITK, 2016).

Permafrost degradation, heavy storms, and coastal erosion can result in the destruction of places that have cultural significance, with potential mental health impacts (Government of Nunavut, 2010; Government of Nunavut, 2012; Donatuto et al., 2014). Such events can also destabilize housing, pipelines, and local civic water, wastewater, and transportation infrastructure and systems, increasing the risk of injury, water-borne illnesses, and environmental contamination, as well as causing disruptions in supply chains (Government of Nunavut, 2010; Government of Nunavut, 2014; Berner et al., 2016; FRMFNMES, 2016). In the Inuvialuit hamlet of Tuktoyaktuk, for example, coastal erosion is already forcing residents to relocate their homes further inland onto higher ground (Faris, 2019). Such impacts place additional financial strains on Inuit households and communities in the context of high living costs, low household income, low population base, and inadequate local government revenues (ITK, 2016). In response to these changes, local Inuit youth formed a filmmaking collective — Tuk TV — and captured these experiences in the documentary *Happening to Us*, which was

9 Palluq (2007) as quoted in Dowsley et al. (2010, p. 156).

10 Country foods include "those harvested from the land sea, comprising primarily wild game, sea mammals, fish, and berries" and can vary from region to region (McGrath-Hanna, et al., 2003).

screened at the 25th session of the Conference of the Parties (COP 25) to the United Nations Framework Convention on Climate Change (UNFCCC) in Madrid, Spain, in 2019.[11]

Warming temperatures and changes in precipitation patterns have led to the increased frequency and severity of extreme weather events such as flooding, wildfires, and heat events (Berry et al., 2014; Bush & Lemmen, 2019). Some First Nations, Inuit, and Métis communities are more vulnerable to these events because of their geographic location, as well as existing socio-economic conditions and infrastructure (CIER, 2008; Christianson et al., 2012; Collier, 2015; McNeill et al., 2017). Over the period 2006 to 2016, approximately 67 First Nations communities experienced a combined total of nearly 100 flooding events, causing significant property and infrastructure damage, disruptions to community services, and impacts to health and well-being (McNeill et al., 2017).

Climate change has contributed to an increased number of extreme heat events and droughts, and to proliferation of pests such as the mountain pine beetle, which, in turn, is increasing the prevalence, magnitude, and intensity of wildfires and the devastation of forests (see Chapter 5: Air Quality). These are taking a tremendous social, psychological, emotional, and financial toll on First Nations and Métis communities across Canada (Scharbach & Waldram, 2016; Howard et al., 2017; Dodd et al., 2018a; Dodd et al., 2018b; ISC, 2018). Many Indigenous communities are located in regions that are expected to see increased wildfire activity over the next 40 years, including parts of British Columbia's coast and Haida Gwaii, Northeastern Alberta, central Saskatchewan, Southern Manitoba and Ontario, and the Northwest Territories (B.J. Stocks Wildfire Investigations Ltd., 2013).

The increased prevalence and severity of extreme weather and climate-related events can have both direct and indirect impacts on human health (see Chapter 3: Natural Hazards). Extreme weather events can lead directly to increased injuries and fatalities (Kipp et al., 2019b). Droughts can affect respiratory health, mental health, exposure to environmental toxins, food security, water security, and rates of injury and infectious diseases, as well as causing increased stress on water treatment systems (Yusa et al., 2015). Flooding can result in water and food contamination from the release of environmental contaminants, bacteria, and other pathogens (Patrick, 2011; Huseman & Short, 2012; Daley et al., 2015). This can lead to increased water- and food-borne infections, skin conditions, and birth defects, as well as obesity, diabetes, hypertension, mental stress, heart disease, liver disease, kidney problems, neurological problems, immunopathology, cancers, thyroid conditions, and infant mortality (Bradford et al., 2016). Flooding and wildfires can damage fish and wildlife habitat important for species reproduction, with subsequent impacts on food security (Kipp et al., 2019b). Wildfires can degrade air quality, contributing to high rates of respiratory and cardiovascular diseases (Liu et al., 2015; Reid et al., 2016), as well as leading to psychological impacts such as stress, anxiety, and depression (Cunsolo Willox et al., 2015; Dodd et al., 2018a; Dodd et al., 2018b; Manning & Clayton, 2018). Extreme heat can result in heat-related illnesses and mortality, especially in Southern Canada and urban centres (Council of Canadian Academies, 2019). While research on Indigenous populations and extreme heat is limited, a comparative study of climate-related morbidities among urban and rural Indigenous populations in Ontario found that urban populations may be at greater risk because of inequities associated with access to health services, health status, poverty, housing, and political marginalization (Tam, 2013).

11 The documentary *Happening to Us* is available by request from Tuk TV.

Box 2.2 Hazard mapping in Kashechewan First Nation

In the flood-prone Cree community of Kashechewan, located in Northern Ontario, Indigenous knowledge about changing seasons, snowmelt, and runoff were used in conjunction with data from geographic information systems to gain a more comprehensive understanding of flooding and its effects on the community (Khalafzai et al., 2019). The federal government has made multiple, unsuccessful attempts to mitigate flooding since the 1990s; heavy ice jams continued to cause erosion and damage to the community's water treatment plant, leading to an *Escherichia coli* (*E. coli*) outbreak in 2005. The community has been evacuated at least 12 times since 2004, at significant financial, emotional, and psychological cost. By 2015, engineers reported that the dyke was "deteriorating and inadequate to protect the growing community" (Khalafzai et al., 2019, p. 4).

In 2016, Kashechewan participated in a study documenting Indigenous knowledge related to spring flooding that used several participatory methods (e.g., in-depth interviews, flood mapping workshops, on-site walks) (Khalafzai et al., 2019). Findings revealed that the warming climate was increasing the frequency and scale of spring ice breakup and ice jams, resulting in earlier and more intense flooding events and greater potential for damage in the community. Participants also identified a number of landscape and human-induced factors that exacerbated the impacts of flooding on the community, including inadequate community infrastructure (e.g., water treatment plant) and flood protection, the region's topography, and resource development activities in the region. These ecological changes have affected local hunting and harvesting practices, sociocultural activities, and the intergenerational transmission of knowledge. Findings from this study may be useful for ongoing flood monitoring and disaster risk-reduction activities in the community.

Climate-related emergencies can also lead to temporary evacuations or long-term displacements from traditional territories, which affect all aspects of Indigenous health and well-being. They disrupt lives; create financial hardship; increase stress, anxiety, and post-traumatic stress disorder; and can bring back historical traumas associated with forced relocations and government interventions in the lives of Indigenous Peoples (Thompson et al., 2014; Scharbach & Waldram, 2016; Bedard & Richards, 2018; Dicken, 2018; Hassler et al., 2019). First Nations people living on reserve, in particular, have been disproportionately affected by displacement due to climate-related events. For example, over the period April 2017 to March 2019, nearly 15,000 First Nations residents were evacuated because of floods, fires, and extreme heat (ISC, 2019, as cited in Parliamentary Information and Research Service, 2020). Going forward, emergency responses to these climate-related events will require adequate funding for emergency planning activities; capacity-building and training; the inclusion of Indigenous Peoples in coordination activities; the use of Indigenous knowledges and expertise; direct and immediate emergency response; evacuation processes that are sensitive to Indigenous Peoples; as well as ongoing efforts for Indigenous communities to recover from such events (Standing Committee on Indigenous and Northern Affairs, 2018).

Box 2.3 Peavine Métis Settlement FireSmart Program

Many Indigenous communities are located in fire-prone forests where climate change is elevating wildfire risk (Christianson et al., 2014). FireSmart Canada works with federal, provincial, and territorial governments and organizations to increase community resilience to wildfires across Canada by implementing principles and best practices for wildfire prevention, mitigation, and preparedness (Christianson et al., 2012; ISC, 2019b; FireSmart Canada, 2020). Using both Indigenous knowledges and scientific information, community members learn and share information about forest, vegetation, and ecosystem management; traditional burning practices; fireguard and fuel break strategies and activities; protection of homes and community infrastructure; and first response, among other issues (Government of the Northwest Territories, 2010; Christianson et al., 2012; Environment and Natural Resources, 2015; Environment and Natural Resources, 2016; Dodd et al., 2018a; Dodd et al., 2018b).

The Peavine Métis Settlement's FireSmart Program involves conducting mitigation activities at residential and community levels. In addition to select, unique community projects, which occur twice annually, the program includes six ongoing activities (Christianson et al., 2012):

- A lawn tractor program encourages residential lawn cutting.
- Agriculture 50/50 supports the conversion of forest to agricultural land vegetation thinning.
- The New Homes Program supports clearing and thinning vegetation from future building sites.
- Fire breaks, or gaps, in vegetation are being installed to help slow or stop wildfire spread.
- The Aboriginal Junior Forest Rangers crew assist with summer FireSmart projects such as vegetation management.
- A volunteer fire department manages fires.

Cultural norms and values influence a community's perception and response to fire risk and mitigation (Christianson et al., 2014). For the Peavine Métis Settlement, these included the importance of assistance to community Elders, participation in subsistence activities on the land, traditional knowledge (TK), social relationships and support for community members, trust, pride in aesthetics, intergenerational knowledge transfer, and self-sufficiency. Each of these values is incorporated into some element of the community's FireSmart Program (Christianson et al., 2012; Christianson et al., 2014).

2.4.2 Mental Health and Well-Being

Climate change threatens the cultural dimensions of Indigenous Peoples' lives and livelihoods that are central to identity, community cohesion, and a sense of place and belonging (Adger et al., 2013). The impact of climate change on mental health and well-being can disproportionately burden some groups, including Indigenous women, children, and individuals from socio-economically disadvantaged communities (see Chapter 4: Mental Health and Well-Being), as well as Elders, who can be deeply disturbed by the changes they are witnessing (FNMFNMES, 2016; Manning & Clayton, 2018). Since First Nations, Inuit, and Métis peoples have disproportionately higher rates of suicide, substance abuse, and violence as a result of intergenerational trauma and socio-economic marginalization (Aguiar & Halseth, 2015; Kumar & Tjepkema, 2019), these climate change impacts can compound existing mental health issues.

First Nations, Inuit, and Métis peoples have a deep economic, social, and spiritual connection to their lands as a source of food, clothing, teaching, recreation, and connection to past, current, and future generations (Mecredi, 2010; Tobias & Richmond, 2014;) and see it as "intertwined and interconnected" to other determinants of health (Harper et al., 2015c, p. 6). Engaging in land- and culture-based activities can provide mental, emotional, social, cultural, and spiritual benefits that support individual and community resilience in the face of climate change. These activities can, for example, help to replenish the spirit, reduce stress, increase physical activity and nutrition, facilitate access to traditional medicines, build self-confidence, foster positive relationships, enhance cultural identities, and increase opportunities for intergenerational knowledge transmission (Cunsolo Willox et al., 2012; Nisga'a First Nation, 2012; Arias-Bustamante, 2013; Cunsolo Willox et al., 2013a; Ulturgasheva et al., 2014; Durkalec et al., 2015; Harper et al., 2015c).

Climate change can disrupt Indigenous Peoples' ability to hunt, fish, trap, forage, and spend time on the land, which can negatively affect their mental and emotional health and well-being. It can introduce new hazards, leading to increased stress and anxiety about the safety of family members travelling on the land (Harper et al., 2015c). It can disrupt the transmission of intergenerational knowledge and land skills to younger generations, which is critical to the formation of a strong cultural identity and resilience (Chandler & Lalonde, 1998; Kral & Idlout, 2009; Wexler, 2013). Extreme climate events, such as wildfires, and resulting evacuations, along with impacts from slow-onset climate change effects can cause stress or worries about the future (Cunsolo Willox, 2012a; Cunsolo Willox, 2012b; Cunsolo Willox et al., 2012; Scharback & Waldram, 2016; Asfaw, 2018; Dodd et al., 2018a; Dodd et al., 2018b; Manning & Clayton, 2018).

Indigenous Peoples may also experience "ecological grief" from past and future climate change-related losses of land, ecosystems and species, environmental knowledge, and cultural identity (Cunsolo & Rigolet Inuit Community Government, 2014; Cunsolo & Ellis, 2018; Meloche, 2018). As the climate warms, anxiety, stress, and "ecological grief" are expected to become increasingly more common (Cunsolo Willox et al., 2013b, Bourque & Cunsolo Willox, 2014; Cunsolo Willox et al., 2015; Harper et al., 2015c; Cunsolo & Ellis, 2018; Cunsolo et al., 2020) (see Chapter 4: Mental Health and Well-Being). Responding to increasing mental health issues will be difficult and challenging, especially given that many First Nations, Inuit, and Métis communities lack adequate mental health services (Mental Health Commission of Canada, 2016; Standing Committee on Indigenous and Northern Affairs, 2017; Carrière et al., 2018). Jurisdictional fragmentation of health care between federal and provincial governments and a lack of dedicated long-term funding for mental health services continue to be significant barriers to achieving health and well-being in First Nations, Inuit, and Métis communities (Boksa et al., 2015).

Box 2.4 Improving mental health and resilience among Selkirk First Nations youth in the face of climate change

Participation in land- and culture-based activities is considered by many First Nations, Inuit, and Métis communities as a pathway to mental health and well-being, particularly for youth (Cunsolo Willox et al., 2012; Auger, 2019; Selkirk First Nation, & Arctic Institute of Community-Based Research, 2019). In the Yukon, the Selkirk First Nation relies on salmon as the mainstay of their diet, and harvesting salmon in fish camps is critical to their mental, physical, emotional, and spiritual well-being as a people (Richards et al., 2019). The community noticed a dramatic decline in the salmon population, which not only threatens their food security, but also the essence of their cultural identity — the age-old tradition of the fish camps. In 2015–2016, Selkirk First Nation received funding through the federal government's Climate Change and Health Adaptation Program to conduct a community-based research and adaptation project related to maintaining food security and TK and culture around the fish camps to ensure the well-being of its community members.

The Selkirk First Nations project had the following short- and long-term objectives:

- engage community members to collectively address issues of climate change;
- build youth capacity in understanding climate change and conducting research;
- build relationships and cohesion in the community;
- present youth perspectives on mental well-being through photography;
- compile community strategies to adapt to climate change impacts to the fish camp and develop a community adaptation plan for climate change and the role of fish camps in youth mental health;
- understand climate change and health from a regional and Northern perspective;
- raise the voices of the Selkirk First Nation on issues of health and climate change while protecting traditional lifestyles; and
- support youth leadership in this area.

The research project was directed by an advisory committee of Elders and community members, while youth carried out surveys of the fish camps so they could learn first-hand the value and role of these camps and the impacts that climate change was having on their lands, community, and culture. The youth learned from the Elders the importance of connecting with TK and cultural traditions for promoting mental health and fostering resilience in the future. They learned valuable skills from on-the-land activities at a winter fish camp for youth, as well as skills involved in conducting community-based research. The "Keeping our traditions for the health and wellbeing of future Selkirk First Nation generations: 'What do we do at the fish camp when there is no fish?'" project resulted in an adaptation strategy that identified a number of actions focused on supporting youth mental health and resilience, including teaching youth about traditional values, lifestyles, and laws; reconnecting them to the land; and supporting cultural activities such as art and dancing (Selkirk First Nation in collaboration with the Arctic Institute of Community-Based Research, 2016).

Exploration of the mental health impacts of climate change for First Nations, Inuit, and Métis peoples is an emerging area of study and has focused primarily on the strong emotional and psychological responses experienced in the face of rapid ecological changes. For Inuit, these responses include intense feelings of anxiety, fear, stress, anger, sadness, disorientation, grief, loss and lament, increased drug and alcohol use, suicide ideation and attempts, violence, and decreased place-based mental solace (Cunsolo Willox, 2012a; Cunsolo Willox, 2012b; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Petrasek MacDonald et al., 2013a; Petrasek MacDonald et al., 2013b; Ulturgasheva et al., 2014; Cunsolo Willox et al., 2015; Harper et al., 2015c; Bunce et al., 2016). As noted by Durkalec and colleagues (2015), climate change is reinforcing environmental dispossession for Inuit, compounding disruption and denigration of Inuit knowledge and ways of life. Research on the mental health impacts of climate change on First Nations and Métis peoples is more limited. One study focused on the impacts of a summer of wildfires on the health and well-being of four First Nations communities in the Northwest Territories. Participants in this study reported experiences of evacuation and isolation, as well as feelings of fear, stress, and uncertainty about the future (Dodd et al., 2018a; Dodd et al., 2018b).

Indigenous Services Canada provides funding for several targeted national strategies, including the National Aboriginal Youth Suicide Prevention Strategy, the National Native Alcohol and Drug Abuse Program, mental health counselling, and the Indian Residential Schools Mental Health Support Program (ISC, 2019c). Most of these programs are accessible to only a relatively small proportion of First Nations and Inuit[12] and do not provide the range and quality of services required to address the complex mental health problems that exist in First Nations, Inuit, and Métis communities (Maar et al., 2009; Boksa et al., 2015). Greater cooperation is needed among federal, provincial, and territorial governments to ensure that these communities have sustainable, dedicated funding to meet the potentially growing need for mental health services in response to climate change impacts.

2.4.3 Air Quality

Weather and climate can affect indoor and outdoor air quality and have impacts on human health (Kinney, 2008) (see Chapter 5: Air Quality). Warming temperatures can increase levels of air pollutants (e.g., ground-level ozone, particulate matter) and the production of aeroallergens (e.g., pollens, molds) that are associated with a greater risk of cardiovascular and respiratory diseases, as well as premature death (Berry et al., 2014; Reid et al., 2016). First Nations, Inuit, and Métis peoples experience a disproportionate burden of chronic respiratory diseases, such as asthma[13] and chronic obstructive pulmonary disease,[14] compared to non-Indigenous people, and these diseases can become exacerbated by poor air quality (Gershon et al., 2014;

12 Under current jurisdictional arrangements, federal funding for most mental health programs and services is provided for community-based services accessible to status First Nations living on reserve and Inuit living in Inuit communities. In smaller, remote communities, access to mental health services may be very limited or non-existent (Boksa et al., 2015). Additionally, non-status First Nations and Métis peoples are not currently entitled to these same services and benefits.

13 First Nations people living off reserve and Métis have rates of asthma 1.6 times higher than Canadian-born non-Indigenous peoples (PHAC, 2018a).

14 Indigenous populations have a prevalence rate of 6.5% for chronic obstructive pulmonary disease, compared to 4% for non-Indigenous populations in Canada (Bird et al., 2017).

Ospina et al., 2015; Carrière et al., 2017; PHAC, 2018a; Koleade et al., 2018). Higher rates of respiratory infections, such as bronchitis, bronchiolitis, pneumonia, and tuberculosis, are also reported for First Nations, Inuit, and Métis children (Kovesi, 2012; Konrad et al., 2013). The risks of exposure to poor air quality are greater for First Nations, Inuit, and Métis peoples because of underlying health determinants such as poor housing conditions (e.g., homes in need of repair, overcrowding, poor ventilation, mold) in many communities, increased exposure to tobacco smoke and wood/oil heating, and geographic proximity to forests that are prone to wildfires and consequent smoke (CIER, 2008; B.J. Stocks Wildfire Investigations Ltd., 2013; Dodd et al., 2018a; Dodd et al., 2018b).

Box 2.5 Yellowknife's Summer of Smoke, 2014

"All that smoke we breathed in, where are you to go? It's not only me. It's the babies and the Elders. And then the vegetation and the runoff from the smoke and the rain all affects the ecosystem right to the water." [15]

During the summer of 2014, the Yellowknife area experienced an extreme wildfire season referred to as the "Summer of Smoke." These fires resulted in a massive spike in air pollution to dangerous levels, confining many residents indoors for extended periods of time (Howard et al., 2017; Dodd et al., 2018a; Dodd et al., 2018b). The poor air quality associated with this wildfire season negatively affected First Nations communities, particularly children and the elderly. For example, the fire season corresponded to significant increases in emergency room visits for respiratory problems (42% over previous years), especially among children up to 4 years old (114% over previous years), as well as more cases of cough, pneumonia, and asthma (Dodd et al., 2018a). Confinement indoors during fires, disruptions in land-based activities, and physical inactivity also contributed to mental health impacts such as stress, anxiety, and depression.

To counteract cabin fever and physical inactivity, the First Nations communities of Kakisa and N'Dilo planned alternative physical and social activities to get away from persistent smoke, including hosting activities at the community hall that promoted physical activity among children and provided opportunities for community members to socialize. In Yellowknife, user fees were waived for recreational centres to encourage indoor physical activities. A documentary of the communities' experiences, entitled Summer of Smoke, can be found at <https://vimeo.com/373958783>

15 Quote from Roxane Landry, Dene, Fort Providence from Summer of Smoke <https://vimeo.com/373958783>.

2.4.4 Food Safety and Security

Food insecurity is an urgent public health issue in Canada (Tarasuk et al., 2014) (see Chapter 8: Food Safety and Security), particularly for Indigenous Peoples in geographically remote regions with high rates of poverty (Loring & Gerlach, 2015; Bhawra et al., 2017; Human Rights Watch, 2020). Many Northern, remote communities rely on traditional or country foods to meet their nutritional needs (Earle, 2011). For example, Statistics Canada data indicate that 65% of Inuit, 35% of Métis, and 33% of First Nations living off reserve hunted, fished, or trapped in 2017, while 30% of off-reserve First Nations and 47% of Inuit gathered wild plants or berries[16] (Kumar et al., 2019). Traditional or country foods are high in nutritional value and offer a number of physical and mental health benefits (Bunce, 2015; Bunce et al., 2016; Cyre & Slater, 2019). Harvesting traditional or country foods promotes physical activity, contributes to social cohesion through food sharing, facilitates spiritual renewal and cultural expression, and plays a role in the development of personal and community self-sufficiency and food sovereignty (Receveur & Kuhnlein, 1998; Earle, 2011; Cidro et al., 2015; Hirsch et al., 2016).

Climate change is affecting the size, distribution, health, and behaviours of wildlife, fish, fowl, and other traditional sources of foods which, in turn, affect the ability to harvest and share them with family, Elders, and other community members (Organ et al., 2014; Statham et al., 2015; Archer, 2016; Spring et al., 2018). These impacts can be both positive and negative for enhancing food security. Warming temperatures have introduced new wildlife and plant species, allowed certain species to flourish, and lengthened growing seasons, making it easier for Northern communities to grow their own foods (Sheedy, 2018). However, a warming climate has altered the timing of harvesting periods and changed ecosystems and habitats in ways that negatively affect species reproduction, leading to declines or disappearances of specific species that constitute traditional livelihoods.

Considerable research has already been undertaken on various climate-related aspects of food security for Indigenous populations, especially studies assessing the availability of traditionally important food sources. For example, many First Nations have been worried about declining numbers of some fish, shellfish, and goose species; the availability and quality of specific berries; and changes to caribou population size, health, distribution, and migration patterns (Mecredi, 2010; Hermann et al., 2012; Teslin Tlingit Council, 2012; Arias-Bustamante, 2013; Donatuto et al., 2014; Kluane First Nations & AICBR, 2016; Parlee & Caine, 2018; Spring et al., 2018; Human Rights Watch, 2020). Inuit have also been alarmed by the changing population size, health, distribution, and/or migration patterns of caribou and other Arctic species, including muskox, seals, whales, and polar bears (Pauktuutit, 2011; Henry et al., 2012; Cuerrier et al., 2015; MacDonell, 2015; Quinn, 2016a; Quinn, 2016b; Mallory & Boyce, 2017; Parlee & Caine, 2018; Waugh et al., 2018). While little research has been conducted specifically on the climate-related food security impacts on Métis people, some have expressed concerns about a shortened goose hunt; changes in the movement and location of fish and their habitat; changes to the health, behaviour, and distribution of caribou and moose; changes in the availability and quality of specific berries; and the impacts of warmer weather on food preservation methods (Guyot et al., 2006; North Slave Métis Alliance community members, Shiga, Evans, King, & Keats, 2018).

16 The authors provide no data on the proportion of Métis who gathered wild plants or berries beyond stating that this proportion remained relatively unchanged from the previous Aboriginal Peoples' Survey.

First Nations, Inuit, and Métis populations share a common concern about the unpredictability of weather and environmental conditions related to climate change and their ability to travel on the land access traditional foods. These impacts can place pressure on already stressed food systems, leading to increased food insecurity in Indigenous communities and a greater reliance on retail foods (Statham et al., 2015; Sheedy, 2018). The move away from traditional or country foods to market foods, often of inferior quality, can exacerbate already high rates of chronic diseases prevalent among Indigenous Peoples, including obesity, diabetes, and cardiovascular diseases (Kolahdooz et al., 2015; Reading, 2015).

Box 2.6 Enhancing food safety and security for urban Indigenous populations in the face of climate change

While Indigenous Peoples in Canada have become increasingly urbanized, there is also a high degree of geographic mobility between rural areas and cities (Norris & Clatworthy, 2011; Snyder & Wilson, 2015). This population trend can result in a loss of Indigenous knowledge and skills that are critical for enhancing nutrition, well-being, and self-reliance in the face of climate change impacts. Indigenous food and food systems are intrinsic to the health and well-being of First Nations, Inuit, and Métis peoples, regardless of whether they live in rural or urban spaces (Ray et al., 2019). Providing urban Indigenous populations with opportunities to learn about traditional practices and connect with TK around food is a way of strengthening Indigenous food sovereignty.

Some urban First Nations health access centres offer programs that foster relationships with the land coordinate traditional practices in urban spaces to provide opportunities for the transmission of Indigenous knowledge and skills. For example, the Shkagmik-Kwe Health Centre, located in Sudbury, Ontario, prepares traditional medicines in-house and holds annual medicine camps to enhance cultural teachings and practices around medicine picking and preparation (Ray et al., 2019). They also support traditional subsistence by organizing community and family hunts, providing basic hunting equipment and financial support for licensing fees to community members (Ray et al., 2019), collecting locally hunted and harvested food that is offered to struggling families through its Wild Food Bank (McLeod-Shabogesic, 2013), and teaching traditional food preparation and cooking methods to its members (Shkagamik-Kwe Health Centre, 2015).

The challenge that climate change poses for heightening food insecurity is compounded by the negative environmental impacts of resource development on the safety of traditional foods and a food system imposed through colonization that leaves Indigenous Peoples increasingly reliant on imported market-based foods (Penner et al., 2019). The ability of Indigenous Peoples to exercise autonomy over their lands and traditional foods is crucial for redressing the colonial narrative of socio-economic marginalization and health disparities (Coté, 2016). This autonomy is embodied in the concept of “food sovereignty,” a human-rights–based model founded on the notion that Indigenous Peoples have a right to “healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and [the] right to define their own food and agricultural systems” (Sélingué, 2007, as cited in Coté, 2016, p. 8). Indigenous food sovereignty recognizes mino-pimatwisin, the Anishinaabe term for "good life," and maligit, the Inuktitut term for "balance" in Qaujimajatuqangit (Inuit TK) (Penner et al., 2019). Innovative examples of Indigenous food sovereignty have been initiated across Canada, including school and community gardens, greenhouses, traditional foods education programs (e.g., conservation), market garden and food cooperatives, country food harvesting and sharing programs, wild food banks, and fish-buying clubs (Thompson et al., 2011; Thompson et al., 2012; Kamal et al., 2015; Martens, 2015; Robin, 2019).

2.4.5 Water Quality, Safety, and Security

"Water is what sustains us. Water is what brings us into this world, and water is what keeps us in this physical world. And so it's our life." [17]

Climate change impacts, such as increased precipitation, flooding, and drought, can significantly affect the quality, quantity, and accessibility of water (Berry et al., 2014) (see Chapter 7: Water Quality, Quantity, and Security), exacerbating health risks related to water quality, safety, and security challenges already present in many First Nations and Inuit communities in Canada. Inadequate water and wastewater systems, a lack of trained staff, and increased exposure to pollutants or environmental contaminants have led to dozens of short- and long-term boil water advisories (White et al., 2012; Medeiros et al., 2016; Wright et al., 2018a; Wright et al., 2018b; ISC, 2020a; ISC, 2020b; ITK, 2020) While some progress has been made in improving the quality of drinking water in many Indigenous communities across Canada, a recent federal government report noted that Indigenous Services Canada was not on track to meet its 2015 commitment to eliminate all long-term drinking water advisories on reserves by March 31, 2021 (Office of the Auditor General of Canada, 2021). For example, there were 51 long-term (as of June 16, 2021) and 26 short-term (as of July 15, 2021) drinking water advisories in place for First Nations public water systems[18] (ISC, 2021a; ISC, 2021b). A further six boil water advisories and seven "do not consume" advisories were in place in First Nations communities across British Columbia as of June 31, 2021 (First Nations Health Authority, 2021). Many Inuit communities have a single established water source, which leads to challenges around water infrastructure, water shortages, municipal water treatment, environmental contamination of water sources, and boil water advisories. The Inuit Tapiriit Kanatami (2020) notes that 298 boil water advisories were issued in 29 Inuit communities between January 2015 and October 1, 2020. The result is that these communities face water emergencies under certain climatic conditions or must rely on trucked water and drinking water stored in containers, thus increasing the risk of contamination (Medeiros et al., 2016; Wright et al., 2018a). As recently as October 12, 2021, the Government of Nunavut flew in 80,000 litres of bottled water to Iqaluit after a state of emergency was declared following the detection of fuel in the community's drinking water (CBC News, 2021).

High-visibility events like boil water advisories can increase distrust in water quality and lead to avoidance of the use of household drinking water supplies (Ekos Research Associates, 2011; Allaire et al., 2019). Small water systems face drinking water advisories as often or more frequently than large municipal water systems and often lack the proper resources to adequately address the advisory (Lane and Gagnon, 2020).

17 Jan Longboat, as quoted in Anderson (2010, p. 7).

18 These statistics exclude British Columbia and the Saskatoon Tribal Council.

Examinations of boil water advisories in Canada have identified that advisories are most often issued for operational or process-related concerns (Environment and Climate Change Canada, 2018; Lane and Gagnon, 2020). Climate-related events, such as intense rainfall, severe storms, dry spells, extremely hot days, and storm surges, can damage water supply infrastructure, diminish the availability of water resources, and reduce the quality of water used for consumption (Kohlitz et al., 2020). Increased pressures on drinking water infrastructure at small drinking water systems are forecasted as climate change accelerates (Kohlitz et al., 2020).

Climate change has already had a significant impact on water security in Indigenous communities. Numerous First Nations communities have reported rapid declines in water levels, with significant impacts on the availability of fish resources and the migration and movement of other animal resources that are important for food security (Mecredi, 2010; Nisga'a First Nation, 2012; Teslin Tlingit Council, 2012; Harper et al., 2015a; FRMFNMES, 2016; Sheedy, 2018). In the Arctic, climate change has increased evaporation of the freshwater supply, the contribution of groundwater to river flows, and permafrost degradation. These impacts will place increasing pressure on the availability of drinking water, diminish water quality as a result of the release of stored environmental contaminants, and place cumulative and increasing pressure on freshwater resources (Nilsson et al., 2013; Goldhar et al., 2014; Bakaic & Medeiros, 2016; Medeiros et al., 2016).

The lack of access to clean, safe water can make it difficult to maintain personal hygiene and contribute to the increased spread of water-borne infectious diseases such as gastrointestinal illness (Harper et al., 2015a; Harper et al., 2015b; Bradford et al., 2016; Chen, 2016), as well as infectious illnesses such as influenza, coronavirus (COVID-19), and methicillin-resistant *Staphylococcus aureus* (Boyd, 2011; Sarkar et al., 2015; Bharadwaj & Bradford, 2018; Stoler et al., 2020). In a scoping review of drinking water quality in Indigenous communities and health outcomes in Canada, Bradford et al., (2016) found gastrointestinal infections were the most commonly reported health concern in the studies reviewed. Other health concerns reported in relation to contaminated drinking water included skin conditions, such as eczema and skin cancer, increased infant mortality and birth defects, as well as elevated levels of obesity, diabetes, and cardiovascular diseases resulting from a reliance on carbonated and sugary drinks in the absence of clean drinking water (Bradford et al., 2016).

The potential mental and spiritual health impacts of climate change on water security cannot be overstated. Several studies across Canada indicate that water insecurity is linked to mental health issues and psychosocial distress in Indigenous individuals (Anderson, 2010; Hanrahan et al., 2014; Sarkar et al., 2015; Cruddas, 2017). Considered life-giving and sacred by First Nations, Inuit, and Métis peoples, water is often used for ceremonial and cultural purposes (Anderson, 2010; McGregor, 2012; AFN, 2013; Omosule, 2017). It is also needed to pursue cultural practices and livelihoods (Bharadwaj & Bradford, 2018). Gathering water from the land is an important part of subsistence culture and Inuit identity, as well as a potential source of healing (Watson, 2017; Wright et al., 2018b). Negative impacts on water security can thus affect mental and spiritual well-being (Powys Whyte, 2014; Lam et al., 2017). Given the physical, emotional, and spiritual importance of water, greater Indigenous sovereignty is needed to protect First Nations, Inuit, and Métis communities from environmental harms to the quantity, quality, and accessibility of water resources arising from climate change and natural resource development projects in their territories.

Box 2.7 Water quality, safety, and security adaptations in the Yukon and Inuvialuit Settlement Region

Yukon

The Yukon River Inter-Tribal Watershed Council conducted three phases of work to address water-quality concerns from the release of environmental contaminants as a result of climate change impacts (Wilson et al., 2015; Yukon River Inter-Tribal Watershed Council, 2017). In Phase 1, Indigenous knowledge was used in conjunction with scientific data collection processes to identify 95 sites of concern. Activities included focus groups, a mapping exercise, and key informant interviews. Phase 2 also brought together TK and Western science to develop climate adaptation strategies. This work also included training youth and community members in field methods for contaminant monitoring and water sampling, along with data collection and manipulation technologies (e.g., databases, geographic information systems). In total, water samples were collected at 25 sites. Phase 3 brought First Nations leaders from across the Yukon to a workshop in which results from Phase 1 and 2 were presented, and actions to address concerns related to water and climate change were discussed. A regional, Indigenous-centred climate adaptation plan for water health and governance was then developed.

Inuvialuit Settlement Region

The *Monitoring and Surveillance of Water Borne Diseases in the Inuvialuit Settlement Region: Adapting to a Changing Climate in the North* project took place from 2009 to 2010. The project included the development of a water sampling program in the Inuvialuit Settlement Region to determine the level of microbes and contaminants in the water, including heavy metals, parasites, and bacteria. Youth were brought into the project to learn about taking care of water and water testing in the communities of Atlavik, Tuktoyaktuk, and Ulukhaktok (Institute for Circumpolar Health Research, 2017).

2.4.6 Infectious Diseases

Changes in weather patterns, such as warmer temperatures, increased precipitation, and more frequent drought and wildfires, are expected to affect the incidence and distribution of water-borne, food-borne, vector-borne, and zoonotic diseases (Greer et al., 2008; Berry et al., 2014; Chen, 2016) (see Chapter 6: Infectious Diseases). Indigenous Peoples globally and across Canada have significantly higher rates of infectious diseases than non-Indigenous populations (Gracey & King, 2009; Hotez, 2010), placing them at greater risk for climate-related infectious diseases. Determinants of health, such as poverty, malnutrition, decreased access to health care, and poor socio-economic conditions, influence an individual's resistance to infection, the progression of disease, and the treatment and management of disease (CPHO, 2013).

First Nations, Inuit, and Métis peoples are at an increased risk of exposure to climate-related infectious diseases because of a strong reliance on traditional or country foods. Recent studies, for example, indicate an increased prevalence of parasites in wildlife, causing trichinellosis in walrus and polar bear, brucellosis in caribou, lungworm infection in muskox, giardiasis in beaver, as well as tularemia, rabies, and cryptosporidiosis (Jenkins et al., 2013; Jenkins et al., 2015; Quinn, 2016a; Quinn, 2016b; Yansouni et al., 2016; Tomaselli et al., 2017; Sheedy, 2018). These diseases have the potential to be transmitted from animals to humans, either directly, from the consumption of traditional foods, or indirectly, through exposure to domestic animals carrying these pathogens (Himsworth et al., 2010; Goyette et al., 2014; Bowser & Anderson, 2018).

A high burden of parasitic and food-borne infectious diseases has been detected among some Indigenous populations in Arctic regions. Associations have been found between the consumption of marine mammals and outbreaks of trichinellosis (Yansouni et al., 2016). A disproportionately high burden of acute gastrointestinal illness, which can be related to both water- and food-borne disease, has been reported in several Inuit communities (Harper et al., 2015a; Harper et al., 2015b). More specifically, a high prevalence of giardiasis has been detected in Northern Canada (Yansouni et al., 2016), while rates of cryptosporidiosis appear to be extremely high among Inuit in the Qikiqtani region of Nunavut (Goldfarb et al., 2013) and the Nunavik region of Quebec (Thivierge et al., 2016) compared to the Canadian average. While acute gastrointestinal illness is generally mild and easily self-resolves, it remains a leading contributor to infant mortality among young children in the Arctic (Yansouni et al., 2016). There is also some evidence that increasing exposure to infected marine and terrestrial animals may be contributing to increasing prevalence of toxoplasmosis among Inuit, with rates ranging from 60% to 87% in some communities (Lavoie et al., 2007; Messier et al., 2009; Elmore et al., 2012; Jenkins et al., 2013; Goyette et al., 2014). Toxoplasmosis manifests most severely in immunocompromised people and in women infected for the first time during pregnancy, leading to miscarriage, stillbirth, and fetal deformities (Jenkins et al., 2015). In addition to physical health impacts, the potential increase in environmentally transmitted parasites and pathogens can have a significant impact on the sustainability, availability, and suitability of animal species that have nutritional, material, cultural, and economic importance to Indigenous Peoples (Government of Nunavut, 2010; Dudley et al., 2015; Sheedy, 2018), which can have implications for mental and spiritual health as well.

A rise in the abundance of mosquitoes, ticks, and other biting insects is also evident across Canada, including in Northern regions, with the potential to transmit new vector-borne diseases, such as Lyme disease and West Nile virus (Nickels et al., 2002; Cuerrier et al., 2015; Chen, 2016; Wudel & Shadabi, 2016; Nelder et al., 2018; Awuor et al., 2019; Bouchard et al., 2019). West Nile virus and Lyme disease have already expanded across all provinces and are recognized as potential health risks by some First Nations (First Nations Centre, 2004; PHAC, 2018b). While enhanced surveillance and monitoring for vector-borne diseases in Canada is needed (Awuor et al., 2019), it appears that Arctic communities are not yet at risk of sustained transmission of such diseases (Chen, 2016).

Box 2.8 A potential role for Indigenous knowledges in mitigating the spread of *Toxoplasma gondii* and other climate-related infectious diseases

Toxoplasmosis, caused by the parasite *Toxoplasma gondii* (*T. gondii*), is an important health issue in the Arctic, and is expected to increase in prevalence due to climate change. Warming temperatures are expected to expand the habitat of felid (wild cat) hosts and the migrating range of infected intermediate hosts such as birds and mammals, opening up new transmission routes to humans, including contaminated water (Reiling & Dixon, 2019). The disease can pose serious health risks, especially in immunocompromised individuals and women infected for their first time during pregnancy (BC Centre for Disease Control, n.d.; Jenkins et al., 2013).

Northern Indigenous populations are at increased risk of acquiring the disease and experiencing adverse health outcomes because of the harvesting, processing, and consumption of country foods, sometimes raw (Reiling & Dixon, 2019), and because many of these communities have poor water-treatment infrastructure and lack access to safe and clean drinking water (Douglas, 2017). Some adaptations to address this health risk include cooking the meat or freezing it for several days to kill the pathogens present in the tissue cysts (El-Nawawi et al., 2008); improving climate and *T. gondii* information collection and monitoring to enable better prediction and early detection of risk; strengthening drinking water treatment systems, water quality monitoring, and operator training; and implementing community education campaigns related to safe food preparation and storage (Douglas, 2017; Bachand et al., 2019).

Indigenous knowledges can be used with scientific knowledge and methods to determine the health of country foods and inform adaptation measures. For example, in a study by Sudlovenick (2019), hunters from Iqaluit were interviewed about the health of ringed seals (*nattit*) to determine whether they were safe to eat based on the presence of five pathogens (*Brucella canis, B. abortus, Erysipelothrix rhusiopathiae, Leptospira interrogans*, and *T. gondii*) and heavy metals. This information was combined with a serological survey to determine the presence of these pathogens in seals. Some clinical signs of *T. gondii* include lethargy, anorexia, and a rash at the flippers. While participating hunters were unable to identify the presence of specific pathogens such as *T. gondii*, they were able to identify and reject sick seals or parts of seals that should not be consumed because they could be unhealthy. They also expressed concerns about the health of harp seals, many of which appeared to be ill. As one hunter noted, "The one thing that I've seen really increase in illness is the harp seals. Young seals you'll see that they are covered in algae, they're covered in lesions, they're skinny. ... But, really sickly. If I see one, I'll shoot them and leave them. I don't even want to touch them with my hook. Cause it would contaminate."[19]

The serological survey identified *T. gondii* antibodies present in nearly 10% of the seal samples. While small scale, the study highlights the potential value of Indigenous knowledge in mitigating the spread of infectious diseases like *T. gondii* and the importance of intergenerational knowledge transmission about the health of country foods as a climate change adaptation strategy.

19 As quoted in Sudlovenick (2019, p. 50).

2.4.7 Health Systems

First Nations, Inuit, and Métis peoples face unique challenges in accessing health care, including mental health services. Inadequate health human resources, high staff turnover, low population density, geographic remoteness, jurisdictional conflicts over health care provision, lack of health and/or transportation infrastructure, reduced political power, increased travel costs, and a deficit of information on Indigenous Peoples' health to inform evidence-based practices all present significant challenges (Ford et al., 2010b; NCCIH, 2019). In rural and remote Indigenous communities, individuals and families must often leave the community for medical emergencies, hospitalization, or appointments with medical specialists, and to access mental health counselling and addictions rehabilitation services (Rondeau, 2012; Harper et al., 2015c; NCCIH, 2019).

Climate-related events can disrupt or damage communication, hospital, and transportation infrastructure, which can restrict travel for health services outside the community. They can also delay the supply of essential pharmaceuticals and medical supplies, compromise patient safety, leave communities isolated and unable to reach help in an emergency, and make it challenging to implement cultural land-based programs focused on promoting health and well-being (Health Care without Harm, n.d.; Paterson et al., 2014; Harper et al., 2015c; Canadian Coalition for Green Health Care, 2020) (see Chapter 10: Adaptation and Health System Resilience). With climate change expected to have considerable impacts on human health, especially in Northern populations, existing health systems may be strained beyond capacity to address emerging health issues such as pandemics. To withstand respond to climate risks, it will be important to draw on local, Indigenous, and scientific knowledges to develop climate change responses that meet needs in locally specific contexts and build the capacity of the health sector and emergency response systems (Kipp et al., 2019b).

Additionally, to ensure Indigenous health systems and services can effectively respond to extreme weather and climate events, broader-level determinants of health need to be addressed. Specifically, there is a need to (Ford et al., 2010a):

- address the material conditions and behaviours associated with poverty that increase Indigenous Peoples' sensitivity to climate change and capacity to adapt;
- enhance surveillance in remote regions to more quickly identify emerging health risks and vulnerabilities;
- develop comprehensive, culturally specific, health assessment measures to assess climate change impacts;
- address issues related to inequitable access to health information, diagnosis, and treatment in Indigenous communities;
- respect the rights and needs of Indigenous Peoples to address continued and persistent inequalities that exacerbate climate change health vulnerability; and
- resolve the jurisdictional issues that limit the ability to identify and prepare for climate change risks and address inequalities.

Box 2.9 Health system adaptations to reduce risks facing First Nations and Inuit peoples

Arctic Climate Change Vulnerability Index

Aviation and marine transportation systems play invaluable roles in the Arctic, not only in supplying perishable goods, food, and mail, but also in accessing timely medical care (Debortoli et al., 2019). Climate change has the potential to disrupt these transportation systems, with significant impacts on health, well-being, and economic vitality in the region. Researchers have developed an Arctic Climate Change Vulnerability Index to assess the physical and social factors that influence exposure, sensitivity, and adaptive capacity to climate change that is reflective of Inuit values and sensitive to the ways in which communities are represented (Debortoli et al., 2019). The index draws on scientific indicators to assess exposure, sensitivity, and vulnerability, as well as qualitative data from Statistics Canada and ISC's Community Well-Being Index to reflect adaptive capacity and resilience. This includes data on socio-economic and housing conditions, age demographics, and Indigenous knowledges. The latter was determined using data on the ability to speak Inuktitut coupled with data on the proportion of the community that consists of new immigrants, who were seen as having limited land skills or knowledge of the Arctic and no Inuit traditional knowledge. The index allows the effects of various climate change scenarios to be projected on air and marine transportation systems and may be useful for health system decision makers to inform adaptation plans.

2.5 Indigenous Knowledges

Indigenous knowledge, traditional ecological knowledge (TEK), traditional knowledge (TK), and Inuit knowledge or Inuit Qaujimajatuqangit[20] are all dynamic and living concepts that denote the understanding, interdependence, and relationality between Indigenous Peoples and the lands they call home, including all Creation and beings (animate and inanimate) within that land (McGregor, 2014). According to the Inuit Circumpolar Council (n.d., para. 4), Indigenous knowledge can be defined as "a systematic way of thinking applied to phenomenon across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, … [as] passed on from generation to generation." TEK is the "knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings, including humans, with one another and with their environment" (Berkes, 2012, p. 7). The direct translation of Inuit Qaujimajatuqangit is "that which Inuit have always known to be true" and it is governed by four natural laws: "1) working for the common good; 2) respecting all living things; 3) maintaining harmony and balance; and 4) continually planning and preparing

20 Inuit Qaujimajatuqangit is the preferred term for Inuit knowledge in Nunavut.

for the future" (Nunavut Department of Education, 2007; Tagalik, 2010, p. 1). According to concepts around Métis peoples' TEK, "understanding the natural world, building skills and behaviour adaptable and applicable to other facets of Métis life…contribute[s] to personal and community spiritual, physical, intellectual and emotional health and development" (Vizina, 2010, p. 13).

Indigenous knowledges are embedded within Indigenous languages and transmitted to younger generations through community knowledge (Task Force on Aboriginal Languages and Cultures, 2005; Battiste, 2010; Tagalik, 2010; Wilder et al., 2016). This includes observations about the land, plants, insects, forests, waterways, sea, sea ice, soil, weather conditions, and migratory patterns of animals (Tagalik, 2010; McGregor, 2014; Sandoval et al., 2016; Windchief & Ryan, 2018). Cosmological, medicinal, pharmacological, agricultural, and botanical knowledges, for example, are shared through direct observation and participation in them, as well as through storytelling, prayers, dance, art, protocols, teachings, and ceremonies (Neeganagwedgin, 2013; Kulnieks et al., 2016; Reo et al., 2017). Indigenous knowledges inform ethical, social, political, legal, governance and moral practices, and are pivotal for community survival and continuity, as well as resource management and sustainability (Alexander et al., 2011; McGregor, 2012; Windchief & Ryan, 2018).

2.5.1 Indigenous Knowledges and Climate Change

"Indigenous people have drawn on Indigenous knowledge and science for millennia to understand respond to climate and environmental changes they faced…. What is different and challenging today is the rate of manmade climate change and our ability to respond to it. We must correct the path we are walking on and return to the special relationships, the teachings, the knowledge and practice that maintains respect, honor, and relationship with the natural world." [21]

Indigenous knowledges have been critical to the survival and resilience of Indigenous Peoples since time immemorial. Although these knowledges are increasingly recognized as equal to scientific information in understanding and adapting to climate change, the meaningful engagement of Indigenous Peoples and their knowledge systems in climate change research and policy remains a challenge. Indigenous-focused content has, for example, been under-represented in the Intergovernmental Panel on Climate Change (IPCC) assessment reports, as well as in policy discussions surrounding the UNFCCC (Ford, 2012; Ford et al., 2016b; Belfer et al., 2019). This disconnect is rooted, in part, in how Indigenous Peoples and Indigenous knowledge systems have been framed in the Western climate change discourse — as powerless victims with static knowledge that is increasingly undermined or made irrelevant by the rapid pace of climate change (Ford et al., 2016b). Critiques of the IPCC and UNFCCC suggest this contributes to the homogenizing of knowledge, cultures, and ways of knowing, and situates Indigenous Peoples alongside marginalized or vulnerable social groups without contextualizing their unique lived experiences or cultural and colonial realities (Ford et al., 2016b). Increased participation of Indigenous scholars, knowledge holders, and organizations is slowly expanding through procedural changes, such as the establishment of the Local Communities and Indigenous Peoples Platform (LCIPP) at the UNFCCC Conference of the Parties (COP) 21 in 2015 and the Facilitative

21 Suzanne Benally, as quoted in Frank (2017, para. 4).

Working Group at UNFCCC COP 24 in 2018. The LCIPP is the first "formal, permanent, and distinct space" created for Indigenous Peoples and is focused on knowledge, capacity for engagement, and climate change policies and actions (Belfer et al., 2019, p. 27). Although recognized as an important first step, the LCIPP has the potential to "silo" Indigenous Peoples' concerns exclusively to the platform (Reed, 2019) and arguably undermines Indigenous Peoples' status and rights by "grouping and conflating Indigenous Peoples with local communities" (Inuit Circumpolar Council, 2020, p. 2).

The use of Indigenous knowledges in climate change and health research is evolving. Indigenous knowledges were initially used in conjunction with scientific knowledge to document observations of climate and environmental changes (Riedlinger & Berkes, 2001). More recently, they have been used as part of community-based studies that engage and are led by Indigenous Peoples in identifying their exposure and vulnerability to climate change effects, real and perceived impacts to their health and well-being, and potential adaptation strategies (Cameron, 2012; Donatuto et al., 2014; Cunsolo Willox et al., 2015; Rosol et al., 2016; Ford et al., 2018; Sawatzky et al., 2018; Kipp et al., 2019a; Sawatzky et al., 2020). Indigenous and scientific knowledge systems can accentuate and strengthen one another, since they identify different types of impacts brought about by climate change (Royer et al., 2013; Baldwin et al., 2018; Makondo & Thomas, 2018). Indigenous knowledges can enrich understanding of environmental change because they focus on the dynamics of the whole system under multiple stressors rather than on a single phenomenon (Mantyka-Pringle et al., 2017).

Indigenous knowledges can inform climate change and health-related decision-making at a variety of levels to benefit diverse stakeholders, including researchers, decision makers and community members (Finn et al., 2017; Mantyka-Pringle et al., 2017). They have been used to establish multiple ecosystem indicators and baselines, which are useful for identifying priority areas for environmental monitoring, protection, and potential remediation (Uprety et al., 2012; Sanderson et al., 2015; York et al., 2016; Baldwin et al., 2018; Gérin-Lajoie et al., 2018). Indigenous knowledges have been used to develop predictive models for identifying climate change vulnerabilities and adaptation options, such as potential impacts on traditional livelihoods and subsequent health implications (Turner & Spalding, 2013; Research Northwest & Herschfield, 2017; Flynn et al., 2018). Indigenous knowledges can and have been used with scientific knowledge to improve risk assessments, enabling individuals to make informed decisions about weather-related risks and hazards associated with traditional harvesting and land-use activities (Riedlinger & Berkes, 2001; Pennesi et al., 2012; Deemer et al., 2018), and aiding the planning and location of future infrastructure (Turner & Spalding, 2013; Flynn et al., 2019). The foundational values and traditional teachings related to Indigenous knowledges around reciprocity, inter-relationships, and spirituality can teach environmental stewardship and enhance governance of biodiversity and ecosystems for human health and well-being (Tengö et al., 2014; Hansen & Antsanen, 2018). This aspect of Indigenous knowledges is relevant not just for Indigenous communities, but also for non-Indigenous communities, nationally and globally (Maldonado et al., 2016; Hansen & Antsanen, 2018).

In the past, the inclusion of Indigenous knowledge systems in adaptation interventions has been variable (Ford et al., 2017). This stems not only from the fact that climate change considerations are often secondary in decision-making, but also from confusion remaining across all levels of government about what it means to include Indigenous knowledge systems in these interventions and how best to do so (MacDonell, 2015; Ford et al., 2017; Ford et al., 2018). Examples are emerging in which Indigenous knowledge has been incorporated into the design, monitoring, and evaluation of adaptation interventions (Debels et al., 2009; Champalle et al., 2015; Ford et al., 2018). Key tenets of these interventions are the adoption of community-driven, participatory, and collaborative approaches and the integration of science and Indigenous knowledge systems, using knowledge co-production[22] frameworks that seek to address the challenge of inequitable power differentials. Several knowledge co-production case studies suggest this approach helps foster community engagement and buy-in, ensures Indigenous Peoples' needs and interests are meaningfully incorporated, reflects local context in terms of available resources and capacity for implementation, and enables learning to maximize adaptive capacity (Armitage et al., 2011; Reid et al., 2014; Schuttenberg & Guth, 2015; Ford et al., 2016a; Diver, 2017). Latulippe & Klenk (2020) caution knowledge co-production scholars, however, to "move away from seeking to better 'integrate' Indigenous knowledges into western science" and instead make way for Indigenous research leadership and Indigenous knowledge sovereignty.

Indigenous Peoples in Canada and globally have increasingly reframed the discussion around climate change, research, and policy within a rights-based, distinctions-based approach. For well over two decades, Inuit have reported how a rapidly changing climate has affected their practices and knowledge around a way of life that is based on the land, sea, and ice. They have also voiced the direct and indirect impacts to their health and human rights caused by climate change (Prior & Heinämäki, 2017; ITK, 2019b). For example, in 2005, Sheila Watt-Cloutier, then chair of the Inuit Circumpolar Conference, presented an "Inuit Petition" on behalf of Inuit in Canada and the United States to the Inter-American Commission on Human Rights that sought "relief from human rights violations resulting from the impacts of climate change" due to greenhouse gas emissions from the United States (Sabine Center for Climate Change Law, 2005). Although the petition was never resolved, various bodies of the United Nations have acknowledged the threat that climate change poses to "the enjoyment of all human rights, including the rights to health, water, food, housing, self-determination, and life itself" (Office of the High Commissioner for Human Rights, 2018, p. 1). The need for climate justice,[23] and the participation of those disproportionately impacted in finding solutions to climate change, have also been recognized. Climate change is "inherently discriminatory" in that Indigenous Peoples, like other populations, are the most vulnerable to climate change, yet have contributed the least to it (UNHRC, 2016, p. 19). As a consequence, decisions around climate change adaptation interventions, "must accord with the obligations owed to those peoples, including, where applicable, the duties to facilitate their participation in the decision-making process and not to proceed without their free, prior and informed consent" (UNHRC, 2016, p. 20).

22 Knowledge co-production is a research practice that seeks to co-produce, with local decision makers and stakeholders, knowledge that is useful and usable (Latulippe & Klenk, 2020).

23 The Mary Robinson Foundation – Climate Justice (2020) defines climate justice as a human-centred approach to addressing climate change that safeguards the "rights of the most vulnerable people and [shares] the burdens and benefits of climate change and its impacts equitably and fairly" (para. 1).

Box 2.10 Using Indigenous knowledges in climate change adaptation

"Our land is very important to us. We live on it. We breathe it. We work on it. It gives us life. Without it we don't have an identity." [24]

Indigenous knowledges and worldviews provide important teachings about environmental stewardship to reduce the severity of climate change (Hansen & Antsanen, 2018). The Indigenous Guardians Pilot Program "supports Indigenous rights and responsibilities in protecting and conserving ecosystems, developing and maintaining stable economies, and continuing the profound connections between Canadian landscape and Indigenous culture" (ECCC, 2020a, para. 2). The program establishes guardians in Indigenous communities to monitor, manage, and provide stewardship over their lands and waters (Nature United, 2020). Funded by a $25 million federal government investment over a five-year period (2017 to 2021), the program is implemented jointly with First Nations, Inuit, and Métis peoples to ensure that their distinct perspectives, rights, responsibilities, and needs are respected and recognized.

Global in scope, these programs are Indigenous-led and -managed community-based initiatives that focus on intergenerational capacity building, leadership and knowledge sharing, and provide First Nations, Inuit, and Métis peoples with greater opportunities to exercise responsibility in stewardship of their traditional lands, waters, and ice (Government of Canada, 2019). Each program is different, but they all employ staff to undertake some or all of the following activities: educate, conduct outreach, inform, influence, implement, collaborate, connect, analyze, monitor, patrol, observe, collect data, research, protect, report, enforce, and undertake cultural activities (Nature United, 2020). In the first year of the program, 28 communities (24 First Nations, three Inuit, and one Métis) received funding, and 33 communities (22 First Nations, six Inuit, and five Métis) received funding in the second year (ECCC, 2020a).

A recent report identified a range of social, economic, cultural, and environmental values and benefits of Indigenous Guardians programs for First Nations communities along coastal British Columbia. The report noted that, for First Nations people participating in the study, the program contributed to taking care of their territory, nurturing cultural well-being, improving general health and community well-being, advancing governance authority for the respective Nations, increasing community capacity, opening and promoting economic opportunities, and providing financial capital inflows to the community (Epi EcoPlan International Inc., 2016). A return of a least 10 times on each dollar invested was estimated for participating First Nations communities. The Indigenous Guardians Toolkit (Nature United, 2020) provides a forum that allows Indigenous communities to share their experiences, learn from each other and get support for their community projects.

24 Norway Rabliauskas, Councillor, Poplar First Nation, Manitoba, as quoted *Indigenous guardians — caring for the land* (YouTube video) (n.d). <https://www.indigenousguardianstoolkit.ca/node/40/resources>.

2.6 Indigenous Peoples' Rights and National and International Commitments

"It is our right to keep on living the way we used to and also the right to adapt for a better future." [25]

First Nations, Inuit, and Métis peoples have a distinct constitutional relationship with the Crown as rights-holders under Section 35 of the *Constitution Act, 1982*, including the inherent right to self-government over their lands, natural resources, and ways of life (Minister of Justice and Attorney General of Canada, 2018). In line with the Government of Canada's commitment to reconciliation and the Truth and Reconciliation Commission's *Calls to Action* (2015), 10 overarching principles were developed in 2018 to support a renewed "nation-to-nation, government-to-government, and Inuit-Crown relationship based on recognition of rights, respect, co-operation, and partnership as the foundation for transformative change" (Minister of Justice and Attorney General of Canada, 2018, p. 3). The *Principles Respecting the Government of Canada's Relationship with Indigenous Peoples* address national commitments, such as treaties or other agreements and negotiations between the Crown and Indigenous Peoples, and acknowledge that distinctions-based approaches are needed to "ensure that the unique rights, interests and circumstances of the First Nations, the Métis Nation and Inuit are acknowledged, affirmed, and implemented" (Minister of Justice and Attorney General of Canada, 2018, p. 17).

The principles also address international commitments, including the *United Nations Declaration on the Rights of Indigenous Peoples*, which was adopted by Canada without qualifications in 2016. This declaration recognizes the urgent "need to respect and promote the inherent rights of Indigenous Peoples which derive from their political, economic and social structures and from their cultures, spiritual traditions, histories and philosophies, especially their rights to their lands, territories and resources" (United Nations, 2007, p. 3). Additionally, it states that "Indigenous knowledge, cultures and traditional practices contribute to sustainable and equitable development and proper management of the environment," and that Indigenous Peoples have "the right to the conservation and protection of the environment and the productive capacity of their lands or territories and resources" (United Nations, 2007, p. 4, 21). Similarly, the United Nation's Sustainable Development Goals articulate a 15-year agenda to eradicate poverty in all its forms and address the global challenge of sustainable development, including goal 13, to take urgent action to combat climate change and its impacts by strengthening resilience and adaptive capacity. Respecting and promoting these rights supports Canada in meeting its domestic and international commitments and is central to climate change efforts going forward.

25 Sam Hunter, Weenusk First Nation, Ontario, as quoted in Human Rights Watch (2020).

2.6.1 Roles and Responsibilities in Indigenous Peoples' Health and Climate Change

Robust adaptation requires collaboration at all levels of government and across a range of sectors (see Chapter 10: Adaptation and Health System Resilience). At the federal level, the *Pan-Canadian Framework on Clean Growth and Climate Change* (PCF) (ECCC, 2018) and the report *A Healthy Environment and a Healthy Economy: Canada's Strengthened Climate Plan to Create Jobs and Support People, Communities and the Planet* (ECCC, 2020b) articulate Canada's commitment to reduce greenhouse gas emissions to meet 2030 targets, to build capacity to adapt to the impacts of climate change, including risks to human health, and to support clean technology in collaboration with provinces and territories. The PCF reiterates Canada's commitment to a renewed relationship with Indigenous Peoples, including mitigation and adaptation action that is based on the recognition of rights, respect, cooperation, and partnership, and the importance of Indigenous knowledges in understanding climate impacts and adaptation measures (ECCC, 2018). As part of this process, the Assembly of First Nations, Inuit Tapiriit Kanatami, and the Métis National Council are working collaboratively with government through distinctions-based senior bilateral tables to ensure a structured, collaborative approach for ongoing engagement in the implementation of the PCF (ECCC, 2019). The proposed objectives of the distinctions-based senior bilateral tables are to (Trudeau, 2016):

- jointly develop real and meaningful approaches for Indigenous Peoples that position them as leaders of climate action, with clear timelines, objectives, and reporting in support of the PCF and other climate change activities;
- ensure inclusive, meaningful, and adequately resourced Indigenous engagement that emphasizes collaborative planning and participation in decision-making;
- advise on and track progress on the implementation of relevant acts, regulations, policies, and programs, such as advancing clean energy solutions for Indigenous Peoples;
- share information and jointly identify and monitor levers, indicators, and results, contributing to transparent reporting on the implementation of the PCF; and
- provide local and regional views, perspectives, and proposals on the implementation of the PCF to federal, provincial, and territorial intergovernmental structures.

These tables also support broader First Nations, Inuit, and Métis-specific clean growth and climate change priorities and actions, including those related to human health and well-being. In 2019, Inuit Tapiriit Kanatami (ITK) developed a National Inuit Climate Change Strategy that laid out objectives, actions, and long-term outcomes for the following five priority areas:

- knowledge and capacity;
- health and well-being, and the environment;
- food systems;
- infrastructure; and
- energy.

A rights-based approach to the development of any climate policies and actions affecting Inuit Nunangat is central to this strategy, with the understanding that climate change is one of many socio-economic and health inequities that challenge their populations and communities (Huntington et al., 2019).

In addition to the work of the Assembly of First Nations, Inuit Tapiriit Kanatami, and the Métis National Council at the national level, grassroots Indigenous-led organizations, such as Indigenous Climate Action, are also playing an important role in climate change in Canada by pushing for the incorporation of Indigenous rights and knowledges in climate change discussions and solutions. Through a series of community engagement activities and grounded in Indigenous rights and knowledge, the organization is developing resources and programs to assist Indigenous communities to take action on climate change.

Several federal policies, programs, and services are already in place to support Indigenous Peoples' health and climate change mitigation and adaptation. At the federal level, the Department of Crown-Indigenous Relations and Northern Affairs Canada (CIRNAC)[26] is responsible for the Climate Change Preparedness in the North[27] and First Nations Adapt[28] programs that work with Indigenous communities, territorial and regional governments, and other relevant stakeholders to identify climate change vulnerabilities and adaptation priorities (INAC, 2018a; INAC, 2018b). CIRNAC also funds the Indigenous Climate Hub,[29] which includes stories, tools, and resources by Indigenous Peoples across Canada in order to exchange information on how they can monitor and adapt to climate change. Other CIRNAC programs include the Indigenous Community-Based Climate Monitoring Program, which supports the use of Indigenous knowledges and scientific knowledge, collaborative approaches to data management and information sharing systems, as well as the Northern Responsible Energy Approach for Community Heat and Electricity to reduce diesel fuel use for electricity and heating in Northern communities. CIRNAC also has several initiatives that address the determinants of health and can enhance First Nations, Inuit, and Métis peoples' resilience to climate change effects. These include the Nutrition North Program, which subsidizes the cost of healthy foods to address food insecurity in the North; the Harvesters Support Grant Program, to help lower the costs associated with traditional hunting and harvesting activities; and a Working Group on Food Security to focus on sustainable food systems. An Arctic and Northern Policy Framework has also been developed in collaboration with First Nations, Inuit, and Métis communities; national Indigenous organizations; and provincial and territorial governments. The framework aims to reorganize and reprioritize federal activities in the Arctic related to infrastructure, sustainable and diversified economies, environmental protection and conservation, the strengthening of peoples and communities, Arctic science and Indigenous knowledge, and Arctic sovereignty and leadership (Government of Canada, 2018).

26 In 2017, the federal department of Indigenous and Northern Affairs was dissolved and two separate departments were created to deal with Indigenous matters — Crown-Indigenous Relations and Northern Affairs Canada and Indigenous Services Canada.

27 For Indigenous communities north of 60 degrees north latitude.

28 For First Nations communities south of 60 degrees north latitude.

29 See <https://indigenousclimatehub.ca/>

Box 2.11 Indigenous Services Canada's Climate Change and Health Adaptation Program

Indigenous Services Canada works collaboratively with partners to improve access to services for First Nations, Inuit, and Métis communities, including access to health services, water and wastewater systems, community infrastructure, housing, education, social programs, and emergency management. Each of these areas plays a critical role in the ability of First Nations, Inuit, and Métis communities to adapt to climate change. In 2008, the Department implemented the Climate Change and Health Adaptation Program (CCHAP), which provides funding to Inuit and First Nations communities north of 60 degrees north latitude to engage in community-based participatory research aimed at identifying climate change–related health issues and developing health-related adaptation plans and communication materials. In 2016, the program was expanded to include First Nations communities south of 60 degrees north latitude. The projects are community-led and employ a multidisciplinary, collaborative approach that incorporates various approaches to science, including Indigenous knowledge and Western science (ISC, 2019d; Richards et al., 2019).

Since the beginning of the program, the CCHAP has funded 227 climate change and health projects, such as numerous film and photo-voice projects that engaged Elders, youth, and community members; community-based ice monitoring, surveillance, and communication networks; adaptation plans; assessments of the impacts of climate change on food security and on the health impacts of wildfire smoke; and information products related to land, water, and ice safety, drinking water, food safety and security, and traditional medicines. Profiles of many of these projects are available at *Climate Telling* (Climate Telling, 2020) and are summarized in *Community Voices on Climate Change and Health Adaptation in Northern Canada* (ISC, 2019d).

Other stakeholders have a role to play in supporting Indigenous Peoples' health in relation to climate change mitigation and adaptation. Provincial governments, for example, work with the federal government to adapt their own targets and take their own actions to reduce greenhouse gas emissions from various economic sectors. They may also take actions to improve health outcomes, develop comprehensive strategies to address climate change, undertake climate change disaster mitigation and infrastructure planning, and develop new technologies and zero emission strategies. All sectors of the economy, including the natural resources sector, have a responsibility to help reduce greenhouse gas emissions, which can be done through the adoption of more environmentally friendly practices. In remote Northern Indigenous communities, mitigating greenhouse gas emissions will have limited impact on slowing the speed of climate change, given the absence of a sizeable industrial base and limited consumption levels; thus, priority must be given to adaptation in these areas (Ford et al., 2010b). In this process, Indigenous stakeholders and communities play important roles in monitoring climate change effects, as they are often the first to observe and experience them. They must also work cooperatively with decision makers to assess vulnerability and develop effective interventions to reduce risks and adapt to climate change (Ford et al., 2010b).

2.7 Knowledge Gaps

There are significant knowledge gaps regarding climate change and First Nations, Inuit, and Métis peoples' health in Canada. Both the population and geographic focus of the research is uneven, with the majority focused on Inuit populations and the Canadian Arctic, which is recognized as a "global hotspot" for climate change (Ford et al., 2014; ITK, 2019b). Relatively little research exists on First Nations communities outside the North, especially First Nations communities in the Prairies and the Atlantic provinces. Métis peoples across Canada are significantly under-represented in climate change research. There is also limited research on climate change in the context of urban First Nations, Inuit, and Métis populations, which is problematic, given that over 50% of Indigenous Peoples in Canada live in urban centres. Similarly, few studies examine the intersection of climate change and gender, particularly the experiences of gender-diverse people. The perspectives of Indigenous Elders and natural resource users are over-represented in the literature, with fewer studies looking at children and youth. These gaps are linked, in part, to the inadequacies of health data and research in Canada, including a lack of disaggregated and longitudinal data specific to First Nations, Inuit, and Métis peoples; the absence of relevant, consistent, and inclusive Indigenous identifiers in population health data sources; and a lack of strength-based and community-driven health indicators (Smylie, 2010; Smylie & Firestone, 2015). As noted in Box 2.1, Indigenous health research also continues to be dominated by non-Indigenous researchers and scientific knowledge paradigms (Saini, 2012; Brown, 2018; Hyett et al., 2018; Anderson, 2019).

In terms of climate change risks to Indigenous health, more research is needed to understand the holistic and long-term impacts of changing temperature and precipitation regimes on food and water safety and security, air quality, health infrastructure, personal safety, mental health, livelihoods, and identity within and among diverse First Nations, Inuit, and Métis peoples and communities. These climate-related risks to health also need to be examined in the context of existing First Nations, Inuit, and Métis peoples' health inequalities and inequities, and related determinants of health. For example, more research is needed to understand how increases in air pollutants and aeroallergens will affect First Nations, Inuit, and Métis peoples who already experience a disproportionate burden of chronic and infectious diseases and poor housing conditions (e.g., homes in need of repair, overcrowding, and poor ventilation). Similarly, little is known about how infectious diseases, such as COVID-19, will affect Indigenous food systems that are already compromised by climate extremes (e.g., drought, record-breaking temperatures, and wildfires) and undermined by historic and ongoing colonization (e.g., land dispossession, social exclusion) (Zavalete-Cortijo et al., 2020). Although Indigenous Peoples are often described as simultaneously vulnerable and resilient in climate change research (Vinyeta et al., 2015), there are few studies that examine resilience and protective factors in regard to climate change.

Research on the direct impacts of climate change on traditional harvesting also dominates the literature, although few examine the indirect effects of potential new economic development opportunities arising from climate change and how they may mediate the negative impacts of climate change to Indigenous Peoples' economy, health, and culture (Ford & Pearce, 2012). Studies on the determinants of adaptive capacity are also limited, including access to financial resources, social networks, flexibility in resource management regimes, the role and potential of social learning in adaptation, and the role of government policies and programs in adaptive capacity (Ford & Pearce, 2012). Similarly, there is a lack of research on the effectiveness of community-based adaptation initiatives and how Indigenous knowledges have been used in adaptation initiatives.

2.8 Conclusion

"Climate change is bad…we feel it in the north a lot more than people in the south…I've noticed in my 16 years of life that snow doesn't get as high as possible because around my house we always had this big huge snowbank, like bigger than the house, about the size of the house. But now it barely comes up to your hips. That's the one thing I've noticed as a child, that my favourite snowdrift hasn't come back. If I've noticed this in such a young stage of life, I can't imagine how the Elders would feel because they obviously have much more experience with the land around me. I am worried because I have noticed this change. Noticing it is the first thing, the next thing is to solve it." [30]

Climate change represents one of the greatest threats to global health in the 21st century (WHO, 2018). For First Nations, Inuit, and Métis peoples in Canada, this threat is exacerbated by their close relationships with and reliance on land, waters, animals, plants, and natural resources for their sustenance, livelihoods, cultures, identities, and health and well-being (Ford, 2012; ILO, 2017; Jones, 2019). Although First Nations, Inuit, and Métis peoples in Canada, and Indigenous Peoples globally, contribute very little to greenhouse gas emissions, they are disproportionately affected by climate change due to pervasive health inequalities, inequities, and determinants of health, including historic and ongoing colonial oppression (Ford, 2012; ILO, 2017). The direct and indirect impacts of climate change are already being felt in First Nations, Inuit, and Métis communities from coast to coast to coast, particularly in geographic areas experiencing rapid change (Ford, 2012; ISC, 2019a). These impacts are interconnected and far-reaching, from increased food and water insecurity and infrastructure damage, to threats to personal safety and basic human rights, all of which are experienced differently within and among First Nations, Inuit, and Métis peoples and communities. To address the growing threat of climate change, Indigenous Peoples are drawing on their unique and diverse knowledge systems and practices, passed down from one generation to the next, that have enabled them to respond, adapt, and survive changing environments for millennia. Indigenous knowledge systems are equal to scientific knowledge and are increasingly recognized as important to climate change mitigation, adaption, research, and policy in Canada and internationally.

Significant knowledge gaps hinder effective adaptation and reflect a lack of distinctions-based, Indigenous-led, community-based participatory research on climate change and health in Canada. Continued focus and sustained research to address these gaps will ensure that First Nations, Inuit, and Métis peoples' perspectives, experiences, knowledges, and voices are centred within climate change discussions, negotiations, and actions at all levels moving forward.

30 Jordan Takkiruq quoted in ITK (2018).

2.9 References

Adger, W. N., Barnett, J., Brown, K., Marshall, N., & O'Brien, K. (2013). Cultural dimensions of climate change impacts and adaption. *Nature Climate Change, 3*, 112-7.

Aguiar, W., & Halseth, R. (2015). *Aboriginal peoples and historic trauma: The processes of intergenerational transmission.* Prince George, BC: National Collaborating Centre for Aboriginal Health.

Alexander, C., Bynum, N., Johnson, L., King, U., Mustonen, T., Neofotis, P., Oettlé, N., Rosenzweig, C., Sakakibara, C., Shadrin, V., Vicarelli, M., Waterhouse, J., & Weeks, B. (2011). Linking Indigenous and scientific knowledge of climate change. *BioScience, 61*(6), 477-85.

Allaire, M., Mackay, T., Zheng, S. and Lall, U. (2019). Detecting community response to water quality violations using bottled water sales. *Proceedings of the National Academy of Sciences, USA, 116*(42), 20917-20922.

Anderson, K. (2010). *Aboriginal women, water and health: Reflections from eleven First Nations, Inuit, and Métis grandmothers.* Halifax, NS & Winnipeg, MB: Atlantic Centre of Excellence for Women's Health & Prairie Women's Health Centre of Excellence. Retrieved from <http://www.pwhce.ca/pdf/womenAndWater.pdf>

Anderson, M. (2019). Indigenous health research and reconciliation. *Canadian Medical Association Journal, 191*, E930-1.

Andrachuk, M., & Smit, B. (2012). Community-based vulnerability assessment of Tuktoyaktuk, NWT, Canada to environmental and socio-economic changes. *Regional Environmental Change, 12*(40), 867-85. doi: 10.1007/s10113-012-0299-0

Archer, L. (2016). *A decadal reanalysis of climate vulnerability in the Canadian Arctic: The case of Arctic bay.* Unpublished MA thesis. Montreal, QC: McGill University.

Arias-Bustamante, J. (2013). *Indigenous knowledge, climate change and forest management: The Nisga'a Nation approach.* Unpublished MSc thesis. Vancouver, BC: University of British Columbia.

Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E., & Patton, E. (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change, 21*(3), 995-1004.

Asfaw, H. W. (2018). *Wildfire evacuation and emergency management in remote First Nations; The case of Sandy Lake First Nation, northern Ontario.* Unpublished PhD dissertation. Edmonton, AB: University of British Columbia.

Assembly of First Nations (AFN). (2013). *Strategy to protect and advance Indigenous water rights.* Ottawa, ON Retrieved from <https://www.afn.ca/uploads/files/water/firstnationswaterstrategy.pdf>

Assembly of First Nations (AFN). (2017). *The First Nations health transformation agenda.* Ottawa, ON.

Assembly of First Nations (AFN). (2019). *Declaring a First Nations climate emergency. Resolution no. 05/2019.* Ottawa, ON. Retrieved from <https://www.afn.ca/wp-content/uploads/2019/08/19-05-Declaring-a-First-Nations-Climate-Emergency.pdf>

Assembly of First Nations (AFN). (2020). *National Climate Gathering Report: Drive change, Leading Solutions.* Retrieved from <https://www.afn.ca/wp-content/uploads/2021/04/Climate_Gathering_Report_ENG.pdf>

Auger, M.D. (2019). 'We need to not be footnotes anymore': Understanding Métis people's experiences with mental health and wellness in British Columbia. *Public Health, 176*, 92-97.

Avery, H. (2019). Old Crow, Yukon, declares climate change state of emergency. *CBC News,* May 21. Retrieved from <https://www.cbc.ca/news/canada/north/old-crow-climate-change-emergency-1.5144010>

Awuor, L., Meldrum, R., & Liberda, E.N. (2019). Prospects of leveraging an existing mosquito-borne disease surveillance system to monitor other emerging mosquito-borne diseases: A systematic review of West Nile Virus surveillance in Canada (2000-2016). *Environmental Health Review, 62*(3), 82-91.

Bachand, N., Aenishaenslin, C., Ravel, A., Reeder, B., & Jenkins, E. (2019). Food safety behavior, awareness and perception of parasites in Inuit exposed to wildlife. In preparation for the Science of the Total Environment. In N. Bachand (Ed.), *Toxoplasma Gondi in wildlife traditionally harvested by Inuit of Nunavik, Canada* (pp. 138-78). Unpublished PhD dissertation, University of Saskatchewan, Saskatoon, Regina, Canada.

Bakaic, M., & Medeiros, A.S. (2016). Vulnerability of northern water supply lakes to changing climate and demand. *Arctic Science, 3*(1), 1-16.

Baldwin, C., Bradford, L., Carr, M. K., Doig, L. E., Jardine, T. D., & Jones, P.D. (2018). Ecological patterns of fish distribution in the Slave River Delta region, Northwest Territories, Canada, as relayed by traditional knowledge and Western science. *International Journal of Water Resources Development, 34*(2), 305-24.

Battiste, M. (2010). Nourishing the learning spirit: Learning is our purpose in life. *Education Canada, 50*(1), 14-18.

BC Centre for Disease Control. (n.d.). *Toxoplasmosis.* Vancouver, BC. Retrieved from <http://www.bccdc.ca/health-info/diseases-conditions/toxoplasmosis>

Bedard, A., & Richards, G. (2018). Addressing mental health impacts in Indigenous communities due to evacuations caused by extreme weather events. *Emergency management in Indigenous communities: Addressing mental health and cultural safety in evacuation processes.* Ottawa, ON: Indigenous Services Canada, Climate Change and Adaptation Program webinar series. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/fsp_webinar_presentation_16_nov_18.pdf>

Belfer, E., Ford, J. D., & Maillet, M. (2017). Representation of Indigenous peoples in climate change reporting. *Climatic Change, 145*(1-2), 57-70.

Belfer, E., Ford, J. D., Maillet, M., Araos, M., & Flynn, M. (2019). Pursuing an Indigenous platform: Exploring opportunities and constraints for Indigenous participation in the UNFCCC. *Global Environmental Politics, 19*, 1.

Berkes, F. (2012). *Sacred ecology, 3rd Edition*. New York, NY: Routledge Press.

Berner, J., Brubaker, M., Revitch, B., Kreummel, E., Tcheripanoff, M., & Bell, J. (2016). Adaptation in Arctic circumpolar communities: Food and water security in a changing climate. *International Journal of Circumpolar Health, 75*, 33820. DOI: 10:3402/ijch.v75.33820.

Berry, P., Clark, K.-L., Fleury, M. D., & Parker, S. (2014). Human health. In F.J. Warren & D.S. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (pp. 191-232). Ottawa, ON: Government of Canada.

Bharadwaj, L., & Bradford, L. (2018). Indigenous water poverty: Impacts beyond physical health. In H. Exner-Pirot, B. Norbye, & L. Butler (Eds.), *Northern and Indigenous health and healthcare*. Saskatoon, SK: University of Saskatchewan. Retrieved from <https://openpress.usask.ca/northernhealthcare/chapter/chapter-4-indigenous-water-poverty-impacts-beyond-physical-health/>

Bhawra, J., Cooke, M. J., Guo, Y., & Wilk, P. (2017). The association of household food security, household characteristics and school environment with obesity status among off-reserve First Nations and Métis children and youth in Canada: Results from the 2012 Aboriginal Peoples Survey. *Health Promotion and Chronic Disease Prevention in Canada, 37*(3), 77-86.

Bird, Y., Moraros, J., Mahmood, R., Esmaeelzadeh, S., & Soe, N. M. K. (2017). Prevalence and associated risk factors of COPD among Aboriginal Peoples in Canada: A cross-sectional study. *International Journal of Chronic Obstructive Pulmonary Disease, 12,* 1915-22.

B.J. Stocks Wildfire Investigations Ltd. (2013). *Evaluating past, current and future forest fire load trends in Canada.* Sault Ste. Marie, ON. Retrieved from <https://www.ccfm.org/pdf/2%20Fire%20Load%20Trends.pdf>

Boksa, P., Joober, R., & Kirmayer, L. J. (2015). Mental wellness in Canada's Aboriginal communities: Striving toward reconciliation. *Journal of Psychiatry & Neuroscience, 40*(6), 363-5.

Bouchard, C., Dibernardo, A., Koffi, J., Wood, H., Leighton, P. A., & Lindsay, L. R. (2019). Increased risk of tick-borne diseases with climate change. *Canada Communicable Disease Report, 45*(4), 81-9.

Bourque, F., & Cunsolo Willox, A. (2014). Climate change: The next challenge for public mental health? *International Review of Psychiatry, 26*(4), 415-22.

Bowser, N.H., & Anderson, N.E. (2018). Dogs (Canis familiaris) as sentinels for human infectious disease and application to Canadian populations: A systematic review. *Veterinary Sciences, 5*, 83. doi: 10.3390/vetsci5040083

Boyd, D. (2011). No taps, no toilets: First Nations and the constitutional right to water in Canada. *McGill Law Journal*, *57*(1), 81-134.

Bradford, L. E. A., Bharadwaj, L. A., Okpalauwaekwe, U, & Waldner, C. L. (2016). Drinking water quality in Indigenous communities in Canada and health outcomes: A scoping review. *International Journal of Circumpolar Health, 75*(1), 32336. DOI: 10.3402/ijch.v75.32336.

Brown, C. (2018). Self-determination and data control vital to Indigenous health research. *Canadian Medical Association Journal, 190*(29), E893.

Bunce, A. (2015). *Gender and the human dimensions of climate change: Global discourse and local perspectives from the Canadian Arctic.* Unpublished Master of Arts thesis, McGill University, Montreal, Quebec, Canada.

Bunce, A., Ford, J.D., Harper, S., Edge, V., & IHACC Research Team. (2016). Vulnerability and adaptive capacity of Inuit women to climate change: A case study from Iqaluit, Nunavut. *Natural Hazards, 83(3)*, 1419-41.

Bush, E., & Lemmen, D. S. (Eds.). (2019). *Canada's changing climate report.* Ottawa, ON: Government of Canada.

Cameron, E. S. (2012). Securing Indigenous politics: A critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian Arctic. *Global Environmental Change, 22*(1), 103-14.

Canadian Association of University Teachers. (2018). *Underrepresented and underpaid: Diversity and equity among Canada's post-secondary education teachers*. Ottawa, ON.

Canadian Broadcasting Corporation News (CBC News). (2021). Don't drink the tap water, Iqaluit mayor tells residents. CBC News. Retrieved from <https://www.cbc.ca/news/canada/north/iqaluit-water-emergency-council-meeting-1.6208466>

Canadian Coalition for Green Health Care. (2020). *Climate-related hazards can have significant implications for demand on health care services.* Halifax, NS. Retrieved from <https://greenhealthcare.ca/climate-change/>

Canadian Institutes of Health Research (CIHR). (2013). *Guidelines for health research involving Aboriginal people.* Ottawa, ON.

Canadian Institutes of Health Research (CIHR), Natural Sciences and Engineering Research Council of Canada (NSERC), and Social Sciences and Humanities Research Council (SSHRC). (2018). *Tri-council policy statement: Ethical conduct for research involving humans – TCPS2 2018.* Ottawa, ON. Retrieved from <https://ethics.gc.ca/eng/documents/tcps2-2018-en-interactive-final.pdf>

Carrière, G. M., Bougie, E., & Kohen, D. (2018). *Acute care hospitalizations for mental and behavioural disorders among First Nations people*. Ottawa, ON: Statistics Canada, Catalogue 82-003-X.

Carrière, G.M., Garner, R., & Sanmartin, C. (2017). Housing conditions and respiratory hospitalizations among First Nations people in Canada. *Health Reports, 28*(4), 9-15.

Centre for Indigenous Environmental Resources (CIER). (2008). *Climate change and First Nations south of 60: Impacts, adaptation, and priorities.* Winnipeg, MB: Submitted to Indian and Northern Affairs Canada. Retrieved July 17, 2020 from <http://caid.ca/CliChaImp2008.pdf>

Champalle, C., Ford, J.D., & Sherman, M. (2015). Prioritizing climate change adaptations in Canadian Arctic communities. *Sustainability, 7*(7), 9268-92.

Chandler, M.J., & Lalonde, C.E. (1998). Cultural continuity as a hedge against suicide in Canada's First Nations. *Transcultural Psychiatry, 35*(2), 191-219.

Chen, S. (2016). *Climate change and infectious disease risk in the Canadian North*. Vancouver, BC: National Collaborating Centre for Environmental Health.

Chief Public Health Officer of Canada (CPHO). (2013). *Report on the state of public health in Canada 2013: Infectious disease – the never-ending threat*. Ottawa, ON: Public Health Agency of Canada.

Christianson, A., McGee, T.K., & L'Hirondelle, L. (2012). Community support or wildfire mitigation at Peavine Métis settlement, Alberta, Canada. *Environmental Hazards, 11*(3), 177-93. DOI: 10.1080/17477891.2011.649710

Christianson, A., McGee, T.K., & L'Hirondelle, L. (2014). The influence of culture on wildfire mitigation at Peavine Métis Settlement, Alberta, Canada. *Society & Natural Resources: An International Journal, 27*(9), 931-47.

Cidro, J., Adekunle, B., Peters, E., & Martens, T. (2015). Beyond food security: Understanding access to cultural food for urban Indigenous people in Winnipeg as Indigenous food sovereignty. *Canadian Journal of Urban Research, 24*(1), 24-43.

Clark, D.G., Ford, J.D., Berrang-Ford, L., Pearce, T., Kowal, S., & Gough, W.A. (2016a). The role of environmental factors in search and rescue incidents in Nunavut, Canada. *Public Health, 137,* 44-9.

Clark, D.G., Ford, J.D., Pearce, T., & Berrang-Ford, L. (2016b). Vulnerability to unintentional injuries associated with land-use activities and search and rescue in Nunavut, Canada. *Social Science & Medicine, 169,* 18-26.

Climate Telling. (2020). *Climate Telling*. <http://www.climatetelling.info/about-the-site.html.>

Collier, B. (2015). *Emergency management on First Nations reserves*. Ottawa, ON: Library of Parliament. Retrieved from <https://lop.parl.ca/sites/PublicWebsite/default/en_CA/ResearchPublications/201558E>

Commission on the Social Determinants of Health (CSDH). (2008). *Closing the gap in a generation: Health equity through action on the social determinants of health. Final report of the Commission on Social Determinants of Health*. Geneva: World Health Organization.

Council of Canadian Academies. (2019). *Canada's top climate change risks: Report of the Expert Panel on Climate Change Risks and Adaptation Potential.* Ottawa, ON.

Coté, C. (2016). "Indigenizing" food sovereignty. Revitalizing Indigenous food practices and ecological knowledges in Canada and the United States. *Humanities, 5*, 57. DOI: 10.3390/h5030057.

Cruddas, E. (2017). *Tapping into mental health: Exploring Indigenous water and mental health issues through Canadian media*. Unpublished Sociology Honours Thesis, Dalhousie University, Halifax, Nova Scotia, Canada.

Cuerrier, A., Brunet, N.D., Gérin-Lajoie, J., Downing, A., & Lévesque, E. (2015). The study of Inuit knowledge of climate change in Nunavik, Quebec: A mixed methods approach. *Human Ecology, 43*(3), 379-94.

Cunsolo, A., Borish, D., Harper, S.L., Snook, J., Shiwak, I., Wood, M., & The Herd Caribou Project Steering Committee. (2020). "You can never replace the caribou": Inuit experiences of ecological grief from caribou declines. *American Imago, 77*(1), 31-59.

Cunsolo, A., & Ellis, N.R. (2018). Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change, 8,* 275-81.

Cunsolo, A., & Rigolet Inuit Community Government. (2014). *Attutauniujuk Nunami/Lament for the Land.* Sydney, NS: Cape Breton University, <https://ashleecunsolo.ca/film/>

Cunsolo Willox, A. (2012a). *Lament for the land: On the impacts of climate change on mental and emotional health and well-being in Rigolet, Nunatsiavut, Canada.* Unpublished PhD dissertation, University of Guelph, Guelph, Ontario, Canada.

Cunsolo Willox, A. (2012b). Climate change as the work of mourning. *Ethics and the Environment, 17*(2), 137-64.

Cunsolo Willox, A., Harper, S.L., Edge, V.L., Landman, K., Houle, K., Ford, J.D., & the Rigolet Inuit Community Government. (2013a). The land enriches the soul: On climatic and environmental change, affect, and emotional health and well-being in Rigolet, Nunatsiavut, Canada. *Emotion, Space and Society, 6,* 14-24.

Cunsolo Willox, A., Harper, S.L., Ford, J.D., Edge, V.L., Landman, K., Houle, K. Blake, S., & Wolfrey, C. (2013b). Climate change and mental health: An exploratory case study from Rigolet, Nunatsiavut, Canada. *Climatic Change, 121*(1-2), 255-70.

Cunsolo Willox, A., Harper, S. L., Ford, J. D., Landman, K., Houle, K., Edge, V.L., & Rigolet Inuit Community Government. (2012). "From this place and of this place:" Climate change, sense of place, and health in Nunatsiavut, Canada. *Social Science & Medicine, 75*(3), 538-47.

Cunsolo Willox, A., Stephenson, E., Allen, J., Bourque, F., Drossos, A., Elgarøy, S., Kral, M.J., Mauro, I., Moses, J., Pearce, T., MacDonald, J.P., & Wexler, L. (2015). Examining relationships between climate change and mental health in the Circumpolar North. *Regional Environmental Change, 15*(1), 169-82.

Cyre, M., & Slater, J. (2019). Honouring the grandmothers through (re)membering, (re)learning, and (re)vitalizing Métis traditional foods and protocols. *Canadian Food Studies, 6*(2), 51-72.

Daley, K., Castleden, H., Jamieson, R., Furgal, C., & Ell, L. (2015). Water systems, sanitation, and public health risks in remote communities: Inuit residents' perspectives from the Canadian Arctic. *Social Science & Medicine, 135,* 124-32.

Debels, P., Szlafsztein, C., Aldunce, P., Neri, C., Carvajal, Y., Quintero-Angel, M., Celis, A., Bezanilla, A., & Martínez, D. (2009). IUPA: A tool for the evaluation of the general usefulness of practices for adaptation to climate change and variability. *Natural Hazards, 50*(2), 211-33.

Debortoli, N.S., Clark, D.G., Ford, J.D., Sayles, J.S., & Diaconescu, E.P. (2019). An integrative climate change vulnerability index for Arctic aviation and marine transportation. *Nature Communications,* 10, 2596.

Deemer, G.J., Bhatt, U.S., Eicken, H., Posey, P.G., Hutchings, J.K., Nelson, J., Heim, R., Allard, R.A., Wiggins, H., & Creek, K. (2018). Broadening the sea-ice forecaster toolbox with community observations: A case study from the northern Bering Sea. *Arctic Science, 4*(1), 42-70.

Dicken, E. (2018). Emergency management in BC. *Emergency management in Indigenous communities: Addressing mental health and cultural safety in evacuation processes.* Ottawa, ON: Indigenous Services Canada, Climate Change and Health Adaptation Program webinar series. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/fncu_presentation_fnihb_final.pdf>

Diver, S. (2017). Negotiating Indigenous knowledge at the science-policy interface: Insights from the Xáxli'p Community Forest. *Environmental Science & Policy, 73*, 1-11.

Dodd, W., Howard, C., Rose, C., Scott, C., Scott, P., Cunsolo, A., & Orbinski, J. (2018a). The summer of smoke: Ecosocial and health impacts of a record wildfire season in the Northwest Territories, Canada. *The Lancet Global Health, 6*(Suppl. 2), S30.

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018b). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health, 109*(3), 327-37.

Donatuto, J., Grossman, E.E., Konovsky, J., Grossman, S., & Campbell, L.W. (2014). Indigenous community health and climate change: Integrating biophysical and social science indicators. *Coastal Management, 42*(4), 355-73. DOI: 10.1080/08920753.2014.923140

Douglas, A. (2017). *Effects of climate change and cultural practices on the risk of toxoplasmosis in Canada's North: Recommendations for public health.* Burnaby, BC: Simon Fraser University Faculty of Health Sciences, Master of Public Health Capstone project.

Downing, A., & Cuerrier, A. (2011). A synthesis of the impacts of climate change on the First Nations and Inuit of Canada. *Indian Journal of Traditional Knowledge, 10*(1), 57-70.

Dowsley, M., Gearheard, S., Johnson, N., & Inksetter, J. (2010). Should we turn the tent? Inuit women and climate change. *Études/Inuit/Studies, 34*(1), 151-65.

Dudley, J.P., Hoberg, E.P., Jenkins, E.J., & Parkinson, A.J. (2015). Climate change in the North American Arctic: A One Health perspective. *EcoHealth, 12*(4), 713-25. DOI: 10.1007/s10393-014-1035-1.

Durkalec, A., Furgal, C., Skinner, M.W., & Sheldon, T. (2015). Climate change influences on environment as a determinant of Indigenous health: Relationships to place, sea ice, and health in an Inuit community. *Social Science & Medicine, 136-7,* 17-26.

Earle, L. (2011). *Traditional Aboriginal diets and health*. Prince George, BC: National Collaborating Centre for Aboriginal Health.

Ekos Research Associates. (2011). *Perceptions of drinking water quality in First Nations communities and general population.*

El-Nawawi, F.A., Tawfik, M.A., & Shaapan, R.M. (2008). Methods for inactivation of Toxoplasma gondii cysts in meat and tissues of experimentally infected sheep. *Foodborne Pathogens and Disease, 5*(5), 687-90.

Elmore, S.A., Jenkins, E.J., Huyvaert, K.P., Polley, L., Root, J.J., & Moore, C.G. (2012). Toxoplasma gondii in circumpolar people and wildlife. *Vector Borne Zoonotic Diseases, 12*(1), 1-9. DOI: 10.1089/vbz.2011.0705

Environment and Climate Change Canada (ECCC). (2018). *Pan-Canadian Framework on Clean Growth and Climate Change: Second annual synthesis report on the status of implementation*. Gatineau, QB: Environment and Climate Change Canada.

Environment and Climate Change Canada (ECCC). (2019). 7.0 Federal engagement and partnership with Indigenous Peoples. In *Pan-Canadian Framework on Clean Growth and Climate Change second annual report* (Section 8). Gatineau, QC. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/climate-change/pan-canadian-framework-reports/second-annual-report/section-8.html>

Environment and Climate Change Canada (ECCC). (2020a). *Indigenous Guardians Pilot Program*. Gatineau, QC. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/environmental-funding/indigenous-guardians-pilot-program.html>

Environment and Climate Change Canada (ECCC). (2020b). *A healthy environment and a healthy economy: Canada's strengthened climate plan to create jobs and support people, communities and the planet*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/healthy-environment-healthy-economy.html>

Environment and Natural Resources. (2015). *Canadian Boreal Community FireSmart Project, 2015 Operations Plan*. Yellowknife, NWT: Prepared in consultation with ENR South Slave Region, Fort Providence Resource Management Board, FP Innovations, and ENR FMD Science Section. Retrieved from <https://www.enr.gov.nt.ca/sites/enr/files/2015_cbcfs_project_operations_plan_1.pdf>

Environment and Natural Resources. (2016). *Canadian Boreal Community Firesmart (CBCFS) Project Draft 5-7ear plan 2016-2021*. Yellowknife, NWT. Retrieved from <http://registry.mvlwb.ca/Documents/MV2016X0008/MV2016X0008%20-%20GNWT-ENR%20-%20New%20LUP%20Application%20-%20May2-16.pdf>

Epi EcoPlan International, Inc. (2016). *Valuing coastal guardian watchmen programs: A business case.* Vancouver, BC: Prepared for the Coastal Steward Network and TNC Canada. Retrieved from <https://www.indigenousguardianstoolkit.ca/sites/default/files/Community%20Resource_Guardians-valuationreport_v10_Final_TNC%20Canada.pdf>

Expert Panel on Climate Change Adaptation and Resilience. (2018). *Measuring progress on adaptation and climate resilience: Recommendations to the Government of Canada*. Ottawa, ON: Environment and Climate Change Canada.

Faris, N. (2019). Eroding Tuktoyaktuk: Every year homes in this northern hamlet are getting closer to the sea. *National Post*, February 28. Retrieved from <https://nationalpost.com/news/canada/eroding-tuktoyaktuk-every-day-homes-in-this-northern-hamlet-are-getting-closer-to-the-sea>

Finn, S., Herne, M., & Castille, D. (2017). The value of traditional ecological knowledge for the environmental health sciences and biomedical research. *Environmental Health Perspectives, 125*(8), 085006.

FiresSmart Canada. (2020). What is FireSmart? Retrieved from <https://firesmartcanada.ca/what-is-firesmart/>

First Nations Centre. (2004). *First Nations' knowledge of and protection from the West Nile virus*. Ottawa, ON. Retrieved from <https://fnigc.ca/sites/default/files/ENpdf/WNV/west_nile_virus_2004.pdf>

First Nations Health Authority. (2021). *Drinking water advisories*. West Vancouver, BC. Retrieved from <https://www.fnha.ca/what-we-do/environmental-health/drinking-water-advisories>. Accessed July 16, 2021.

First Nations Information Governance Centre. (2014). *Ownership, Control, Access and Possession (OCAP™): The Path to First Nations Information Governance.* Akwesasne, ON.

Flynn, M., Ford, J.D., Labbé, J., Schrott, L., & Tagalik, S. (2019). Evaluating the effectiveness of haard mapping as climate change adaptation for community planning in degrading permafrost terrain. *Sustainability Science, 14*(4), 1041-56.

Flynn, M., Ford, J.D., Pearce, T., Harper, S.L., & IHACC Research Team. (2018). Participatory scenario planning and climate change impacts, adaptation and vulnerability research in the Arctic. *Environmental Science & Policy, 79*, 45-53.

Ford, J.D. (2012). Indigenous Health and Climate Change. *American Journal of Public Health, 102*(7), 1260-6.

Ford, J.D., Berrang-Ford, L., King, M., & Furgal, C. (2010a). Vulnerability of Aboriginal health systems in Canada to climate change. *Global Environmental Change, 20*(4), 668-80.

Ford, J.D., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Willox, A.C., & Pearce, T. (2016b). Including Indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change, 6*, 349-53.

Ford, J.D., Cunsolo Willox, A., Chatwood, S., Furgal, C., Harper, S., Mauro, I., & Pearce, T. (2014). Adapting to the effects of climate change on Inuit health. *American Journal of Public Health, 104*, e9-e17.

Ford, J.D., Kind, N., Galappaththi, E.K., Pearce, T., McDowell, G., & Harper, S.L. (2020). The resilience of Indigenous Peoples to Environmental Change. *One Earth, 2*(6), 532-43.

Ford, J.D., Labbé, J., Flynn, M., Araos, M., & IHACC Research team. (2017). Readiness for climate change adaptation in the Arctic: A case study from Nunavut, Canada. *Climatic Change, 145*, (1-2), 85-100.

Ford, J.D., & Pearce, T. (2012). Climate change vulnerability and adaptation research focusing on the Inuit subsistence sector in Canada: Directions for future research. *The Canadian Geographer, 56*(2), 275-87.

Ford, J.D., Pearce, T., Duerden, F., Furgal, C., & Smit, B. (2010b). Climate change policy responses for Canada's Inuit population: The importance of and opportunities for adaptation. *Global Environmental Change, 20*(1), 177-91.

Ford, J.D., Sherman, M., Berrang-Ford, L., Llanos, A., Carcamo, C., Harper, S., Lwasa, S. Namanya, D., Marcello, T., Maillet, M., & Edge, V. (2018). Preparing for the health impacts of climate change in Indigenous communities: The role of community-based adaptation. *Global Environmental Change, 49*, 129-39.

Ford, J.D., Stephenson, E., Cunsolo Willox, A., Edge, V., Farahbakhsh, K., Furgal, C., Harper, S. Chatwood, S., Maura, I., Pearce, T., Austin, S., Bunce, A., Bussalleu, A.,……Sherman, M. (2016a). Community-based adaptation research in the Canadian Arctic. *WIREs Climate Change, 7*, 175-91.

Four Rivers Matawa First Nations Management Environmental Services (FRMFNMES). (2016). *Northern Ontario First Nation climate change workshop.* Ottawa, ON: For Indigenous and Northern Affairs Canada and Health Canada. Retrieved from <http://www.nokiiwin.com/upload/documents/climate-change/2016_december_northern-ontario-climate-c.pdf>

Fournier, S., & Crey, E. (1997). *Stolen from our embrace.* Vancouver, BC: Douglas and McIntyre.

Frank, M.A. (2017). Rising voices: Collaborative science with Indigenous knowledge for climate solutions, *Cultural Survival Quarterly Magazine, June,* <https://www.culturalsurvival.org/publications/cultural-survival-quarterly/rising-voices-collaborative-science-indigenous-knowledge>

Gérin-Lajoie, J., Herrmann, T.M., MacMillan, G.A., Hébert-Houle, E., Monfette, M., Rowell, J.A., Soucie, T.A., Snowball, H., Townley, E., Lévesque, E., Amyot, M., Franssen, J., & Dedieu, J. P. (2018). Imalirijiit: A community-based environmental monitoring program in the George River watershed, Nunavik, Canada. *Ecoscience, 25*(4), 381-99. DOI: <https://doi.org/10.1080/11956860.2018.1498226>

Gershon, A.S., Khan, S., Klein-Geltink, J., Wilton, D., To, T., Crighton, E.J., Pigeau, L., Macquarrie, J., Allard, Y., Russell, S.J., & Henry, D. A. (2014). Asthma and chronic obstructive pulmonary disease (COPD) prevalence and health service use in Ontario Métis: A population-based cohort study. *PLoS One, 9*(4), e95899.

Goldfarb, D.M., Dixon, B., Moldovan, I., Barrowman, N., Mattison, K., Zentner, C., Baikie, M., Bidawid, S., Chan, F., & Slinger, R. (2013). Nanolitre real-time PCR detection of bacterial, parasitic, and viral agents from patients with diarrhea in Nunavut, Canada. *International Journal of Circumpolar Health, 72*, 19903. DOI: 10.3402/ijch.v72i0.19903.

Goldhar, C., Bell, T., & Wolf, J. (2014). Vulnerability to freshwater changes in the Inuit Settlement Region of Nunatsiavut, Labrador: A case study from Rigolet. *Arctic, 67*(1), 71-83.

Government of Canada. (2018). *Crown-Indigenous Relations and Northern Affairs Canada*, <https://www.canada.ca/en/crown-indigenous-relations-northern-affairs.html>

Government of Canada. (2019). *Indigenous Guardians Pilot Program*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/environmental-funding/indigenous-guardians-pilot-program.html>

Government of the Northwest Territories. (2010). *Environment and natural resources framework for action 2008-2012: Status report to December 2010.* Yellowknife, NWT. Retrieved from <https://www.assembly.gov.nt.ca/sites/default/files/11-03-01td160-165.pdf>

Government of Nunavut. (2010). *Upagiaqtavut: Setting the course – Climate change impacts and adaptation in Nunavut.* Iqaluit, NU. Retrieved from <https://www.climatechangenunavut.ca/sites/default/files/3154-315_climate_english_reduced_size_1_0.pdf>

Government of Nunavut. (2012). *Changing times: Climate change impacts and adaptation in Nunavut.* Iqaluit, NU. Retrieved from <http://www.climatechangenunavut.ca/sites/default/files/summer_2012_newsletter.pdf>

Government of Nunavut. (2014). *Climate change adaptation resource guide: Nunavut's built infrastructure.* Iqaluit, NU. Retrieved from <https://www.climatechangenunavut.ca/sites/default/files/rg3_built_infrastructure_0.pdf>

Goyette, S., Cao, Z., Libman, M., Ndao, M., & Ward, B.J. (2014). Seroprevalence of parasitic zoonoses and their relationship with social factors among the Canadian Inuit in Arctic regions. *Diagnostic Microbiology & Infectious Diseases, 78,* 404-10.

Gracey, M., & King, M. (2009). Indigenous health Part 1: Determinants and disease patterns. *The Lancet, 374*, 65-75.

Greenwood, M., de Leeuw, S., & Lindsay, N. (2018). Challenges in health equity for Indigenous peoples in Canada. *The Lancet, 391*(10131), 1645-1648.

Greer, A., Ng, V., & Fisman, D. (2008). Climate change and infectious diseases in North America: The road ahead. *Canadian Medical Association Journal, 178*(6), 715-22.

Guyot, M., Dickson, C., Paci, C., Furgal, C., & Chan, H.M. (2006). Local observations of climate change and impacts on traditional food security in two northern Aboriginal communities. *International Journal of Circumpolar Health, 65*(5), 403-15.

Hania, P. (2019). Revitalizing Indigenous women's water governance roles in impact and benefit agreement processes through Indigenous legal orders and water stories. *Les Cahiers de droit, 60*(2), 519-56.

Hanrahan, M., Sarkar, A., & Hudson, A. (2014). *Water insecurity in Indigenous Canada: A case study of illness, neglect, and urgency*. St. John's, NF: Paper presented at the 2014 International Conference on Marine and Freshwater Environments. Retrieved from <http://nlwater.ruralresilience.ca/wp-content/uploads/2014/09/iMFE-Paper-Submission-Revised-August-2014.pdf>

Hansen, J.G., & Antsanen, R. (2018). What can traditional Indigenous knowledge teach us about changing our approach to human activity and environmental stewardship in order to reduce the severity of climate change? *International Indigenous Policy Journal, 9*(3), 6.

Harper, S.L., Edge, V.L., Ford, J., Cunsolo Willox, A., Wood, M., IHACC Research Team, RICG, & McEwen, S.A. (2015c). Climate-sensitive health priorities in Nunatsiavut, Canada. *BMC Public Health, 15*, 605.

Harper, S.L., Edge, V.L., Ford, J., Thomas, M.K., IHACC Research Group, Rigolet Inuit Community Government, & McEwen, S.A. (2015a). Lived experience of acute gastrointestinal illness in Rigolet, Nunatsiavut: "Just suffer through it". *Social Science & Medicine, 126*, 86-98.

Harper, S.L., Edge, V.L., Ford, J., Thomas, M.K., Pearl, D.L., Shirley, J., IHACC, & McEwen, S.A. (2015b). Acute gastrointestinal illness in two Inuit communities: Burden of illness in Rigolet and Iqaluit, Canada. *Epidemiology & Infection, 143*, 3048-63.

Hassler, P., Watson, G., & Ndubuka, N. (2019). *Mental health impacts of community evacuation – Lac La Ronge wildfire case study* [webinar]. Prince Albert, SK: Northern Inter-Tribal Health Authority, <https://www.prairiesrac.com/wp-content/uploads/2019/02/Climate-Change-Impacts-on-Mental-Health_6Mar19.pdf>

He, S., Kosatsky, T., Smargiassi, A., Bilodeau-Bertrand, M., & Auger, N. (2018). Heat and pregnancy-related emergencies: Risk of placental abruption during hot weather. *Environ Int., 111*, 295-300. DOI: 10.1016/j.envint.2017.111.004

Health Care without Harm Physician Network. (n.d.). *Climate change, health, and health care: How physicians can help*. Retrieved from <https://noharm-uscanada.org/sites/default/files/Climate.Physician.Network.pdf>

Henry, G.H.R., Harper, K.A., Chen, W., Deslippe, J.R., Grant, R.F., Lafleur, P.M., Lévesque, E., Siciliano, S.D., & Simard, S. (2012). Effects of observed and experimental climate change on terrestrial ecosystems in northern Canada: Results from the Canadian IPY program. *Climatic Change, 115*(1), 207-34.

Hermann, T.M., Royer, M.-J.S., & Cuciurean, R. (2012). Understanding subarctic wildlife in Eastern James Bay under changing climatic and socio-environmental conditions: Bringing together Cree hunters' ecological knowledge and scientific observations. *Polar Geography, 35*(3-4), 245-70.

Himsworth, C.G., Skinner, S., Chaban, B., Jenkins, E., Wagner, B.A., Harms, N.J. Leighton, F.A., Thompson, R. C., & Hill, J. E. (2010). Multiple zoonotic pathogens identified in canine feces collected from a remote Canadian Indigenous community. *American Journal of Tropical Medicine & Hygiene, 83*(2), 338-41.

Hirsch, R., Furgal, C., Hackett, C., Sheldon, T., Bell, T., Angnatok, D., Winters, K., & Pamak, C. (2016). Going off, growing strong: A program to enhance individual youth and community resilience in the face of change in Nain, Nunatsiavut. *Etudes/Inuit/Studies, 40*(1), 63-84.

Hotez, P.J. (2010). Neglected infections of poverty among the Indigenous peoples of the Arctic. *PLoS Neglected Tropical Diseases, 4*(1), e606.

Howard, C., Rose, C., Dodd, W., Scott, P., Cunsolo-Willox, A., & Orbinski, J. (2017). PO62: SOS: Summer of Smoke – A mixed-methods, community-based study investigating the health effects of a prolonged, severe wildfire season on a subarctic population. *Canadian Journal of Emergency Medicine, 19*(S1), p. S99.

Human Rights Watch. (2020). "My fear is losing everything": The climate crisis and First Nations' right to food in Canada. New York, NY. Retrieved from <https://www.hrw.org/sites/default/files/media_2020/10/canada1020_web_1.pdf>

Hunt, S. (2016). *An Introduction to the Health of Two-Spirit People: Historical, contemporary and emergent issues*. Prince George, BC: National Collaborating Centre for Aboriginal Health.

Huntington, H.P., Carey, M., Apok, C., Forbes, B.C., Fox, S., Holm, L.K., Ivanova, A., Jaypoody, J., Noongwook, G., & Stammler, F. (2019). Climate change in context: Putting people first in the Arctic. *Regional Environmental Change*, *19*, 1217-23.

Huseman, J., & Short, D. (2012). 'A slow industrial genocide': Tar sands and the Indigenous peoples of northern Alberta. *The International Journal of Human Rights, 16*(1), 216-37.

Hyett, S., Marjerrison, S., & Gabel, C. (2018). Improving health research among Indigenous peoples in Canada. *Canadian Medical Association Journal, 190*(20), E616-21.

Indigenous and Northern Affairs Canada (INAC). (2018a). Climate change preparedness in the North Program. Ottawa, ON. Retrieved from <https://www.aadnc-aandc.gc.ca/eng/1481305554936/1481305574833>

Indigenous and Northern Affairs Canada (INAC). (2018b). First Nation Adapt Program. Ottawa, ON. Retrieved from <https://www.aadnc-aandc.gc.ca/eng/1481305681144/1481305709311>

Indigenous Guardians – caring for the land [YouTube video] (n.d). *Indigenous Guardians toolkit,* <https://www.indigenousguardianstoolkit.ca/node/40/resources>

Indigenous Services Canada (ISC). (2018, November 26). *Emergency management in Indigenous communities: Addressing mental health and cultural safety in evacuation processes.* Ottawa, ON: ISC and Climate Change and Health Adaptation Program webinar series. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/fncu_presentation_fnihb_final.pdf>

Indigenous Services Canada (ISC). (2019a). *Community voices on climate change and health adaptation in northern Canada: Research and action and the stories behind them 2012-2016.* Ottawa, ON.

Indigenous Services Canada (ISC). (2019b). *News release: Government of Canada announces new investments in wildfire protection for First Nations communities.* Ottawa, ON. Retrieved from <https://www.sac-isc.gc.ca/eng/1565705092824/1565705114188?wbdisable=true>

Indigenous Services Canada (ISC). (2019c). *Mental health and wellness in First Nations and Inuit communities.* Ottawa, ON. Retrieved from <https://www.sac-isc.gc.ca/eng/1576089278958/1576089333975>

Indigenous Services Canada (ISC). (2021a). *Short-term drinking water advisories*. Ottawa, ON. Retrieved from <https://www.sac-isc.gc.ca/eng/1562856509704/1562856530304>

Indigenous Services Canada (ISC). (2021b). *Ending long-term drinking water advisories.* Ottawa, ON. Retrieved from <https://www.sac-isc.gc.ca/eng/1506514143353/1533317130660>

Institute for Circumpolar Health Research. (2017). Water Quality - Inuvialuit Settlement Region, Northwest Territories. *ClimateTelling.* Retrieved from <http://www.climatetelling.info/inuvialuit-settlement-region.html>

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, R.K. Pachauri and L.A. Meyer, Eds.) Geneva, Switzerland.

International Labour Organization (ILO). (2017). *Indigenous peoples and climate change: From victims to change agents through decent work.* Geneva, Switzerland.

International Labor Organization (ILO). (2019). *Indigenous Peoples and climate change: Emerging research on Traditional Knowledge and livelihoods*. Geneva, Switzerland.

Inuit Circumpolar Council (ICC). (n.d.). *Indigenous knowledge.* Ottawa, ON. Retrieved from <https://www.inuitcircumpolar.com/icc-activities/environment-sustainable-development/indigenous-knowledge/>

Inuit Circumpolar Council. (2020). *Policy paper on the matter of "local communities".* Ottawa, ON. Retrieved from <https://secureservercdn.net/104.238.71.250/hh3.0e7.myftpupload.com/wp-content/uploads/FINAL-ICC-Policy-Paper-on-matter-of-local-communities-2.pdf>

Inuit Tapiriit Kanatami (ITK). (2014). *Social determinants of Inuit health in Canada.* Ottawa, ON.

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

Inuit Tapiriit Kanatami (ITK). (2018). *National Inuit strategy on research.* Ottawa, ON.

Inuit Tapiriit Kanatami (ITK). (2019a). *ITK Board of Directors adopts Inuktut Qaliujaaqpait as unified orthography for Inuktut.* Ottawa, ON. Retrieved from <https://www.itk.ca/itk-board-of-directors-adopts-inuktut-qaliujaaqpait-as-unified-orthography-for-inuktut/>

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

Inuit Tapiriit Kanatami (ITK). (2020). Access to drinking water in Inuit Nunangat. Ottawa, ON. Retrieved from <https://www.itk.ca/access-to-drinking-water-in-inuit-nunangat/>

Islam, N.S, & Winkel, J. (2017). *Climate change and social inequality*. New York, NY: United Nations, Department of Economic and Social Affairs Working Paper, No. 152.

Jacob, C., McDaniels, T., & Hinch, S. (2010). Indigenous culture and adaptation to climate change: Sockeye salmon and the St'á'imc people. *Mitigation and Adaptation Strategies for Global Change, 15*, 859-76.

Jenkins, E.J., Castrodale, L.J., de Rosemond, S.J., Dixon, B.R., Elmore, S.A., Gesy, K.M., Hoberg, E.P., Polley, L., Schurer, J.M., Simard, M., & Thompson, R.C. (2013). Traditional and transition: Parasitic zoonoses of people and animals in Alaska, northern Canada, and Greenland. *Advances in Parasitology, 82*, 33-204.

Jenkins, E.J., Simon, A., Bachand, N., & Stephen, C. (2015). Wildlife parasites in a One Health world. *Trends in Parasitology, 31*(5), 174-80.

Jetñil-Kijiner, K., & Niviâna, A. (n.d.). Rise. *350.org.* Retrieved from <https://350.org/rise-from-one-island-to-another/#poem>

JF Consulting. (2020). *Metis National Climate Change and Health Vulnerability Assessment.* Not publicly available.

Jones, R. (2019). Climate change and Indigenous health promotion. *Global Health Promotion, 26*(Supp. 3), 73-81.

Kamal, A.G., Linklater, R., Thompson, S., Dipple, J., & Ithinto Mechisowin Committee. (2015). A recipe for change: Reclamation of Indigenous food sovereignty in O-Pipon-Na-Piwin Cree Nation for decolonization, resources sharing, and cultural restoration. *Journal of Globalizations, 12*(4), 559-75.

Khalafzai, M.-A.K., McGee, T.K., & Parlee, B. (2019). Flooding in the James Bay region of northern Ontario, Canada: Learning from traditional knowledge of Kashechewan First Nation. *International Journal of Disaster Risk Reduction, 36*, 101100.

Kielland, N., & Simeone, T. (2014). *Current issues in mental health in Canada: The mental health of First Nations and Inuit communities*. Ottawa, ON: Library of Parliament.

Kilian, A., Fellows, T.Y., Giroux, R., Pennington, J., Kuper, A., Whitehead, C., & Richardson, L. (2019). Exploring the approaches of non-Indigenous researchers to Indigenous research: a qualitative study. *CMAJ OPEN, 7*(3), E504-E509.

Kinney, P. (2008). Climate change, air quality, and human health. *American Journal of Preventative Medicine, 35*(5), 459-67.

Kipp, A., Cunsolo, A., Gillis, D., Sawatzky, A., & Harper, S.L. (2019a). The need for community-led, integrated and innovative monitoring programs when responding to the health impacts of climate change. *International Journal of Circumpolar Health, 78*(2), 1517581.

Kipp, A., Cunsolo, A., Vodden, K., King, N., Manners, S., & Harper, S.L. (2019b). Climate change impacts on health and wellbeing in rural and remote regions across Canada: A synthesis of the literature. *Health Promotion and Chronic Disease Prevention in Canada, 39*(4), 122-26.

Kirmayer, L.J., Brass, G.M., & Tait, C.L. (2000). The mental health of Aboriginal peoples: Transformations of identity and community. *The Canadian Journal of Psychiatry, 45*, 607-16.

Kluane First Nations, & Arctic Institute of Community-Based Research (AICBR). (2016). *Nourishing our future: Building on Kluane First Nations community food security strategy & youth engagement in traditions related to fisheries and fish health in Kluane Lake.* Burwash Landing, YK.

Kolahdooz, F., Sadeghirad, B., Corriveau, A., & Sharma, S. (2015). Prevalence of overweight and obesity among Aboriginal populations in Canada: A systematic review and meta-analysis. *Critical Review of Food Science & Nutrition, 57*(7), 1316-27. DOI: 10.1080/10408398.2014.913003

Koleade, A., Farrell, J., Mugford, G., & Gao, Z. (2018). Prevalence and risk factors of ACO (Asthma-COPD Overlap) in Aboriginal people. *Journal of Environmental and Public Health,* Article ID 4657420. <https://doi.org/10.1155/2018/4657420>

Kohlitz, J., Chong, J., & Willetts, J. (2020). Rural drinking water safety under climate change: The importance of addressing physical, social, and environmental dimensions. *Resources, 9(6), 1-18.*

Konrad, S., Hossain, A., Senthilselvan, A., Dosman, J.A., & Pahwa, P. (2013). Chronic bronchitis in Aboriginal people – prevalence and associated factors. *Chronic Diseases and Injuries in Canada, 33*(4), 218-25.

Kovats, R.S., & Hajat, S. (2007). Heat stress and public health: A critical review. *Annual Review of Public Health, 29,* 41-55.

Kovesi, T. (2012). Respiratory disease in Canadian First Nations and Inuit Children. *Paediatrics and Child Health*; *17*(7), 376-80

Kral, M.J., & Idlout, LO. (2009). Community wellness and social action in the Canadian Arctic: Collective agency as subjective wellbeing. In L.J. Kirmayer, & G.G. Vasaskakis (Eds.), *Healing traditions: The mental health of Aboriginal peoples in Canada* (pp. 315-34). Vancouver, BC: University of British Columbia Press.

Kulnieks, A., Longboat, D. R., & Young, K. (2016). Engaging eco-hermeneutical methods: Integrating Indigenous and environmental curricula through an eco-justice-arts-informed pedagogy. *AlterNative: An International Journal of Indigenous Peoples, 12*(1), 43-56.

Kumar, M.B., Furgal, C., Hutchinson, P., Roseborough, W., & Kootoo-Chiarello, S. (2019). *Aboriginal Peoples Survey: Harvesting activities among First Nations people living off reserve, Métis and Inuit: Time trends, barriers and associated factors*. Ottawa, ON: Statistics Canada, Catalogue no. 89-653-X2019001.

Kumar, M.B., & Tjepkema, M. (2019). *Suicide among First Nations people, Métis and Inuit (2011-2016): Findings from the 2011 Canadian Census Health and Environment Cohort (CanCHEC), National Household Survey*. Ottawa, ON: Statistics Canada. Retrieved July 17, 2020 from <https://www150.statcan.gc.ca/n1/pub/99-011-x/99-011-x2019001-eng.htm>

Kumar, M. B., Wesche, S., & McGuire, C. (2012). Trends in Métis-related health research (1980-2009): Identification of research gaps. *Canadian Journal of Public, 103*(1), 23-8.

Lam, S., Cunsolo, A., Sawatzky, A., Ford, J., & Harper, S. (2017). How does the media portray drinking water security in Indigenous communities in Canada? An analysis of Canadian newspaper coverage from 2000-2015. *BMC Public Health*, *17*, 282.

Lane, K., & Gagnon, G. (2020). Evaluating the use and intent of drinking water advisories in Atlantic Canada. *Water Policy, 22*(5), 908-924.

Latulippe, N., & N. Klenk. (2020). Making room and moving over: Knowledge co-production, Indigenous knowledge sovereignty and the politics of global environmental change. *Current Opinion in Environmental Sustainability*, *42,* 7-14.

Lavoie, E., Lèvesque, B., Proulx, J., Grant, J., Ndassebe, A.D., Gingras, S., Hubert, B., & Libman, M. (2007). Evaluation of the toxoplasmosis screening program among pregnant Nunavik (Canada) women between 1994-2003. *Epidemiology, 18*(5), S32-33.

Lemelin, H., Matthews, D., Mattina, C., McIntyre, N., Johnston, M., Koster, R., & Weenusk First Nation. (2010). Climate change, wellbeing and resilience in the Weenusk First Nation at Peawanuck: The Moccasin Telegraph goes global. *Rural and Remote Health, 10*(2), 1333.

Liu, J.C., Pereira, G., Uhl, S.A., Bravo, M.A., & Bell, M.L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildlife smoke. *Environmental Research, 136,* 120-32.

Longboat, S. (2013). Security for Mother Earth. *Canadian Woman Studies, 30*(2/3), 6-13.

Loring, P.A., & Gerlach, S.G. (2015). Searching for progress on food security in the North American North: A research synthesis and meta-analysis of the peer-reviewed literature. *Arctic, 68*(3), 380-92.

Lux, M. (2016). *Separate beds: A history of Indian hospitals in Canada, 1920s-1980s.* Toronto, ON: University of Toronto Press.

Maar, M.A., Erskine, B., McGregor, L., Larose, T.L., Sutherland, M.E., Graham, D., Shawande, M., & Gordon, T. (2009). Innovations on a shoestring: A study of collaborative community-based Aboriginal mental health service model in rural Canada. *International Journal of Mental Health Systems, 3,* 27.

MacDonell, H. (2015). *Examining community adaptation readiness to climate change in the Inuvialuit Settlement Region, Northwest Territories.* Unpublished Masters of Marine Management thesis, Dalhousie University, Halifax, Nova Scotia, Canada.

Makondo, C.C., & Thomas, D.S.G. (2018). Climate change adaptation: Linking Indigenous knowledge with western science for effective adaptation. *Environmental Science & Policy, 88*, 83-91.

Maldonado, J., Bull Bennett, T.M., Chief, K., Cochran, P., Cozzetto, K., & Gough, B. (2016). Engagement with Indigenous peoples and honoring traditional knowledge systems. *Climatic Change, 135*(1), 111-26.

Mallory, C.D., & Boyce, M. S. (2017). Observed and predicted effects of climate change on Arctic caribou and reindeer. *Environmental Reviews, 26*(1), 13-25. https://doi.org/10.1139/er-2017-0032

Manning, C., & Clayton, S. (2018). Threats to mental health and wellbeing associated with climate change. In S. Clayton & C. Manning (Eds.), *Psychology and Climate change: Human perceptions, impacts and responses* (pp. 217-44). Amsterdam: Academic Press.

Mantyka-Pringle, C.S., Jardine, T.D., Bradford, L., Bharadwaj, L., Kythreotis, A.P., Fresque-Baxter, J., Kelly, E., Somers, G., Doig, L.E., Jones, P.D., & Lindenschmidt, K.E. (2017). Bridging science and traditional knowledge to assess cumulative impacts on stressors in ecosystem health. *Environment International, 102,* 125-37.

Marmot, M. (2007). Achieving health equity: From root causes to fair outcomes. *Lancet,* 370, 1153-63.

Mary Robinson Foundation – Climate Justice. (2020). *Principles of climate justice.* Dublin, Ireland. Retrieved from <https://www.mrfcj.org/principles-of-climate-justice/>

Martens, P., Bartlett, J., Burland, E., Prior, H., Burchill, C., Huq, S., Romphf, L., Sanguins, J., Carter, S., & Bailly, A. (2010). *Profile of Metis health status and healthcare utilization in Manitoba: A population-based study.* Winnipeg, MB: Manitoba Centre for Health Policy in collaboration with the Manitoba Metis Federation, University of Manitoba.

Martens, T. (2015). *Understanding the value and promise of Indigenous food sovereignty in western Canada.* Unpublished Master's thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

McCallum, M.J., & Perry, A. (2018). *Structures of indifference: An Indigenous life and death in a Canadian city.* Winnipeg, MB: University of Manitoba Press.

McGrath-Hanna, N. K., Greene, D. M., Tavernier, R. J., & Bult-Ito, A. (2003). Diet and mental health in the Arctic: is diet an important risk factor for mental health in circumpolar peoples?--a review. *International journal of circumpolar health*, *62*(3), 228–241. <https://doi.org/10.3402/ijch.v62i3.17560>

McGregor, D. (2012). Traditional knowledge: Considerations for protecting water in Ontario, *International Indigenous Policy Journal, 3*(3), 1-21.

McGregor, D. (2014). Traditional knowledge and water governance: The ethic of responsibility. *AlterNative: An International Journal of Indigenous Peoples, 10*(5), 493-507.

McLeod-Shabogesic, P. (2013). Good food is good medicine. *Anishinabek News,* November 13, <http://anishinabeknews.ca/2013/11/13/good-food-is-good-medicine/>

McNeill, K., Binns, A., & Singh, A. (2017). *Flood history analysis and socioeconomic implications of flooding for Indigenous Canadian communities*. Winnipeg, MB: Paper presented at the CSBE/SCGAB 2017 Annual Conference, August 6-10, 2017. Retrieved from <http://www.csbe-scgab.ca/docs/meetings/2017/CSBE17137.pdf>

Mecredi, T. (2010). *Our changing homeland, our changing lives*. Vuntut Gwichin Government & Arctic Health Research Network - Yukon. Culture Unplugged Foundation. Retrieved from <http://www.cultureunplugged.com/documentary/watch-online/play/53398/Our-Changing-Homelands-Our-Changing-Lives>

Medeiros, A.S., Wood, P., Wesche, S.D., Bakaic, M., & Peters, J.F. (2016). Water security for northern peoples: Review of threats to Arctic freshwater systems in Nunavut, Canada. *Regional Environmental Change, 17,* 635-47.

Meloche, K. (2018). *Mourning landscapes and homelands: Indigenous and Non-Indigenous Peoples' ecological griefs*. Edmonton, AB: Canadian Mountain Network. Retrieved from <http://canadianmountainnetwork.ca/mourning-landscapes-and-homelands-indigenous-and-non-indigenous-peoples-ecological-griefs/>

Mental Health Commission of Canada. (2016). *Towards creating a mental health action plan for Canada: Roundtable report – 2015.* Ottawa, ON.

Messier, V., Lévesque, B., Proulx, J.F., Rochette, L., Libman, M.D., Ward, B.J., Serhir, B., Couillard, M., Ogden, N. H., Dewailly, E., Hubert, B., Déry, S., Barthe, C., Murphy, D., & Dixon, B. (2009). Seroprevalence of toxoplasma gondii among Nunavik Inuit (Canada). *Zoonoses Public Health, 56*(4), 188-97. DOI: 10.1111/j.1683-2378.2008.01177.x

Métis National Council. (2016). *Resolution on climate change and environment.* Vancouver, BC: Special sitting of the General Assembly, October 13-15. Retrieved from <https://www.metisnation.ca/wp-content/uploads/2016/10/FINAL-20161015-MNC-Special-GA-Resolution-on-Climate-Change-and-Environment-0915am.pdf>

Minister of Justice and Attorney General of Canada. (2018). *Principles respecting the government of Canada's relationship with Indigenous Peoples.* Ottawa, ON.

Natcher, D.C. (2013). Gender and resource co-management in northern Canada. *Arctic, 66*(2), 218-221.

National Aboriginal Health Organization (NAHO). (2011). *Principles of ethical Métis research.* Ottawa, ON.

National Collaborating Centre for Aboriginal Health (NCCAH). (2012). *The state of knowledge of Aboriginal health: A review of Aboriginal public health in Canada.* Prince George, BC: NCCAH.

National Collaborating Centre for Aboriginal Health (NCCAH). (2017). *Housing as a social determinant of First Nations, Inuit, and Métis health.* Prince George, BC. NCCAH.

National Collaborating Centre for Indigenous Health (NCCIH). (2019). *Access to health services as a social determinant of First Nations, Inuit, and Métis health*. Prince George, BC.

Nature United. (2020). *Indigenous Guardians toolkit*. Toronto, ON. Retrieved from <https://www.indigenousguardianstoolkit.ca/>

Neeganagwedgin, E. (2013). Ancestral knowledges, spirituality and Indigenous narratives as self-determination. *AlterNative: An International Journal of Indigenous Peoples*, *9*(4), 322-34.

Nelder, M.P., Wijayasri, S., Russell, C.B., Johnson, K.O., Marchand-Austin, A., Cronin, K., Johnson, S., Badiani, T., Patel, S. N., & Sider, D. (2018). The continued rise of Lyme disease in Ontario Canada: 2017. *Canada Communicable Disease Report, 44*(10), 231-6.

Nickels, S., Furgal, C., Castelden, J., Moss-Davies, P., Buell, M., Armstrong, B., Dillon, D., & Fonger, R. (2002). Putting the human face on climate change through community workshops: Inuit knowledge, partnerships, and research. In I. Krupnick, & D. Jolly (Eds.), *The Earth is faster now: Indigenous observations of Arctic environmental change* (pp. 300-33). Washington, DC: Arctic Research Consortium of the United States, Arctic Studies Centre, Smithsonian Institute.

Nilsson, L.M., Destouni, G., Berner, J., Dudarev, A.A., Mulvad, G., Odland, J.Ø., Parkinson, A., Tikhonov, C., Rautio, A., & Evengård, B. (2013). A call for urgent monitoring of food and water security based on relevant indicators for the Arctic. *Ambio, 42*(7), 816-22.

Nisga'a First Nation. (2012). Healthy foods and shelters in the alpine permafrost: Nisga'a women remember. *Climate Telling*. Retrieved from <https://vimeo.com/39303445>

Norris, M.J., & Clatworthy, S. (2011). Urbanization and migration patterns of Aboriginal populations in Canada: A half century in review (1951 to 2006). *Aboriginal Policy Studies, 1*(1), 13-77.

North Slave Métis Alliance community members, Shiga, S., Evans, P., King, D., & Keats, B. (2018). Continual change and gradual warming: A summary of the North Slave Métis Alliance's recorded cultural knowledge on climate and environmental change. In J.M. Galloway & R.T. Patterson (compilers), *Report prepared for Geological Survey of Canada Geoscience Tools for Environmental Assessment of Metal Mining* (pp. 99-116). Ottawa, ON: Geological Survey of Canada, Project Number #1519-149, Polar Knowledge: Aqhaliat 2018, Polar Knowledge Canada. Retrieved from <https://www.canada.ca/content/dam/polar-polaire/documents/pdf/aqhaliat/Aqhaliat-2018-13-NSMA-et-al.pdf>

Nunavut Department of Education. (2007). *Inuit Qaujimajatuqangit education framework*. Iqaluit, NU.

Office of the Auditor General of Canada. (2021). *Report 3 – Access to safe drinking water in First Nations ommunities - Indigenous Services Canada.* Parliament of Canada. <https://www.oag-bvg.gc.ca/internet/English/parl_oag_202102_03_e_43749.html>

Office of the High Commissioner for Human Rights. (2018). *The climate crisis is a human rights crisis*. Geneva, Switzerland: United Nations Office of the High Commissioner. Retrieved from <https://www.ohchr.org/Documents/Issues/ClimateChange/FactSheetClimateChange.pdf>

Omosule, A. (2017). *Exploring water insecurity in Canadian Indigenous communities.* Rural Policy Learning Commons. Retrieved from <http://rplc-capr.ca/wp-content/uploads/2015/04/ExploringWate-InsecurityInCanadianIndigenousCommunities_LiteratureReview_AyoOmosule.pdf>

Organ, J., Castleden, H., Furgal, C., Sheldon, T., & Hart, C. (2014). Contemporary programs in support of traditional ways: Inuit perspectives on community freezers as a mechanism to alleviate pressures of wild food access in Nain, Nunatsiavut. *Health & Place, 30*, 251-59.

Ospina, M.B., Voaklander, D., Senthilselvan, A., Stickland, M.K., King, M., Harris, A.W., & Rowe, B.H. (2015). Incidence and prevalence of chronic obstructive pulmonary disease among Aboriginal peoples in Alberta, Canada. *PLoS One, 10*(4), e0123204.

Parlee, B.L., & Caine, K.J. (Eds.). (2018). *When the caribou do not come: Indigenous knowledge and adaptive management in the western Arctic*. Vancouver, BC: University of British Columbia Press.

Parliamentary Information and Research Service. (2020). *Climate change: Its impact and policy implications.* Ottawa, ON: Economics, Resources and International Affairs Division, Legal and Social Affairs Division, Government of Canada, Publication No. 2019-460E.

Paterson, J., Berry, P., Ebi, K., & Varangu, L. (2014). Health care facilities resilient to climate change impacts. *International Journal of Environmental Research and Public Health, 11*(12), 13097-116.

Patrick, R.J. (2011). Uneven access to safe drinking water for First Nations in Canada: Connecting health and place through source water protection. *Health & Place, 17*(1), 386-89.

Pauktuutit Inuit Women of Canada (Pauktuutit). (2011). *Inuit women's perspectives on climate change*. Ottawa, ON.

Pearce, T., Ford, J.D., Caron, A., & Kudlak, B.P. (2012). Climate change adaptation planning in remote, resource-dependent communities: An Arctic example. *Regional Environmental Change, 12*(4), 825-37.

Penner, S., Kevany, K., & Longboat, S. (2019). *Indigenous food sovereignty in Canada: Policy paper 2019.* Rural Policy Learning Commons.

Pennesi, K., Arokium, J., & McBean, G. (2012). Integrating local and scientific weather knowledge as a strategy for adaptation to climate change in the Arctic. *Mitigation and Adaptation Strategies for Global Change, 17*(8), 897-922.

Petrasek MacDonald, J., Ford, J.D., Cunsolo Willox, A., & Ross, N.A. (2013a). A review of protective factors and causal mechanisms that enhance the mental health of Indigenous Circumpolar youth. *International Journal of Circumpolar Health, 72*, 21775. DOI: 10.3402/ijch.v72i0.21775.

Petrasek MacDonald, J., Harper, S.L., Cunsolo Willox, A., Edge, V.L., & Rigolet Inuit Community Government. (2013b). A necessary voice: Climate change and lived experiences of youth in Rigolet, Nunatsiavut, Canada. *Global Environmental Change, 23*(1), 360-71.

Powys Whyte, K. (2014). Indigenous women, climate change impacts, and collective action. *Hypatia: A Journal of Feminist Philosophy, 29*(3), 599-616.

Prior, T.L., & Heinämäki, L. (2017). The rights and role of Indigenous women in the climate change regime. *Arctic Review on Law and Politics, 8*, 193-221.

Public Health Agency of Canada (PHAC). (2018a). *Key health inequalities in Canada: A national portrait.* Ottawa, ON.

Public Health Agency of Canada (PHAC). (2018b). *Multidisciplinary roundtable discussion on Lyme Disease. WebEx meeting*. Wednesday, October 24, 2018, Information package for participants. Ottawa, ON. Retrieved from <https://www.lymehope.ca/uploads/8/4/2/8/84284900/follow-up_information_package-mulitdisciplinary_rountable_en.pdf>

Quinn, E. (2016a). Video documentary: How Indigenous knowledge is changing what we know about the Arctic. Eye on the Arctic, December 23. *Radio Canada, International.* <http://www.rcinet.ca/en/2016/12/23/video-documentary-how-indigenous-knowledge-is-changing-what-we-know-about-the-arctic/>

Quinn, E. (2016b). Is climate change making the muskoxen sick on Victoria Island? Eye on the Arctic, October 31. *Radio Canada, International.* Retrieved from <http://www.rcinet.ca/eye-on-the-arctic/2016/12/05/is-climate-change-making-the-muskoxen-sick-on-victoria-island/>

Ray, L., Burnett, K., Cameron, A., Joseph, S., LeBlanc, J., Parker, B., Recollet, A., & Sergerie, C. (2019). Examining Indigenous food sovereignty as a conceptual framework for health in two urban communities in northern Ontario, Canada. *IUHPE – Global Health Promotion, 26*(Suppl 3), 54-63.

Reading, C. (2018). Structural determinants of Aboriginal Peoples' health. In M. Greenwood, S. de Leeuw, & N.M. Lindsay (Eds.), *Determinants of Indigenous Peoples' health, Second Edition* (Chapter 1). Toronto, ON: Canadian Scholar's Press.

Reading, C., & Wien, F. (2009). *Health inequalities and social determinants of Aboriginal peoples' health.* Prince George, BC: National Collaborating Centre for Aboriginal Health.

Reading, J. (2015). Confronting the growing crisis of cardiovascular disease and heart health among Aboriginal peoples in Canada. *Canadian Journal of Cardiology, 31*(9), 1077-80.

Receveur, O., & Kuhnlein, H. (1998). Benefits of traditional food in Dene/Métis communities. *International Journal of Circumpolar Health, 57*(Suppl), 219-21.

Reed, G. (2019). *Connecting the local communities and Indigenous Peoples platform to domestic climate challenges in Canada*. Waterloo, ON: Centre for International Governance Innovation.

Reid, C.E., Brauer, M., Johnston, F.H., Jerrett, M., Balmes, J.R., & Elliott, C.T. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives, 124,* 1334-43.

Reid, M.G., Hamilton, C., Reid, S.K., Trousdale, W., Hill, C., Turner, N., Picard, C.R., Lamontagne, C., & Matthews, H.D. (2014). Indigenous climate change adaptation planning using a values-focused approach: A case study with the Gitga'at Nation. *Journal of Ethnobiology, 34*3), 401-24.

Reiling, S.J., & Dixon, B.R. (2019). Toxoplasma gondii: How an Amazonian parasite became an Inuit health issue. *Canada Communicable Disease Report, 45*(7/8), 183-90.

Reo, N.J., Whyte, K.P., McGregor, D., Smith, M.A., & Jenkins, J.F. (2017). Factors that support Indigenous involvement in multi-actor environmental stewardship. *AlterNative, 13*(2), 58-68.

Research Northwest & Hershfield, M. (2017). *Yukon 'state of play': Analysis of climate change impacts and adaptation.* Whitehorse, YK: Environment Yukon Climate Change Secretariat, <https://yukon.ca/sites/yukon.ca/files/env/env-yukon-state-play-analysis-climate-change-impacts-adaptation.pdf>

Richards, G., Frehs, J., Myers, E., & Van Bibber, M. (2019). Commentary - the Climate Change and Health Adaptation Program: Indigenous climate leaders' championing adaptation efforts. *Health Promotion and Chronic Disease Prevention in Canada, 39*(4), 127-130.

Riedlinger, D., & Berkes, F. (2001). Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar Record, 37*, 315-28.

Robin, T. (2019). Our hands at work: Indigenous food sovereignty in Western Canada. *Journal of Agriculture, Food Systems, and Community Development, 9*(Suppl. 2), 85-99.

Rondeau, K.V. (2012). *Critical resource requirements for the delivery of primary health care services in rural, remote and isolated First Nations communities: A discussion paper.* Edmonton, AB: Prepared for First Nations Inuit Health Branch – Alberta.

Rosol, R., Powell-Hellyer, S., & Chan, H. M. (2016). Impacts of decline harvest of country food on nutrient intake among Inuit in Arctic Canada: Impact of climate change and possible adaptation plan. *International Journal of Circumpolar Health, 75*(1), 31127.

Royal Commission on Aboriginal Peoples (RCAP). (1996). *Ethical guidelines for research*. Ottawa, ON.

Royal Canadian Geographical Society, the. (2018). *Canadian geographic Indigenous Peoples of Canada atlas – Inuit.* Ottawa, ON: The Royal Canadian Geographic Society.

Royer, M.J.S., Hermann, T.M., Sonnentag, O., Fortier, D., Delusca, K., & Cuciurean, R. (2013). Linking Cree hunters' and scientific observations of changing inland ice and meteorological conditions in the subarctic eastern James Bay region, Canada. *Climatic Change, 119*(3-4), 719-32.

Sabine Center for Climate Change Law, in collaboration with Arnold & Porter Kay Scholer LLP. (2005). *Petition to the Inter-American Commission on Human Rights seeking relief from violations resulting from global warming caused by acts and omissions of the United States.* New York, NY: Columbia University Law. Retrieved from <http://climatecasechart.com/non-us-case/petition-to-the-inter-american-commission-on-human-rights-seeking-relief-from-violations-resulting-from-global-warming-caused-by-acts-and-omissions-of-the-united-states/?cn-reloaded=1>

Saini, M. (2012). *A systematic review of western and Aboriginal research designs: Assessing cross-validation to explore compatibility and convergence.* Prince George, BC: National Collaborating Centre for Aboriginal Health.

Sanderson, D., Picketts, I.M., Déry, S.J., Fell, B., Baker, S., Lee-Johnson, E., & Auger, M. (2015). Climate change and water at Stellat-en First Nation, British Columbia, Canada: Insights from western science and traditional knowledge. *The Canadian Geographer, 59*(2), 136-50.

Sandoval, C.D.M., Lagunas, R.M., Montelongo, L.T., & Díaz, M.J. (2016). Ancestral knowledge systems - A conceptual framework for decolonizing research in social science. *AlterNative: An International Journal of Indigenous Peoples, 12*(1), 18-31.

Santisteban, R.S. (Ed.). (2020). *Indigenous women & climate change.* Copenhagen: International Work Group for Indigenous Affairs. Retrieved from <https://www.iwgia.org/images/publications/new-publications/Indigenous_Women_and_Climate_Change_IWGIA.pdf>

Sarkar, A., Hanrahan, M., & Hudson, A. (2015). Water insecurity in Canadian Indigenous communities: Some inconvenient truths. *Rural and Remote Health, 15*, 3354.

Sawatzky, A., Cunsolo, A., Jones-Bitton, A., Gillis, D., Wood, M., Flowers, C., Shiwak, I., & Harper, S. L. (2020). "The best scientists are the people that's out there": Inuit-led integrated environment and health monitoring to respond to climate change in the Circumpolar North. *Climatic Change, 160*, 45-66. <https://doi.org/10.1007/s10584-019-02647-8>

Sawatzky, A., Cunsolo, A., Jones-Bitton, A., Middleton, J., & Harper, S.L. (2018). Responding to climate and environmental change impacts on human health via integrated surveillance in the Circumpolar North: A systematic realistic review. *International Journal of Environmental Research and Public Health, 15*(12), 2706. DOI: 10.3390/ijerph15122706.

Scharbach, J., & Waldram, J.B. (2016). Asking for a disaster: Being 'at risk' in the emergency evacuation of a northern Canadian Aboriginal community. *Human Organization, 75*(1), 59-70.

Schuttenberg, H.Z., & Guth, H.K. (2015). Seeking our shared wisdom: A framework for understanding knowledge co-production and coproductive capacities. *Ecology and Society, 20*(1), 15. <http://dx.doi.org/10.5751/ES-07038-200115>

Selkirk First Nation, Yukon Territory, in collaboration with the Arctic Institute of Community-Based Research. (2016). *Adapting to climate change and keeping our traditions.* Selkirk First Nation. Retrieved from <https://static1.squarespace.com/static/56afc7218259b53bd8383cb8/t/57ab923e59cc68307527742f/1470861914849/Selkirk+Climate+Change+Adaptation+Plan_CommunityReport_final%5B2%5D.compressed.pdf>

Selkirk First Nation, & Arctic Institute of Community-Based Research. (2019). *Keeping our traditions for the health and wellbeing of future Selkirk First Nation generations: "What do we do at the fish camp when there are no fish?"*. Whitehorse, YK. Retrieved from <https://www.aicbr.ca/selkirk-project>

Sellers, S. (2018). *Climate change and gender in Canada: A review.* New York, NY: Women's Environment and Development Organization. Retrieved from <https://wedo.org/wp-content/uploads/2018/04/GGCA-CA-RP-07.pdf>

Sheedy, A. (2018). *The impacts of climate change on traditional and local food consumption in the Yukon.* Whitehorse, YK: Arctic Institute of Community-based Research for Northern Health and Well-Being.

Shkagamik-Kwe Health Centre. (2015). *2015 calendar*. Sudbury, ON. Retrieved from <https://www.skhc.ca/books/AnnualCalendars/2015/SKHC_Calendar_2015_LOW.pdf>

Sinclair, R. (2007). Identity lost and found: Lessons from the Sixties Scoop. *First Peoples Child & Family Review, 3*(1), 65-82.

Smylie, J. (2010). *Achieving strength through numbers: First Nations, Inuit, and Métis health information.* Prince George, BC: National Collaborating Centre for Aboriginal Health.

Smylie, J., & Firestone, M. (2015). Back to the basics: Identifying and addressing underlying challenges in achieving high quality and relevant health statistics for Indigenous populations in Canada. *Statistical Journal of the International Association for Official Statistics, 31*(1), 67-87.

Snyder, M., & Wilson, K. (2015). "Too much moving … there's always a reason": Understanding urban Aboriginal peoples' experiences of mobility and its impact on holistic health. *Health & Place, 34*, 181-9.

Spring, A., Carter, B., & Blay-Palmer, A. (2018). Climate change, community capitals, and food security: Building a more sustainable food system in a northern Canadian boreal community. *Canadian Food Studies, 5*(2), 111-41.

Standing Committee on Indigenous and Northern Affairs. (2017). *Breaking point: The suicide crisis in Indigenous communities.* Ottawa, ON: House of Commons.

Standing Committee on Indigenous and Northern Affairs (2018). *From the ashes: Reimagining fire safety and emergency management in Indigenous communities.* Ottawa, ON: House of Commons.

Staples, K., & Natcher, D.C. (2015a). Gender, decision-making, and natural resource co-management in Yukon. *Arctic, 68*(3), 356-66.

Staples, K., & Natcher, D.C. (2015b). Gender, critical mass, and natural resource co-management in the Yukon. *Northern Review, 41.* 139.

Statham, S., Ford, J.D., Berrang-Ford, L., Lardeau, M.-P., Gough, W., & Siewierskia, R. (2015). Anomalous climatic conditions during winter 2010–2011 and vulnerability of the traditional Inuit food system in Iqaluit, Nunavut. *Polar Record, 51*(3), 301-17.

Statistics Canada. (2016). *Infographic - The Aboriginal population in Canada, 2016 Census of population*. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2017027-eng.htm>

Statistics Canada. (2017). *Aboriginal peoples in Canada: Key results from the 2016 Census*. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/daily-quotidien/171025/dq171025a-info-eng.htm>

Stoler, J., Jepson, W.E., & Wutich, A. (2020). Beyond handwashing: Water insecurity undermines COVID-19 response in developing areas. *Journal of Global Health, 10*(1), 1-4.

Sudlovenick, E. (2019). *A serological survey and Inuit Qaujimajatuqangit of ringed seals (nattit) in Frobisher Bay, Nunavut.* Unpublished Masters of Science thesis, University of Prince Edward Island, Charlottetown, PEI, Canada.

Szach, N.J. (2013). *Keepers of the water: Exploring Anishinaabe and Métis women's knowledge of water and participation in water governance in Kenora, Ontario.* Unpublished Masters of Natural Resources Management thesis, University of Manitoba, Winnipeg, Manitoba, Canada.

Tagalik, S. (2010). *Inuit Qaujimajatuqangit: The role of Indigenous Knowledge in supporting wellness in Inuit communities in Nunavut*. Prince George, BC: NCCAH.

Tam, B. (2013). *The effects of weather and climate variability on the well-being of a rural and urban Aboriginal group in Ontario, Canada.* Unpublished PhD dissertation, University of Toronto, Toronto, Ontario, Canada.

Tarasuk, V., Mitchell, A., & Dachner, N. (2014). *Household food insecurity in Canada.* Toronto, ON: PROOF: Research to identify policy options to reduce food insecurity.

Task Force on Aboriginal Languages and Cultures. (2005). *Towards a new beginning: A foundational report for a strategy to revitalize First Nation, Inuit, and Métis languages and cultures*. Ottawa, ON: Minister of Canadian Heritage.

Tengö, M., Brondizio, E.S., Elmqvist, T., Malmer, P., & Spierenburg, M. (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. *Ambio, 43*(5), 579-91.

Teslin Tlingit Council. (2012). Teslin's voice [documentary]. *Climate Telling*. Retrieved from <https://vimeo.com/39303443>

Thivierge, K., Iqbal, A., Dixon, B., Dion, R., Levesque, B., Cantin, P., Cédilotte, L., Ndao, M., Proulx, J. F., & Yansouni, C. P. (2016). Cryptosporidium hominis is a newly recognized pathogen in the Arctic Region of Nunavik, Canada: Molecular characterization of an outbreak. *PLoS Neglected Tropical Diseases, 10*(4), e0004534.

Thompson, S., Ballard, M., & Martin, D. (2014). Lake St. Martin First Nation community members' experiences of induced displacement: "We're like refugees". *Refuge, 29*(2), 75-86.

Thompson, S., Gulrukh, A., Ballard, M., Beardy, B., Islam, D., Lozeznik, V., & Wong, K. (2011). Is community economic development putting healthy food on the table? Food sovereignty in northern Manitoba's Aboriginal communities. *Journal of Aboriginal Economic Development, 7*(2), 14-39.

Thompson, S., Kamal, A., Alam, M.A., & Wiebe, J. (2012). Community development to feed the family in northern Manitoba communities: Evaluating food activities based on their food sovereignty, food security, and sustainable livelihood outcomes. *Canadian Journal of Nonprofit and Social Economy Research, 3*(2), 43-66.

Tobias, J.K., & Richmond, C.A.M. (2014). "That land means everything to us as Anishinaabe….": Environmental dispossession and resilience on the North Shore of Lake Superior. *Health & Place, 29*, 26-33.

Tomaselli, M., Kutz, S., Gerlach, C., & Checkley, S. (2017). Local knowledge to enhance wildlife population health surveillance: Conserving muskoxen and caribou in the Canadian Arctic. *Biological Conservation, 217*, 337-48.

Trudeau, J., Prime Minister of Canada. (2016). *Process document for ongoing engagement on the Pan-Canadian Framework on Clean Growth and Climate Change.* Ottawa, ON: Prime Minister's Office.

Truth and Reconciliation Commission of Canada (TRC). (2015). *Honouring the truth, reconciling for the future: Summary of the final report of the Truth and Reconciliation Commission of Canada*. Ottawa, ON: Government of Canada.

Turner, N., & Spalding, P.R. (2013). "We might go back to this": Drawing on the past to meet the future in Northwestern North American Indigenous communities. *Ecology and Society, 18*(4), 29.

Ulturgasheva, O., Rasmus, S., Wexler, L., Nystad, K., & Kral, M. (2014). Arctic Indigenous youth resilience and vulnerability: Comparative analysis of adolescent experiences across five circumpolar communities. *Transcultural Psychiatry, 51*(5), 735-56.

United Nations. (2007). *United Nations Declaration on the Rights of Indigenous Peoples* (UNDRIP). New York, NY. Retrieved from <https://www.un.org/development/desa/indigenouspeoples/wp-content/uploads/sites/19/2018/11/UNDRIP_E_web.pdf>

United Nations Human Rights Council (UNHRC). (2016). *Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment.* New York, NY: United Nations General Assembly, Thirty-first session A/HRC/31/52.

Uprety, Y., Asselin, H., Bergeron, Y., Doyon, F., & Boucher, J.-F. (2012). Contribution of traditional knowledge to ecological restoration: Practices and applications. *Ecoscience, 19*(3), 225-37.

Vinyeta, K. Whyte, K.P., & Lynn, K. (2015). *Climate change through an intersectional lens: Gendered vulnerability and resilience in Indigenous communities in the United States*. Portland, OR: United States Department of Agriculture Pacific Northwest Research Station.

Vinyeta, K., Whyte, K. P., & Lynn, K. (2016). Indigenous masculinities in a changing climate: Vulnerability and resilience in the United States. In E. Enarson, & B. Pease (Eds.), *Men, masculinities and disaster* (Chapter 12). Routledge. Retrieved from <https://www.researchgate.net/profile/Kyle_Whyte/publication/304386709_Indigenous_masculinities_in_a_changing_climate_vulnerability_and_resilience_in_the_United_States/links/576dec5608ae0b3a3b75573b/Indigenous-masculinities-in-a-changing-climate-vulnerability-and-resilience-in-the-United-States.pdf>

Vizina, Y. (2010). *Métis traditional environmental knowledge and science education*. Unpublished Master of Education theses, Department of Educational Foundations, University of Saskatchewan, Saskatoon, SK.

Watson, V. (2017). *Perceptions of water among the Inuit community in Iqaluit, Nunavut: An anti-colonialist, feminist political ecology*. Unpublished Master of Arts thesis, York University, Toronto, ON.

Waugh, D., Pearce, T., Ostertag, S.K., Pokiak, V., Collings, P., & Loseto, L.L. (2018). Inuvialuit traditional ecological knowledge of beluga whale (Delphinapterus leucas) under changing climatic conditions in Tuktoyaktuk, NT. *Arctic Science, 4*, 242-58.

Wexler, L. (2013). Looking across three generations of Alaska Natives to explore how culture fosters Indigenous resilience. *Transcultural Psychiatry, 51*(1), 73-92.

White, J.P., Murphy, L., & Spence, N. (2012). Water and Indigenous peoples: Canada's paradox. *The International Indigenous Policy Journal, 33*, Article 3.

Wilder, B.T., O'Meara, C., Monti, L., & Nabhan, G.P. (2016). The importance of Indigenous Knowledge in curbing the loss of language and biodiversity. *BioScience*, *66*(6), 499-509.

Williams, L., Fletcher, A., Hanson, C., Neapole, J., & Pollack, M. (2018). *Women and climate change impacts and action in Canada: Feminist, Indigenous, and intersectional perspectives.* Ottawa, ON: Canadian Research Institute for the Advancement of Women.

Wilson, K., & Young, K. (2008). An overview of Aboriginal health research in the social sciences: Current trends and future directions. *International Journal of Circumpolar Health, 67*(2-3), 179-89.

Wilson, N.J., Inkster, J., Mutter, E., Jochum, K., & McGrath, K. (2015). *Water action planning workshop report.* Whitehorse, YK: Yukon River Inter-Tribal Watershed Council. Retrieved from <https://riskcultureandenvironment.files.wordpress.com/2014/08/final_waterreport_2014-2015.pdf>

Windchief, S., & Ryan, K. E. (2018). The sharing of indigenous knowledge through academic means by implementing self-reflection and story. *AlterNative: An International Journal of Indigenous Peoples*, *15*(1), 82-89. DOI: 10.1177/1177180118818188.

World Health Organization. (2014). *Gender, climate change and health*. Geneva, Switzerland.

World Health Organization. (2018). *COP24 Special report: Health & climate change*. Geneva, Switzerland.

Wright, C.J., Sargeant, J.M., Edge, V.L., Ford, J.D., Farahbakhsh, K., RICG, Shiwak, I., Flowers, C., IHACC Research Team, & Harper, S. L. (2018a). Water quality and health in northern Canada: Stored drinking water and acute gastrointestinal illnesses in Labrador Inuit. *Environmental Science and Pollution Research, 25*(33), 32975-87.

Wright, C.J., Sargeant, J.M., Edge, V.L., Ford, J.D., Farahbakhsh, K., Shiwak, I., Flowers, C., Gordon, A. C., RICG, IHACC Research Team, & Harper, S. L. (2018b). How are perceptions associated with water consumption in Canadian Inuit? A cross-sectional survey in Rigolet, Labrador. *Science of the Total Environment, 618,* 369-78.

Wudel, B., & Shadabi, E. (2016). *A short review of literature on the effects of climate change on mosquito-borne illnesses in Canada.* Winnipeg, MB: National Collaborating Centre for Infectious Diseases.

Yansouni, C.P., Pernica, J.M., & Goldfarb, D. (2016). Enteric parasites in Arctic communities: Tip of the iceberg? *Trends in Parasitology, 32*(11), 834-38.

Yeednoo Diinehdoo Ji'heezrit Nits'oo Ts'o' Nan He'aa Declaration. (n.d.). Retrieved from <http://www.vgfn.ca/pdf/CC%202019%20Declaration.pdf>

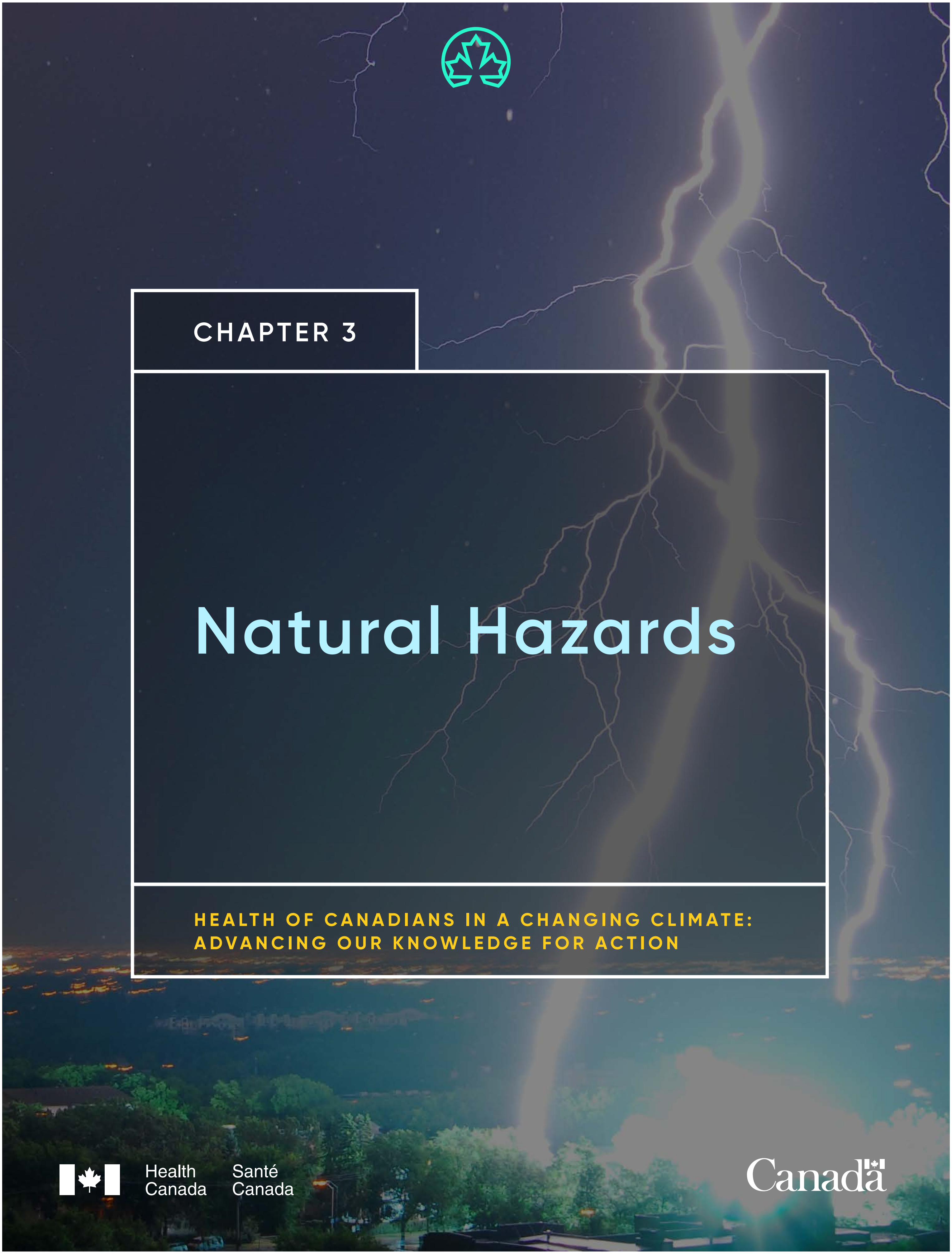
York, J., Dowsley, M., Cornwell, A., Kuc, M., & Taylor, M. (2016). Demographic and traditional knowledge perspectives on the current status of Canadian polar bear subpopulations. *Ecology and Evolution, 6*(9), 2897-2924.

Young, T.K. (2003). Review of research on Aboriginal populations in Canada: Relevance to their health needs. *British Medical Journal, 327*, 419-22.

Yukon River Inter-Tribal Watershed Council. (2017). Water Quality - Yukon River Inter-Tribal Watershed, Yukon project. *ClimateTelling*. Retrieved from <http://www.climatetelling.info/yukon-river.html>

Yusa, A., Berry, P., Cheng, J.J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health, 12*(7), 8359-8412.

Zavalete-Cortijo, C., Ford, J., Arotoma-Rojas, I., Lwasa, S., Lancha-Rucoba, G., Garcia, P., Miranda, J., Namanya, D. B., New, M., Wright, C. J., Berrang-Ford, L., Indigenous Health Adaptation to Climate Change Research Team, & Harper, S. L. (2020). Climate change and COVID-19: Reinforcing Indigenous food systems. *The Lancet Planetary Health, 4(9): E381-E382.* <https://doi.org/10.1177/1177180118818188>



CHAPTER 3

Natural Hazards

HEALTH OF CANADIANS IN A CHANGING CLIMATE:
ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Authors

Pierre Gosselin, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Céline Campagna, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Contributing Authors

David Demers-Bouffard, Institut national de santé publique du Québec

Sami Qutob, Health Canada

Mike Flannigan, University of Alberta

Suggested Citation

Gosselin, P., Campagna, C., Demers-Bouffard, D., Qutob, S., & Flannigan, M. (2022). Natural Hazards. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

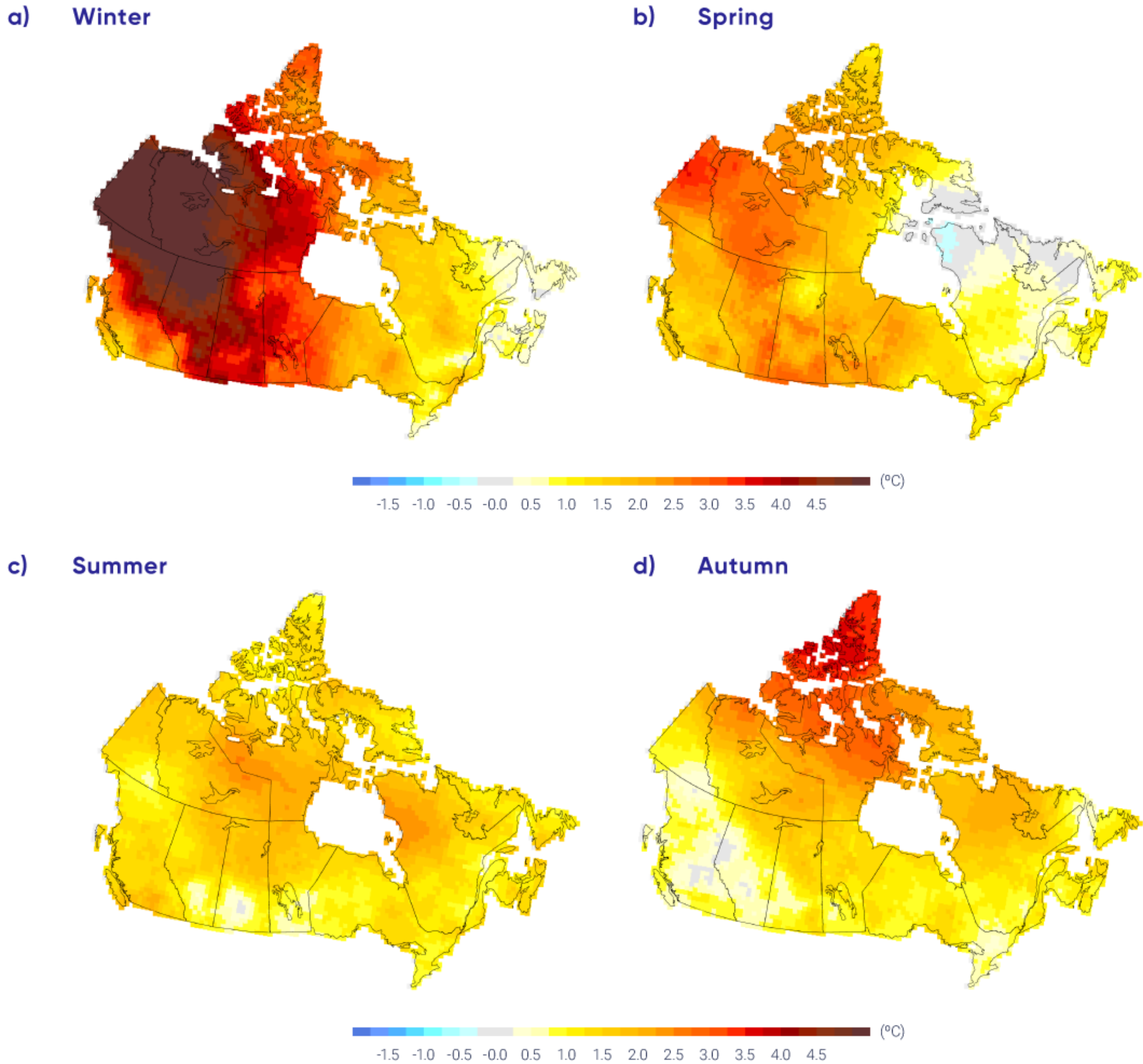
Summary

Heatwaves, major floods, wildfires, coastal erosion, and droughts are examples of natural hazards whose frequency and intensity are influenced by climate change. These hazards can cause loss of life, injury and various health problems, damage to property, social and economic disruption, or environmental degradation. The impacts of natural hazards on human health are of particular concern. From heat stroke to cardiovascular and respiratory diseases, including psychological and social impacts, the health impacts of natural hazards can be serious and depend on complex processes involving individual, social, economic, and environmental factors. Canada has seen many examples of severe impacts from these hazards on the health and safety of the population in the last few years (e.g., heatwave and drought in British Columbia, Fort McMurray fires in Alberta, heatwaves and floods of 2018 in Ontario and Quebec, storms in the Maritime provinces). As climate change accelerates, these impacts on populations will increase unless effective adaptation measures are implemented to reduce them and to protect populations most at risk of being affected. Examples of these adaptation measures specific to each hazard already exist, and should be vigorously implemented by civil society, municipalities, health authorities, provinces, and the federal government.

Key Messages

- Many extreme weather events, and their health impacts on Canadians, are expected to increase in the coming decades, driven by the widespread warming. For example, extreme heat will become more frequent and more intense. This will increase the severity of heatwaves, and contribute to increased drought and wildfire risks. For most of Canada, precipitation is projected to increase, on average, although summer rainfall may decrease in some areas. Urban flood risks will increase due to more intense rainfalls.
- Deaths in Canada are projected to increase significantly by the end of the century due to the effects of rising temperatures (and extreme heat) if greenhouse gas (GHG) emissions continue to rise at the same rate seen over the past 30 years. Added to this are potential health effects of the changing pattern of some extreme weather events (e. g., wildfires, droughts, heatwaves, extreme precipitation) such as an increase in accidental injuries, anxiety and depression, water-borne diseases, cardiovascular problems, and respiratory illnesses. Workers directly exposed to those extreme events are already experiencing an increased burden of illness and injuries.
- Coastal regions face a multitude of increased risks to communities. Coastal flooding is expected to increase in many areas of Canada due to local sea level rise. The loss of sea ice in the Arctic, Eastern Quebec, and Atlantic Canada further increases the risk of damage to coastal infrastructure and ecosystems as a result of larger storm surges and waves.

- Some populations in urban and rural areas have limited access to the financial, social, health, and human resources needed to adapt to natural hazards influenced by climate change. Many First Nations, Inuit, and Métis communities experience a greater existing burden of health inequities and related determinants of poor health. This, combined with their close reliance on the environment for their sustenance, livelihoods, and cultural practices means they are uniquely sensitive to the impacts of climate change, including from natural hazards.
- Seniors are particularly at risk of suffering from the health impacts of climate change related events, such as heatwaves, cold snaps, drought, wildfire smoke, and floods. Age and chronic diseases are the main factors of vulnerability, and the fact that our society is aging rapidly will increase this risk in the next few decades. Seniors' vulnerability can be compounded by loss of community cohesion, socio-economic inequality and unhealthy behaviours.
- Provinces, municipalities, civil society, health authorities, and the federal government all have a key role to play in adapting to climate change. Despite progress on many efforts, adaptation measures are still lacking, especially for droughts, storms, and heavy precipitation. Moreover, populations at increased risk, and the preventable conditions that increase those risks, are often neglected by stakeholders when implementing adaptation measures.
- Many solutions that can reduce human exposure and vulnerability to natural hazards influenced by climate change are already known and should be better promoted. Those solutions include greening living environments, identifying at-risk areas, using early warning systems, improving access to resources, practising integrated land-use planning, updating infrastructure, and raising public awareness.
- The pace, nature, and extent of adaptation measures must increase rapidly and substantially to reduce the current and future health impacts in Canada, including climate-related evacuations and forced displacement.



Observed changes (°C) in seasonal mean temperatures from 1948 to 2016 for four seasons. Source: Zhang et al., 2019.

Overview of Climate Change Impacts of Natural Hazards on Health

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Temperature extremes and gradual warming	• More frequent, more severe and longer heatwaves • Increased urban heat island effect • Combined climate-related hazards (e.g., heat, wildfires, drought, flooding) • Decrease in cold extremes and averages • Long-term warming and heatwaves	• Increase in direct heat-related illnesses (e.g., heat edema, heat rash, heat exhaustion, heat stroke) and deaths, especially for workers • Increase in respiratory disorders • Increase in cardiovascular disorders, especially for seniors and people with chronic diseases • Perinatal care complications (such as miscarriage, premature birth, congenital complications) • Increase emergency visits for mental health problems • Psychosocial impacts • Possible changed patterns of illness and death due to gradually warming temperatures (e.g., due to increased outdoor activity levels) • Impacts on health infrastructure • Impacts on health and social services • Potential decrease in cold-related morbidity and mortality • Increased risk of zoonotic infectious diseases directly transmitted from animals and arthropod vectors; and acquired by inhalation from environmental sources

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Extreme weather events and natural hazards	• More frequent, longer, and more violent thunderstorms, more severe hurricanes and other types of severe weather • Increased extreme precipitations and related flooding events, except for spring flooding events which will decrease • Landslides and avalanches • Increased coastal flooding, coastal erosion, and storm surge episodes • Increased drought especially in the Prairies, Quebec, and Interior British Columbia • Increased damage to the natural and built environments • Increased frequency, severity, and area burned of wildfires • Combined or cascading climate-related hazards (such as heat, wildfires, drought, flooding)	• Deaths, injuries and illnesses from violent storms, floods, and other hazards • Increase mortality and respiratory illnesses related to wildfire smoke • Psychological health effects, including mental health effects and stress-related illnesses due to extreme events (such as flood, wildfire, drought) • Physical and mental health impacts of food insecurity and/or water shortages • Illnesses related to drinking and recreational water contamination (mostly infectious) • Deaths, illnesses, and injuries due to evacuation or displacement of populations, and related pressures on civil protection, emergency shelters, and health infrastructure • Indirect health impacts from ecological changes, infrastructure damage and interruptions in health services from extreme events

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Extreme weather events and natural hazards (continued)		• Exacerbation of chronic and infectious diseases and injuries due to infrastructure damage (such as to housing, water, sanitation, health facilities) • Poorer health outcomes due to restrictions on travel for health and emergency services, delayed supply of essential pharmaceuticals and medical supplies, and compromised patient safety • Epidemics of mosquito-borne diseases

3.1 Introduction

Climate change is projected to increase the frequency, intensity, and overall consequences of many extreme weather conditions in Canada, even under a low emissions scenario (Bush & Lemmen, 2019). In this chapter, these conditions are referred to as natural hazards, although they are not entirely natural since they are influenced by several human factors, including greenhouse gas (GHG) emissions. A natural hazard is a phenomenon — often an extreme meteorological or hydrometeorological condition (e.g., heavy precipitation or extreme temperatures) — that is likely to cause loss of life, injury, property damage, social and economic disruption, or environmental degradation (Morin, 2008). Thus, natural hazards involve impacts on humans or on infrastructure communities rely on.

The impacts of natural hazards on human health are of particular concern. From heat strokes to cardiovascular and respiratory diseases, and psychological and social impacts, the health impacts of natural hazards are numerous and depend on complex processes involving individual, social, economic, and environmental factors. With growing recognition of these impacts, a significant number of research studies on such impacts have been carried out in Canada and abroad.

This chapter describes the state of knowledge on past and projected climate change on natural hazards, the links between those hazards and population health in Canada or similar countries (by demography, gross domestic product [GDP], climate), and key health vulnerabilities or risks. It also examines possible adaptation measures to these hazards to reduce their impact on the health of the population, based on published scientific studies. This chapter is therefore neither a descriptive nor exhaustive picture of the impacts experienced by communities in Canada, of the programs available to adapt, or of the measures put in place by decision makers. Only natural hazards influenced by climate change have been considered in this analysis.

3.2 Methods and Approach

A review of scientific literature, published between 2008 and 2019, was conducted on knowledge related to natural hazards, health, and adaptation in developed countries with a temperate or polar climate, such as in Canada. To be included, a study had to demonstrate the relationships between health and a natural hazard influenced by climate change, for example, address vulnerability to a natural hazard or the effect of adaptation measures on these hazards and their potential to directly or indirectly minimize impacts on health.

The information in this chapter provides an update to previous Health Canada assessments from 2008 and 2014. Information on Canada's changing climate and its changes in average conditions as well as changes in extremes (referred here as natural hazards) were obtained from the relevant chapters of *Canada's Changing Climate Report* published by the Government of Canada (Bush & Lemmen, 2019). Other relevant studies were identified after the literature search phase and were included in the literature review. Grey literature was used to supplement existing scientific literature or to highlight relevant case studies. Studies conducted in Canada have been given priority, and studies from other similar countries (e.g., the Organisation for Economic Co-operation and Development [OECD]) were used when information specific to the Canadian context was lacking. Some were used for comparison with the Canadian context. Uncertainty in current data (e.g., unknown or little-known data) is taken into consideration by highlighting gaps in the scientific literature, limitations of some studies, or conflicting results. Research gaps and uncertainty in scientific evidence were also highlighted.

3.3 General Trends in the Intensity and Frequency of Natural Hazards Influenced by Climate Change, and Links to Health

As concluded in *Canada's Changing Climate Report* (Bush & Lemmen, 2019), warming of the Earth during the Industrial Era is unequivocal, and it is extremely likely that human activities, especially emissions of greenhouse gases (GHGs), have been the main cause of this warming since the middle of the 20th century. This global-scale warming has also been accompanied by increases in extreme heat and decreases in cold extremes, increases in atmospheric water vapour, warming of the ocean, and decreases in snow and ice cover. Global mean sea level has risen due to the expansion of ocean water caused by warming and by the addition of meltwater previously stored in glaciers and ice sheets on land. These global changes driven by warming of the climate system affect Canada (Figure 3.1).

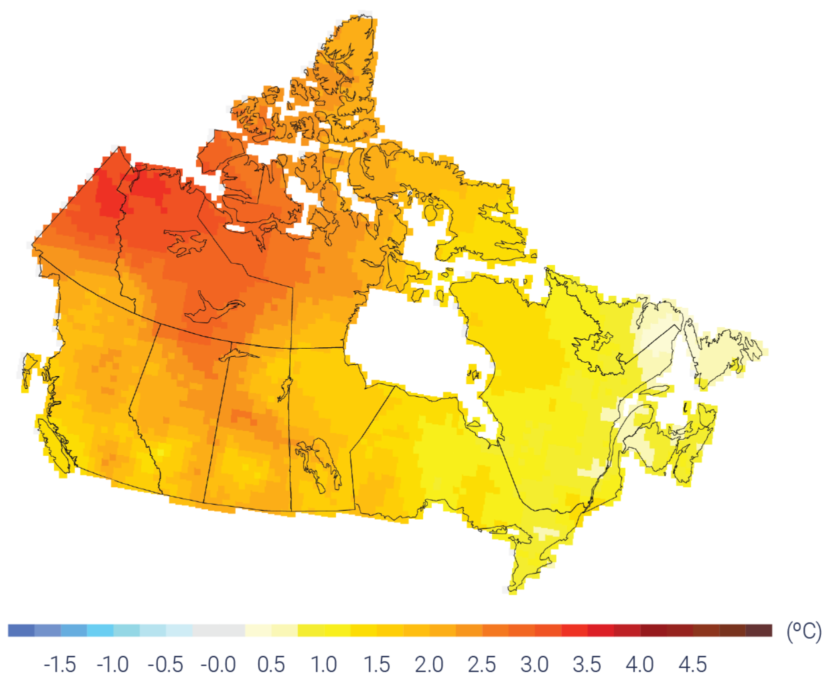


Figure 3.1 Observed changes (°C) in annual temperature across Canada between 1948 and 2016, based on linear trends. Source: Zhang et al., 2019.

This widespread warming drives changes to, including increases in, many natural hazards: extreme heat, extreme precipitation and storms, drought, wildfires, flood risk, landslides, avalanches, and permafrost melt. These changes alter many ecosystems that then affect different populations. The climate and climatic events are determinants of health in many ways. They can affect the health of individuals directly (for example, through extreme heat or cold) or indirectly (by altering ecosystems which, in turn, lead to the emergence of new diseases), or by influencing other determinants including social determinants of health (e.g., loss of income during an extreme event) (Bélanger et al., 2019).

However, individuals and social groups do not have the same ability to adapt to climate change (Bélanger et al., 2019) and some populations are at greater risk of the direct, indirect or social effects. This risk is a concept built around three variables: the occurrence of a natural hazard, the actual exposure of populations, and pre-existing vulnerability, which includes sensitivity to impacts and the adaptive capacity of individuals, populations and communities. To address public health challenges related to climate change, research and response must focus on these three parameters: understanding and delineating future hazards, identifying at-risk groups, and understanding their adaptive capacity. The following sections provide information on the impact of these past and projected changes on the health and safety. Public health officials can use this information to develop or update needed policies and programs with partners to protect Canadians.

3.4 Average Warming and Extreme Heat Events

3.4.1 Impacts of Climate Change on Heat – Trends and Projections

3.4.1.1 Annual Average Temperatures

The consequences of climate change are essentially the result of an increase in global average temperatures. Canada is no exception, having experienced an increase in average temperatures of 1.7°C between 1948 and 2016 (Figure 3.1), about twice the average warming observed globally (Zhang et al., 2019). Canada's Northern regions (Northern Canada) are particularly affected, with an average increase of 2.3°C – about three times the global rate of warming (Zhang et al., 2019). Average temperatures for Canada as a whole are projected to rise by 1.8°C, under a low emissions scenario, and by 6.3°C, under a high emissions scenario, for the end of century (2081–2100) compared to 1986–2005. As a result, average summer temperatures will rise across Canada, albeit with large variations depending on region and climate scenario (Jeong et al., 2016). Under a high emissions scenario (RCP 8.5), southern cities such as Fredericton, Quebec City, Calgary, and Victoria could see their average summer temperatures rise by 4°C to 5°C for the 2051–2080 period, compared to observed temperatures between 1976 and 2005 (Prairie Climate Centre, 2019). In all cases, Northern Canada will continue to warm faster than Southern Canada, particularly in winter (Figure 3.2).

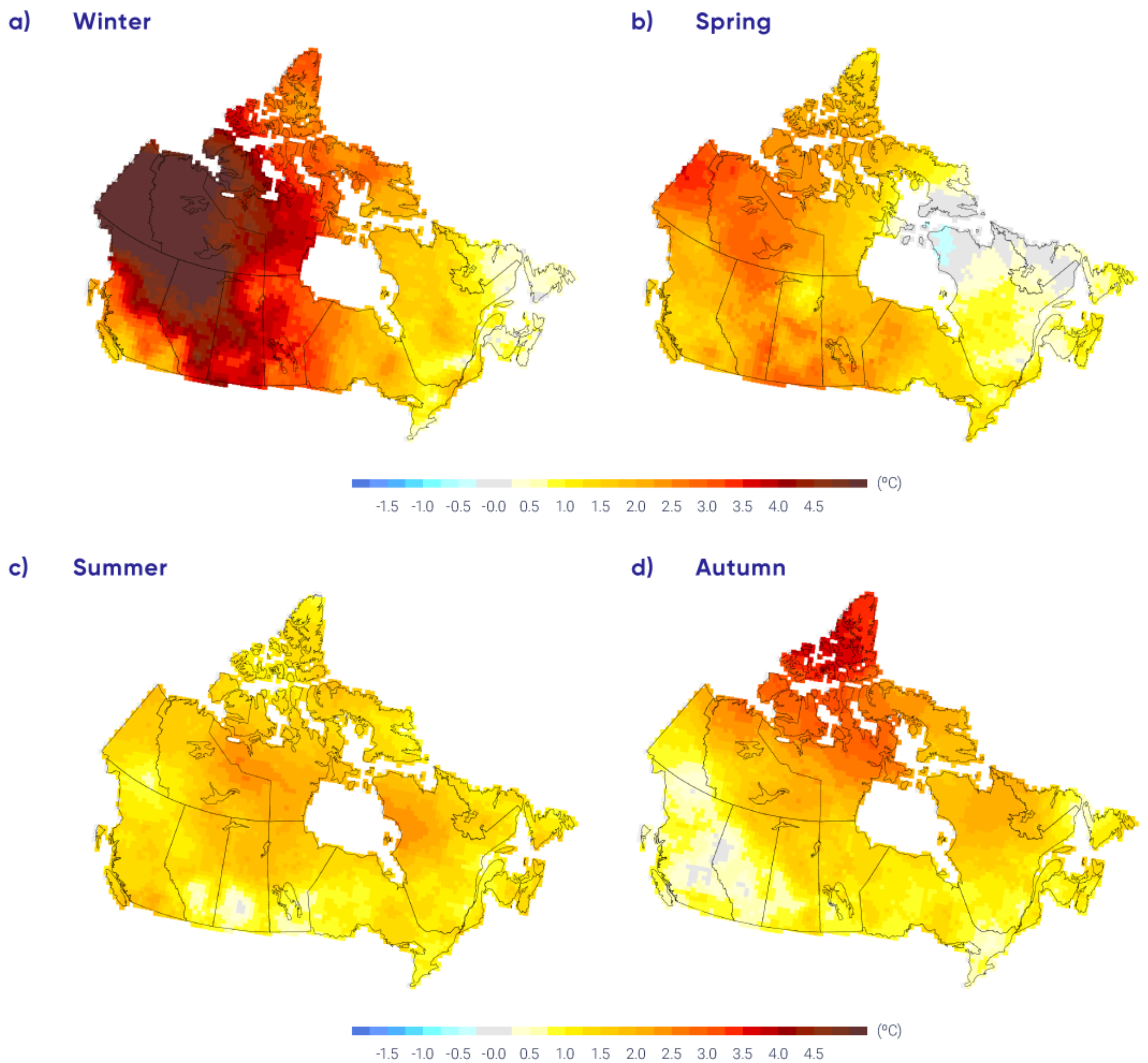


Figure 3.2 Observed changes (°C) in seasonal mean temperatures from 1948 to 2016 for four seasons. Source: Zhang et al., 2019.

3.4.1.2 Extreme Heat Events

There is no universal definition for extreme heat events (also sometimes referred to as heatwaves), and there is no consensus on terminology to describe hot weather (Gachon et al., 2016). The average increase in temperature also increases the frequency and duration of extreme heat events. Hot days with a maximum temperature above 30°C are rarely observed in regions north of 60° north latitude (Zhang et al., 2019). In Southern Canada, the number of hot days above 30°C increased annually by about one to three days over the period 1948–2016 at some stations, and is expected to increase there by up to 50 days annually by the late century under RCP8.5 (Zhang et al., 2019). Under this scenario, the annual median number of hot days is expected to vary from about 3 to 38 across Canada for the 2081–2100 period, with the Prairies and Ontario regions being more affected. As extreme hot temperatures will become more frequent and intense, it will increase the severity of extreme heat events (Zhang et al., 2019). The number of extreme heat events of at least three days above 32°C[1] is likely to increase in regions of Southern Canada, where most Canadians live (Jeong et al., 2016). Some regions, such as the St. Lawrence Lowlands (in Quebec) and the Prairies, may experience two to three additional events per summer for the 2049–2070 period, compared to the 1970–1999 period (Jeong et al., 2016). The intensity and duration of these extreme heat events are also projected to increase (Sillmann et al., 2013).

3.4.2 Effects of Heat on Health

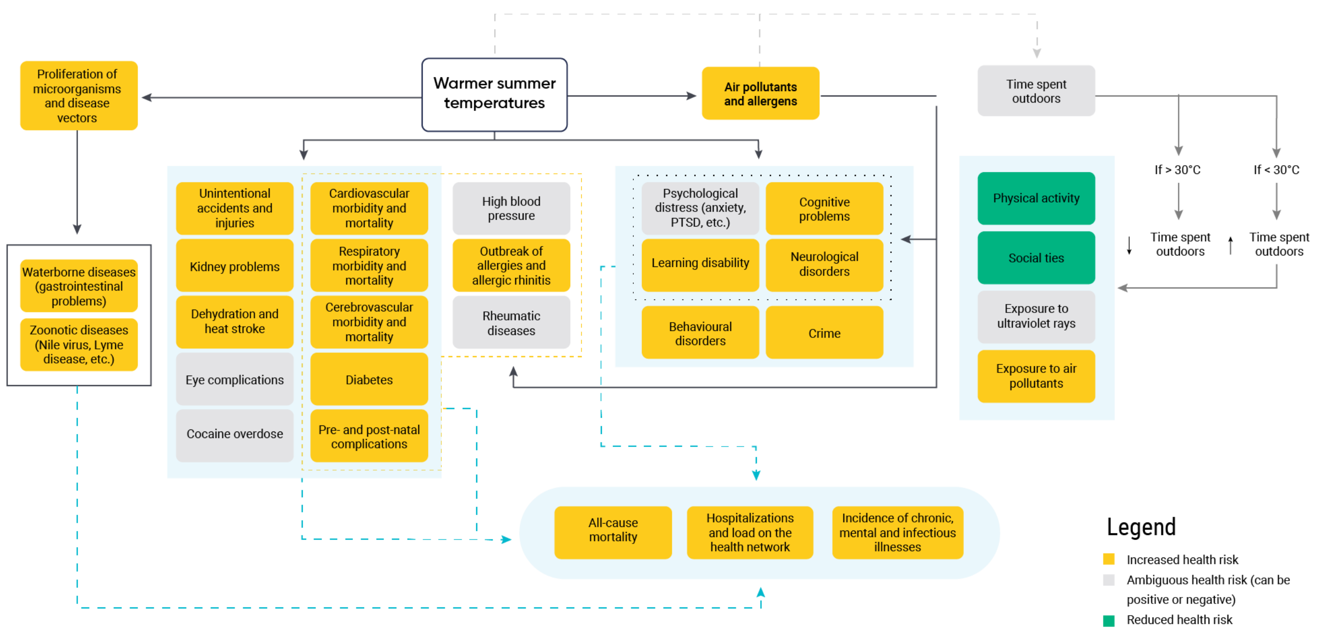


Figure 3.3 Conceptual framework showing the direct and indirect effects of extreme heat and increased temperatures on population health in Canada. The orange boxes indicate that the health risk is increased, the green boxes indicate that the risk is reduced, while the grey boxes indicate that the direction of health effects based on current knowledge cannot be determined. Solid and dashed lines distinguish among clusters of impacts. Source: Credit – David Demers-Bouffard, INSPQ.

1 Environment and Climate Change Canada's definition of a heatwave. <https://www.canada.ca/en/environment-climate-change/services/sky-watchers/glossary.html>

In Canada, the natural hazards with the best-documented health consequences are extreme heat events. Around the world, extreme heat is associated with increased all-cause mortality (Gasparrini et al., 2015; Xu et al., 2016) and an increased risk of hospitalization for cardiovascular and pulmonary disease (Basu et al., 2012; Turner et al., 2012b; Lavigne et al., 2014; Moghadamnia et al., 2017; Sun et al., 2018). The following subsections describe the observed or projected health impacts of extreme heat (Figure 3.3).

3.4.2.1 All-Cause Mortality During Extreme Heat Events

Between 1986 and 2010, the average percentage of all-cause mortality attributed to extreme heat events in Canada was 0.53% (varying between 0.18% and 0.72% depending on the region) (Gasparrini et al., 2015). In 26 Canadian cities for which risk has been assessed, an extreme heat event appears to increase the risk of mortality by an average ranging from 2% to 13% (Guo et al., 2018). Another meta-analysis also found that the risk of mortality related to extreme heat events increases between 3% and 16%, depending on the definition of extreme heat event or heatwave used (Xu et al., 2016).

In British Columbia, 815 deaths could be attributed to extreme heat between 1986 and 2010. These deaths represent a 4% to 19% increase in the mortality rate the day after the event and a 2% to 19% increase within a week of the event (Henderson et al., 2013), depending on the city. An extreme heat event of nearly five days in Quebec in 2010 increased daily mortality by 33% in Greater Montréal and the rate of emergency department visits by 4% compared to similar periods (Bustinza et al., 2013). A very similar event at the end of the same summer had no measurable impact, which seems to indicate a physical and behavioural acclimatization to heat. Such impacts were also not detected during subsequent extreme heat events in Quebec from 2011 to 2015, except in the Montréal region (Lebel et al., 2017). It is essential to take into account night temperatures and the local environment to understand the impacts of heat on health. In British Columbia, a 5% increase in mortality was associated with forecast daytime temperatures of 29°C to 35°C and overnight temperatures of 14°C to 18°C, depending on the region (McLean et al., 2018). Humidity may have a significant effect on the relationship between heat and mortality, but the evidence is inconsistent in the literature (Barnett et al., 2010; Barreca, 2012; Xu et al., 2012; Parsons, 2014; Ho et al., 2016; Zeng et al., 2017).

3.4.2.2 Characterization of the Relationship Between Mortality and Heat

In general, mortality associated with an extreme heat event increases as intensity and duration increases, with intensity having a greater effect (Xu et al., 2016). For example, an extreme heat event in Quebec in the summer of 2018 caused 86 deaths, while 291 excess deaths were recorded during the 2010 extreme heat event (Lebel et al., 2019). Although the two events were similar in scope, duration, and timing, the 2010 extreme heat event was more intense. Worldwide, heat-related mortality tends to decrease with warming global temperatures independently of the level of air conditioning use, indicating that people can become less susceptible to heat as a result of physical acclimatization, behavioural changes, and the implementation of structural adaptation measures (Arbuthnott et al., 2016) (see Chapter 10: Adaptation and Health System Resilience).

3.4.2.3 Mortality Related to Climate Projections

As noted above, as climate warming continues, in addition to increases in average annual and seasonal temperatures, the intensity and frequency of extreme heat events will increase, as well as their impact on mortality in the absence of further adaptations. Compared to 1971–2020, mean excess mortality[2] in 2031–2080 related to extreme heat events across Canada is expected to increase from 155% to 390%, depending on the GHG emission scenario (RCP2.6 for the lowest estimate and RCP8.5 for the highest). With high population growth in the future, these percentages range from 188% to 455% (Guo et al., 2018).

3.4.2.4 All-Cause and Cardiovascular Disease Hospitalizations

In Ontario, the hottest days (99th percentile) between 1986 and 2013 showed a 6% increase in hospitalizations for cardiovascular disease compared to optimal temperatures, which showed the lowest mortality rate (Bai et al., 2017). For this period, an estimated 1.2% of overall hospitalizations for cardiovascular disease can be attributed to heat, with the majority of these admissions being related to moderate rather than extreme heat. In Toronto specifically, the number of heat-related ambulance calls was 12.3% higher during extreme heat events in 2005, 2006, and 2010 than during the week before and after (Graham et al., 2016). Increases in potentially heat-related hospitalizations and emergency department visits were also observed during regional heatwaves in some Quebec regions between 2010 and 2015 (Lebel et al., 2017). The 2018 extreme heat event in Quebec increased the number of ambulance trips in all affected regions by 11% to 23%, with some also seeing an increase in emergency department visits and hospitalizations (Lebel et al., 2019). Physiological acclimatization to heat appears to play a role: between 1989 and 2006, Quebec hospitalizations for ischemic heart disease were higher among seniors in early summer and decreased as the season progressed (Bayentin et al., 2010).

3.4.2.5 Cardiovascular and Other Diseases

As described above, extreme heat events increase the risk of cardiovascular-related hospitalizations and excess deaths. In Ontario, for example, each 5°C increase in temperature during the summer from 1996 to 2010 was associated with a 2.5% increase in deaths, especially those related to cardiovascular disease (Chen et al., 2016). On the other hand, the duration of an extreme heat event also seems to play a role in the impact on cardiovascular disease. The association between cardiovascular disease and point days (one day) of extreme heat is more ambiguous than that associated with extreme heat events (Phung et al., 2016). In addition, various cardiovascular diseases do not appear to be similarly affected by heat (Phung et al., 2016). The effects of individual extreme-heat point days (one or two days) on cardiovascular mortality can generally persist to a week after the event, but not all studies agree (Huang et al., 2011; Martin et al., 2012; Ye et al., 2012; Huynen & Martens, 2015). In addition to these effects, extreme heat aggravates diabetes- and kidney-related complications (Hajat et al., 2017; Lim et al., 2018) as well as increases the risk of unintentional injury (accidents) (Kampe et al., 2016), renal colic (Ordon et al., 2016), retinal detachment (Auger et al., 2017f),

2 Excess mortality is defined in this study as all-cause mortality due to non-optimal temperatures, with optimal temperature considered the temperature at which the minimum mortality is observed.

and cocaine overdose (Auger et al., 2017a). In an Ontario study, however, heat did not appear to affect hospitalizations for high blood pressure or heart arrhythmia (Bai et al., 2016).

3.4.2.6 Perinatal Effects

Several perinatal complications are also associated with heat, such as premature birth and early delivery during exposure in the third trimester (Auger et al., 2014), miscarriage (Auger et al., 2017d), and congenital complications, such as heart or neural tube defects, from exposure in the first trimester (Auger et al., 2017b; Auger et al., 2017c).

3.4.2.7 Indirect Impacts from Lower Water and Air Quality

Heat also has indirect impacts on water and air quality (see Chapter 5: Air Quality and Chapter 7: Water Quality, Quantity, and Security). Among these impacts, it increases the risk of water-borne diseases in the population by promoting the proliferation of bacteria and cyanobacteria in freshwater sources (Funari et al., 2012; Sterk et al., 2013; Herrador et al., 2015; Chapra et al., 2017; Mayer-Jouanjean & Bleau, 2018). Increased temperatures also increase recreational water activities (e.g., swimming, kayaking, sailing, surfing), increasing the risk of skin (e.g., dermatitis) or gastrointestinal symptoms (Lévesque et al., 2014; Boyer et al., 2017; Askew & Bowker, 2018). A full review of health impacts related to the degradation of water quality or quantity in Canada is provided in Chapter 7: Water Quality, Quantity, and Security.

In terms of air quality, heat promotes the formation of air pollutants such as ozone, which are known to increase lung and cardiovascular disease morbidity and mortality (World Health Organization, 2013a; Beelen et al., 2014). A comprehensive review of health impacts related to the degradation of air quality due to climate change in Canada is available in Chapter 5: Air Quality.

3.4.2.8 Psychosocial Health

Hot temperatures also affect psychological and social health. Among their effects, high temperatures increase stress and people's propensity for aggressive behaviour, as reflected in increased crime and violent crime rates observed in certain U.S. cities, particularly in deprived neighbourhoods; in 20% of these neighbourhoods, half of the increase in crime during specific periods has been attributed to high temperatures (Mares, 2013; Ranson, 2014). Extreme heat can also lead to isolation at home by discouraging outdoor activities such as sports and recreation (Zivin & Neidell, 2014), which can in turn reduce social interaction and physical activity. Isolation can also endanger the health of individuals who depend on their social network to cope with hazards, particularly seniors, minority groups, or low-income individuals (Bolitho & Miller, 2017; Williams et al., 2017).

Extreme heat also contributes to the development of psychological and behavioural problems. In Toronto, for example, the highest temperatures (99th percentile) between 2002 and 2010 corresponded with a 29% increase in emergency department visits for schizophrenia, mood disorders, and neurotic disorders over a seven-day period compared to visits during average temperatures (Wang et al., 2014). A similar trend was seen in the southern region of Quebec (Vida et al., 2012), where in addition to heat, high humidity was associated with emergency department visits for mental health problems among those under 65 years of age.

In about 15 studies, high ambient temperatures were positively correlated with an increase in the suicide rate, with relative risk increasing by 1% to 37% on average for every 1°C increase in annual average temperature (Thompson et al., 2018). A meta-analysis covering 341 cities in 12 countries estimated that the highest risk of suicide was observed at an average temperature of 27°C (93rd percentile), but that each country was unique (Kim et al., 2019). In Canada, this maximum risk was observed at an average temperature 24°C, the 99th annual temperature percentile (Kim et al., 2019). The authors note that these analyses have limitations, and that further studies are needed. The exact cause of the increase in suicides on hot days is unknown.

The increased demand for social services and care in health care facilities due to the effects of heat increases the burden on these institutions, which may be challenged to meet these demands (Curtis et al., 2017). Increases in the health care demand related to heat also result in additional stress on social service and health care workers by increasing their workload (more clients); this stress can also increase the risk of reduced quality of care (Curtis et al., 2017). See also Chapter 4: Mental Health and Well-Being for an assessment of the impacts of climate change on mental health in Canada.

3.4.2.9 Beneficial Impacts

The increase in temperatures, apart from extreme events, may have some positive impacts. Extending the summer season and increasing the number of days conducive to outdoor activity could encourage people to be more physically active or participate in more social events (Baert et al., 2011; Witham et al., 2014; Remmers et al., 2017). However, this effect will be partially or fully offset by the deterrent effect of extreme heat; time spent on outdoor activities plateaus and decreases when temperatures exceed 30°C (Zivin & Neidell, 2014).

3.4.3 Populations at Increased Risk to Heat

3.4.3.1 Seniors

Seniors (generally 65 years and over) are at higher risk of the health effects of heat compared to younger adults because of their diminished ability to adapt physically, the fact that they adopt fewer preventive behaviours, and their higher level of social isolation and dependence (Bélanger et al., 2015; Laverdière et al., 2015; Laverdière et al., 2016; Valois et al., 2017b). Pre-existing chronic diseases such as cardiovascular disease, high blood pressure, and diabetes, which are more prevalent in seniors, are also risk factors for heat-related impacts on seniors (Laverdière et al., 2015; Laverdière et al., 2016; Hajat et al., 2017). In addition, people aged 70 and older do not always see themselves as vulnerable, which may make them less predisposed to engage in preventive behaviours (Boeckmann & Rohn, 2014; Valois, et al., 2020b). As the population ages in Canada, it is expected that the extent of heat-related health impacts will increase, in the absence of further adaptations.

Risk factors, such as low socio-economic status, pre-existing conditions, use of medications, living in an urban heat island, social isolation, and loss of autonomy, can increase impacts from extreme heat. For example, seniors in southern Quebec (south of 49 degrees north latitude) with six or more of the above risk factors are eight times more likely to be admitted to emergency and seven times more likely to die or be hospitalized during extreme heat compared to those with no risk factors or only one (Laverdière et al., 2016).

The health risks for seniors also seem to be modulated by increasing temperatures or temperature variations between night and day. From 2006 to 2010, Quebec seniors were admitted to emergency departments and hospitalized 1.7 and 2.7 times more often on hot days, respectively, compared to normal summer days (Laverdière et al., 2016). According to meta-analyses, every one-degree increase in temperature increases all-cause mortality rates by 2% to 5%, cardiovascular illness rates by 3.4%, respiratory illness rates by 3.6%, and stroke rates by 1.4% on average among seniors, in addition to increasing the risk of diabetic, genito-urinary and infectious complications (Yu et al., 2012; Bunker et al., 2016). Variations in daytime temperatures also affect senior mortality, in part because of their decreased ability to adapt physically. A study examining impacts of heat on health in Montréal between 1984 and 2007 showed that a temperature change of 6°C to 11°C over 30 days increased daily mortality by 5% among seniors, and this increase reached 11% for a change of 11°C to 17.5°C (Vutcovici et al., 2014).

Box 3.1 Heat and COVID-19

The coronavirus disease (COVID-19) pandemic has compounded the risk of extreme heat impacts for some population groups. Canada's hot days began very early in spring 2020 and lasted until September, and Canada's number of extreme heat events broke new records that year. Some people who are at increased risk to heat are also among those most at risk of hospitalization and death due to COVID-19: seniors and people with one or more chronic health condition, such as cardiovascular, pulmonary or kidney disease, high blood pressure, or obesity (Public Health Agency of Canada, 2020a). In addition, heat stroke symptoms can be confused with COVID-19 symptoms, such as muscle pain, headache, unusual fatigue or exhaustion, generalized discomfort, difficulty breathing, vomiting or nausea, and fever or an increase in body temperature (Health Canada, 2020a). These issues can lead to poor management of problems related to extreme heat and COVID-19.

At the time of writing, epidemiological analyses of the health impacts of extreme heat events in Canada in the context of COVID-19 had not been conducted. Yet, long-term care homes for seniors, or those who require continuous care, have been outbreak sites in Canada (Public Health Agency of Canada, 2020b). These centres often have little or no access to centralized air conditioning during extreme heat events, putting additional pressure on an already fragile population. In addition, COVID-19 has led to a reduction in the use of fans to cool off in these establishments during heatwaves, in order to minimize the risk of airborne transmission of the disease when more than one person is in the same room (INSPQ, 2020a).

The widespread closure of several sectors of the economy, coupled with recommendations for isolation and physical distancing to control the pandemic, can also increase feelings of exclusion and stress among people already at increased risk to extreme heat due to physical or mental health issues (Findlay et al., 2020).

The majority of available studies do not compare seniors with other age groups; as a result, it is difficult to state with certainty that seniors are more affected. According to a meta-analysis comparing seniors to younger groups (15 to 64 years), the risk of heat-related death is only 2% higher for seniors (Benmarhnia et al., 2015). Other research indicates that people under 65 years of age are sometimes the most affected, as they spend more time outdoors (Alberini et al., 2011; Song et al., 2017). As a result, although older adults' sensitivity to heat tends to increase with age, exposure may decrease. In Vancouver, for example, persons aged 65 to 74 had a higher risk of death than those aged 85 and over during the hottest week of 2009; the risk was highest for persons not living in institutions (senior residences, hospitals, clinics, etc.) (Kosatsky et al., 2012). Other vulnerability co-factors (e.g., chronic diseases) sometimes associated with seniors are discussed in the following sections.

3.4.3.2 Children

Children are at an increased risk of extreme heat impacts due to their limited ability to acclimatize physically and to respond appropriately to stress. For example, the rate of temperature-related physical trauma visits and fractures is higher in children than in adults (Ali & Willett, 2015). Also, the incidence of kidney problems, fever, electrolyte imbalance, and respiratory diseases (e.g., asthma) in children increases significantly during extreme heat events (Xu et al., 2014b).

In regard to mortality, a systematic review of extreme heat events found that the existing literature is inconclusive about the relationships between child mortality and extreme heat events (Xu et al., 2014b). Although infant mortality associated with extreme heat events is low overall, it increases as age decreases, with children under the age of one being the most vulnerable, compared to children aged up to four years and aged five to 14 years (Xu et al., 2012). In Quebec, temperatures above 29°C were associated with almost three times the risk of sudden infant death (Auger et al., 2015). Finally, children living in urban areas are at increased risk of extreme heat event impacts, owing to increased exposure in urban heat islands and higher concentrations of air pollutants in cities (Vanos, 2015).

3.4.3.3 Sex and Gender

Men appear to be more at risk from the impacts of heat, but the causes are not well characterized. Quebec men aged 45 to 64 had a higher risk of hospitalization due to ischemic heart disease during extreme heat events from 1989 to 2006 (Bayentin et al., 2010). In addition, men between the ages of 40 and 69 also appear to be at greater risk of developing renal colic in extreme heat (Ordon et al., 2016). The current proposed hypothesis is that men are more likely to be employed in occupations with higher risks of exposure. In heat, there is an increased risk of placental abruption in full-term pregnancies, which can be fatal to both the mother and fetus (He et al., 2018).

3.4.3.4 Chronic Diseases

People with certain pre-existing diseases or reduced mobility are another population group vulnerable to the effects of heat. For example, in Fredericton, Winnipeg, Windsor, Regina, and Sarnia, people with cardiovascular or lung disease reported feeling ill more often during the previous extreme heat event (Alberini et al., 2011). In a study in Toronto, diabetes increased the likelihood of going to the emergency department or being admitted for a cardiovascular problem during heat events: other factors (high blood pressure, kidney problems, cancers, etc.) were also correlated, but were not significant (Lavigne et al., 2014). Respiratory diseases, and pre-existing cancer, have also been identified as comorbidity factors associated with going to or being admitted to emergency for a cardiovascular problem during heat events (Lavigne et al., 2014). Age can also influence the relationship between heat and comorbidity. In Quebec, people aged 65 and under in the most deprived neighbourhoods with at least two chronic diseases reported 4.2 times more heat-related health problems (Bélanger et al., 2014). Reporting of health problems was 5.6 times higher for people aged 65 and over. Between 2006 and 2010, seniors in Southern Quebec with significant disabilities (who require assistance to carry out daily activities) were 2.5 times more likely to be admitted to emergency and 2.7 times more likely to be physically affected by heat (Laverdière et al., 2016).

3.4.3.5 Medication Use or Substance Misuse

Medication can increase an individual's risk of extreme heat impacts by accelerating dehydration and body heat production. Certain medications affecting the central nervous system (anticonvulsants, antidepressants, anticholinergics, and psychotropic drugs in general), diuretics, immunosuppressants, interferons, and some anticoagulants may increase the risk of hyperthermia (Health Canada, 2011; Bélanger et al., 2015).

Excessive drug or alcohol use can also make individuals more sensitive to the effects of heat. In England, people with substance misuse problems were at higher risk of dying at temperatures above the 93rd percentile of annual temperature distribution (Page et al., 2012). Similarly, increased risk of mortality was associated with cocaine use during extreme heat events in Montréal (Auger et al., 2017a).

3.4.3.6 Occupational Exposure

Outdoor workers in construction, agriculture, forestry, and similar work environments have higher exposure to heat and its health risks, although some indoor workplaces, such as industrial settings and restaurants, may also be conducive to hyperthermia. The risk of injury and illness or disease at work increases during extreme heat, while worker productivity decreases (Adam-Poupart et al., 2014; Acharya et al., 2018; Levi et al., 2018; Adam-Poupart et al., 2021). In Ontario, from 2004 to 2010, every degree above 22°C increased the median number of hospitalizations for heat-related occupational illnesses and diseases by 75% (Fortune et al., 2014). In the provinces of Quebec, Ontario, Manitoba, Saskatchewan, and Alberta from 2001 to 2016, each 1°C increase in the maximum daily summer temperature increased the number of daily heat-related illness claims (e.g., edema, syncope, exhaustion, sunstroke/heatstroke) from occupational health and safety compensation agencies by 28% to 51%, depending on the province and the meteorological heat indicator (Adam-Poupart et al., 2021). The claims for traumatic injuries (e.g., fractures, cuts, burns) also increase by 0.2% to 0.6% for each 1°C increase in summer temperature — where a 0.2% increase represents 64 additional traumatic injury claims by summer in Quebec, for example (Adam-Poupart et al., 2021). This risk of injuries is not influenced by the type of task (manual vs. non-manual tasks) (Adam-Poupart et al., 2015), but heat-related injuries are more frequent for men and younger workers (Adam-Poupart et al., 2021). Jobs requiring work outdoors, or in environments conducive to heat accumulation, place workers at higher risk of heat-related injuries (Adam-Poupart et al., 2015; Acharya et al., 2018; Varghese et al., 2018; Adam-Poupart et al., 2021).

3.4.3.7 Urban Heat Islands

Urban heat islands represent the observed temperature difference between urban and surrounding rural areas, as well as between areas of a given city — for example, between a park and an adjacent parking lot (intra-urban islands). These intra-urban heat islands are formed as a result of impervious surfaces and low albedo (solar reflectivity level) of urban spaces, combined with a low level of vegetation (Beaudoin & Gosselin, 2016). Albedo in cities like Toronto and Montréal hover around 0.2 on a scale of 1, indicating that the materials and colours used, such as dark roofs and asphalt, absorb a lot of heat during the day and release it at night (Touchaei & Akbari, 2015; Graham et al., 2016). These characteristics, combined with heat produced by motor vehicles, industry, appliances and air conditioning, raise the ambient temperature.

This results in higher rates of heat-related mortality in urban areas than in rural areas (Tan et al., 2010; Gabriel & Endlicher, 2011; Wouters et al., 2017). Although heat exposure is higher in urban centres, heat sensitivity in rural and remote communities may be higher (Liang & Kosatsky, 2020). Health consequences of heat exposure are therefore closely associated with the intensity gradient of intra-urban heat islands. In Montréal, for example, the mortality rate for respiratory diseases from 1990 to 2003 was higher in high-intensity heat islands than in cooler locations (difference of 6°C to 8°C), with rates being 1.4 to 14 times higher, depending on the intensity of the island as well as on ground-level ozone concentrations (Smargiassi et al., 2009). In addition, home property value was negatively associated with mortality: a higher value was generally representative of higher housing quality and better insulation, greater ventilation and air conditioning and possibly better health and, therefore, lower vulnerability. Urban heat islands also exacerbate health inequities. Individuals with low socio-economic status tend to live in neighbourhoods with high-intensity heat islands where the prevalence of greenspace is low, increasing their risk of heat exposure (Bélanger et al., 2014; Ngom et al., 2016).

3.4.3.8 Indigenous Populations

First Nations, Inuit, and Métis are particularly sensitive to the impacts of climate change, including the indirect impacts of rising temperatures on the environment and the direct and indirect impacts of extreme heat (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Indigenous Peoples have close ties to the land, sea, animals, and natural resources that are being disrupted by climate change, particularly in Northern regions where many communities are located.

Despite the lack of extreme heat in Northern Canada, Arctic and sub-Arctic Indigenous Peoples are being affected by warming temperatures. Reduced and weakened sea ice, permafrost, and ground snow cover, for example, have a wide range of impacts such as increased risk of injury and an increase in the number of search-and-rescue operations, and impacts on transportation, hunting, the ability to access traditional/country foods, and loss of Indigenous knowledge (Durkalec et al., 2014; Clark et al., 2016a; Clark et al., 2016b) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Warmer temperatures could also increase the incidence of food-borne illnesses by promoting bacterial growth and toxin formation in food storage sites (Hedlund et al., 2014; Bruce et al., 2016) (see Chapter 8: Food Safety and Security). Inuit populations, who use natural conservation methods and consume raw meats, are primarily at risk. These consequences could lead to a decrease in traditional food consumption among Inuit, Métis, and First Nations peoples. Traditional food is generally more nutritious and utilized more for spiritual traditions, compared to store-bought or processed foods. Inuit are already experiencing impacts of warming on traditional foods which is affecting food security in many communities. Nearly half of the First Nations populations in Canada experience severe or moderate food insecurity (First Nations Information Governance Centre, 2018). As a result of warming temperatures, First Nations peoples may reduce the quantity or quality of consumed food.

3.4.3.9 Material and Social Deprivation

In addition to having more pre-existing illnesses, low-income individuals more often live in housing that is poorly insulated, poorly ventilated, and lacking air conditioning (Kosatsky et al., 2009; Bélanger et al., 2014; Bélanger et al., 2016). In Vancouver, the mortality rate in neighbourhoods with over 20% of residents living below the poverty line was 23% higher than other neighbourhoods during the 2009 extreme heat event (Kosatsky et al., 2012). However, a meta-analysis has indicated that the risk of heat-related death is not different between people living in areas considered deprived and those living in areas considered privileged (Benmarhnia et al., 2015). This finding was also observed in Quebec when comparing deprived to very deprived distribution areas and other distribution areas for the 2010 and 2011 extreme heat events (Lebel et al., 2015). While the impact of socio-economic status on deaths during hot periods is less established, the impact on medical or hospital visits is more obvious. In Quebec, people in the lowest income quintile were 20% more likely to see a doctor during extreme heat events because they were more affected by the health consequences of such events (Bélanger et al., 2014). From 2006 to 2010, seniors in southern Quebec with a household income under $20,000 were almost three times more likely to go to the emergency department, be hospitalized, or die from heat when temperatures exceeded 30°C (Laverdière et al., 2016).

3.4.3.10 People Experiencing Homelessness

People experiencing homelessness are more affected by extreme heat, which exacerbates existing health problems or causes new ones (Ramin & Svoboda, 2009; Cusack et al., 2013; Pendrey et al., 2014). A large proportion of the people experiencing homelessness experience mental health and substance misuse issues, ranging from 23% to 67% by city (CICH, 2007). They also have a higher prevalence of chronic diseases. However, this population's health conditions remain poorly documented in Canada (Mental Health Commission of Canada, 2014). Between 136,000 and 156,000 Canadians use emergency shelters each year (Advisory Committee on Homelessness, 2018).

3.4.3.11 Ethnicity and Race

The effects of heat on the health of racialized populations have not been studied in depth in Canada; relevant studies have mainly been conducted in the United States. For example, Black people were at a higher risk of being hospitalized during extreme heat events between 2001 and 2010 in the United States (Schmeltz et al., 2015). In most of 175 largest U.S. cities, racialized people have an average urban heat island exposure greater than non-Hispanic White people and people below the poverty line (in half of the cities), suggesting widespread inequalities in heat exposure in racialized people may not be well explained by differences in income alone (Hsu et al., 2021). However, the relationship between heat and mortality among racialized people is rather complex, according to current literature, which indicates decreased, increased, or no effects across different groups (Gronlund, 2014).

For Indigenous Peoples, heat may cause significant health problems because of a number of compounding factors. Existing health inequality and inequities related to determinants of health among First Nations, Inuit, and Métis peoples increase their sensitivity to the health impacts of extreme heat. Indigenous populations generally have a higher prevalence of certain diseases, such as cardiovascular disease and diabetes (Chu et al., 2019; Hu et al., 2019), low income, and substandard housing, and all of these factors are associated with exacerbated effects of significant heat (Chief Public Health Officer of Canada, 2016). A disproportionate share of people experiencing homelessness in Canadian cities are Indigenous (Patrick, 2014) and, as highlighted above, homelessness is associated with higher risk of heat impacts on health.

3.4.4 Heat Adaptation Measures

3.4.4.1 Individual Adaptation Measures

Air Conditioning

Air conditioning is often cited as a heat adaptation measure that should be prioritized. In buildings without air conditioning, indoor temperatures can reach 1.5 times the outside temperature (Lundgren Kownacki et al., 2019). In the United States, the risk of heat-related death is affected by temperature and the use of air conditioning (Nordio et al., 2015). The risk of heat stroke hospitalizations is also lower in counties with a higher prevalence of central air conditioning during an extreme heat event (Wang et al., 2016b). In the most deprived neighbourhoods of the largest Quebec cities, fewer people with indoor air conditioning reported experiencing adverse effects during extreme heat (Bélanger et al., 2015). Nevertheless, current literature in Canada and the United States also appears to indicate insignificant effects or no correlation between air conditioning and self-reported impacts of heat on health (Alberini et al., 2011; Bobb et al., 2014; Bélanger et al., 2015; Arbuthnott et al., 2016).

Widespread use of air conditioning can also increase outdoor temperature due to increased electricity demand and the release of hot air outside the home. Simulations in Paris and Houston showed that widespread air conditioning could lead to a 2°C increase in outdoor temperatures in dense urban environments (de Munck et al., 2013; Salamanca et al., 2014). For low-income individuals, prolonged use of air conditioning in the home can significantly increase their electricity bills, meaning they have to choose between paying electricity or other expenses like rent (Ng et al., 2015). Thus, access to or the use of air-conditioned or cooling-off areas (public swimming pools, water play areas, parks) may be preferable for this type of population. Last, moderate use of air conditioning combined with other measures (structural modifications to roofs and windows, use of reflective materials, greening of the home or neighbourhood) may limit the negative effects of air conditioning (Mavrogianni et al., 2012; Fisk, 2015; Raji et al., 2015). The effect on GHG emissions, based on the electricity source used, must also be considered, given the effects on climate change and air pollution, which could significantly increase in Canada (Berardi & Jafarpur, 2020).

Fans

Some studies report that fans are ineffective in reducing heat health impacts when temperatures are too high or when humidity is high. In Canada, however, using fans may be beneficial for individuals who are well hydrated given that observed temperature levels are often lower during extreme heat events than elsewhere in the world (around 31°C to 33°C) (Gupta et al., 2012; Jay et al., 2015; Ravanelli et al., 2015; Gagnon et al., 2016).

Behaviours and Lifestyle

Several other preventive measures can be adopted by individuals to reduce risks related to extreme heat, such as decreasing the use of certain electrical appliances (computer, dryer, oven, etc.), taking additional showers or baths, drinking more water, going out to cool places, and decreasing physical activity (Valois et al., 2017b). In Quebec, a heat adaptation index was developed with 18 adaptation measures associated with various variables, such as income, age, sex, and perception, to monitor these behaviours over time (Valois et al., 2017b). Perceptions of risk, control and personal vulnerability also influence individuals' predisposition to adopt heat-prevention measures (Valois et al., 2020b). Whether people adopt preventive behaviours could explain the complex relationship between the risk of cardiovascular disease and occasional short-term exposure to extreme heat (Phung et al., 2016).

Box 3.2 Adjusting heat adaptation measures in the COVID-19 context

Although measures to adapt to heat or reduce its health risks have been known and implemented for several years, the COVID-19 pandemic forced a revision of these measures. Several heat adaptation measures are incompatible with COVID-19's close-contact mode of transmission. For example, public health authorities across Canada, along with their counterparts around the world, have revised their action plans and population heat-protection recommendations for extreme heat events (B.C. Centre for Disease Control, 2020; Bustinza, 2020; Centers for Disease Control and Prevention, 2020; Public Health England, 2020). Examples of adjustments include:

- Recommendations to use cool, air-conditioned locations such as libraries, community centres, and shopping centres, may not be able to be applied, as these locations are often inaccessible or restricted. Instead, it is advisable to go to cool or air-conditioned places in your own home, to spend time in a shaded green space while respecting physical distancing, or to use cooling centres established by local authorities for high-risk populations, while respecting appropriate public health and ventilation recommendations.
- Swimming pools and splash pads should be used to cool off, in accordance with hygiene and physical distancing guidelines. Unsafe use of swimming areas (e.g., closed beach, river) may lead to increased risk of injury or drowning. In addition, children and parents staying at home while teleworking during the summer can also lead to increased risk of children drowning due to a lack of supervision.
- The ventilation and air conditioning of congregate settings and shelters (seniors' homes, prisons, youth centres, child care centres etc.), day camps, schools, and health care facilities must be maintained in order to keep people cool during extreme heat events. However, ventilation or air conditioning needs to be adapted so as not to promote the spread of disease among individuals (residents, patients, workers, etc.). Canadian and provincial recommendations are available (Alberta Health Service, 2020; Health Canada, 2020a; INSPQ, 2020a, INSPQ, 2020b; INSPQ, 2020c).
- Parks and green spaces can promote heat adaptation despite the COVID-19 pandemic. When physical distancing measures are followed, parks and green spaces are among the few safe places to engage in various physical and social activities. They improve several dimensions of physical and mental health, as well as offer cooling sites during an extreme heat event (INSPQ, 2020d). Several Canadian municipalities have reopened parks and green spaces, as well as allowing people to walk freely in the streets, with measures in place to minimize the risk of infection (Freeman & Eykelbosh, 2020; INSPQ, 2020d).

3.4.4.2 Public Health Adaptation Measures

Heat Warning Systems and Action Plans

Following deadly extreme heat events in recent decades, several governments around the world have developed heat (or extreme heat event) health action plans, usually coupled with weather and health watch and warning systems. Heat action plans and warning systems should be based on pre-determined weather thresholds at which severe health risks increase, to ensure optimal implementation. Various guides are available in Canada on this topic, including a guide on determining warning thresholds for extreme heat events that was developed to help health authorities, municipalities, and all other stakeholders implement warning systems (Gachon et al., 2016); a guide on best practices for implementing a warning system and an extreme heat response plan (Health Canada, 2012); and a set of guidelines on medications, risk factors, and symptoms related to extreme heat stress to help health care professionals respond appropriately to extreme heat (Health Canada, 2011).

In Quebec, a semi-real-time weather and health monitoring and early warning system called SUPREME has been implemented since 2010. This may partially explain the significant decrease in mortality observed between the 2010 and 2018 extreme heat events, in addition to action plans implemented since then (Toutant et al., 2011; Canuel et al., 2019; Lebel et al., 2019).

Public health alerts issued through a variety of media and mechanisms (e.g., smartphones, radio, television, social media, community associations) activated when the outside temperature reaches a certain threshold and indicating preventive measures to be taken before and during extreme heat, are a way to quickly reach and inform people at higher risk. Research suggests that this type of system can decrease mortality and the number of people transported by ambulance to health centres for care (Toloo et al., 2013; Boeckmann & Rohn, 2014). However, the challenge for these warning systems is reaching the most vulnerable people, such as those who are isolated and experiencing homelessness, or those without electronic or telephone communication methods. In the Montérégie region of Quebec, this type of system was designed for seniors or those with certain pre-existing conditions. It increased people's intention to go to cool locations during an extreme heat event, or to stay inside among participants, who adopted measures to keep cool at home (Mehiriz & Gosselin, 2017; Mehiriz et al., 2018). Women participating in a study on the system consulted a health care provider half as often as those in a control group.

Action plans should also include provisions to support the most socially isolated individuals. For example, in Rome, the proportional increase in all-cause mortality among people aged 75 and above was 50% lower in neighbourhoods where a social outreach program had been implemented to improve social support for isolated and sick individuals (Liotta et al., 2018).

Box 3.3 Improving practices through the Montréal heat response action plan

In the Montréal region, health and municipal authorities have implemented an extreme heat response action plan that is triggered by a temperature that stays at or above 33°C (cumulative average) during the day and does not go below 20°C at night, for three consecutive days or a temperature at or above 25°C for two consecutive nights (City of Montréal, 2021). It includes measures targeting awareness campaigns at the highest-risk neighbourhoods; making cooling centres and areas available; extending opening hours of public pools; as well as checking on households door-to-door. Compared to extreme heat events before the plan was implemented, these measures have decreased the number of daily deaths fivefold, with the effect being most apparent among seniors (Benmarhnia et al., 2016). By targeting neighbourhoods with low socio-economic status, the plan has also reduced the gap in heat-related mortality between communities with high and low socio-economic status.

Occupational Health and Safety

The decrease in the number of claims during extreme heat events in Australia, Europe and the USA seems to indicate that adaptation measures that are mandatory at a certain threshold (e.g., longer rest periods, more worker turnover, and better monitoring of worker hydration or level of physical effort) are effective in decreasing the effects of heat on workers (Xiang et al., 2014; Varghese et al., 2018).

3.4.4.3 Infrastructural Adaptation Measures

Greening Neighbourhoods

Greening is an adaptation measure that can reduce the urban heat island effect (Giguère, 2012; Health Canada, 2020b). During extreme heat events in Toronto, the number of heat-related ambulance calls was five times higher in neighbourhoods with a tree canopy less than 5% compared to other neighbourhoods (Graham et al., 2016). This difference is 18 times higher compared to neighbourhoods with a tree canopy of over 70%. According to a simulation, a 10% increase in vegetation in the City of Toronto could cool daytime summer temperatures by 0.5°C to 0.8°C (Wang et al., 2015).

The benefits of vegetation can lead to a reduced mortality rate for people who live near greening projects and parks in general. A cohort study conducted over 11 years in 30 Canadian cities, with adjustments made for confounding variables found that increasing vegetation by one quartile in an area less than 500 metres from a residence decreased all-cause mortality related to diabetes and cardiovascular or respiratory systems by 8% to 12% (Crouse et al., 2017).

Box 3.4 Co-benefits of greening communities

In addition to reducing discomfort and health impacts from heat, greening measures offer many co-benefits, such as reducing stress, reducing concentrations of fine particle matter in the air, providing better water management (Tallis et al., 2011; Nowak et al., 2013; Beaudoin & Levasseur, 2017). Access to parks and green spaces is not always equal. For example, In Toronto, Ontario, low-income and racialized communities have less access to tree canopy cover and public green spaces, which can increase their exposure to extreme heat (Greene et al., 2018; Conway & Scott, 2020). Equitable access to green spaces must be considered when implementing greening strategies (see Chapter 9: Climate Change and Health Equity).

Several dozen greening and soil permeability projects have been implemented across Quebec to combat urban heat islands in low socio-economic neighbourhoods. People affected by these measures reported an improvement in their quality of life through an increased sense of security, social cohesion, and autonomy for the communities involved (Beaudoin & Gosselin, 2016; Health Canada, 2020b).

Material Reflectivity (Albedo)

Increasing cities' ability to cool down in hot weather is optimized when greening urban environments is combined with installing coatings and using high-albedo[3] materials (Health Canada, 2020b). In general, a 0.1 increase in albedo (solar reflectivity) can reduce ambient temperatures by approximately 1°C during extreme heat (Santamouris, 2014). In a simulation, increasing ground albedo by 0.2 to 0.4, roof albedo by 0.3 to 0.7, and increasing vegetation in the City of Toronto by 10% could decrease perceived summer daytime temperatures by 3.6°C to 4.6°C (Wang et al., 2015). In Montréal, increasing albedo from 0.2 to 0.65 would decrease annual temperatures by 0.2°C and reduce temperatures on hot days up to 4°C (Touchaei & Akbari, 2015). This impact on ambient temperature has a direct effect on health. In three U.S. metropolitan areas (Atlanta, Philadelphia, and Phoenix), substantial greening (at least 50% of urban area) or a significant increase in albedo (above 0.45) could reduce projected increases in heat-related mortality by 40% to 99% by 2050 (Stone et al., 2014). In California, widespread installation of reflective roofs could reduce the increase in heat exposure from climate change by 51% to 100% by 2050, depending on the emission scenario (Vahmani et al., 2019).

Built Environment, Urbanization, and Community Infrastructure

Urban design can also influence the health effects of extreme heat (Health Canada, 2020b). In Vancouver, the risk of death in dense areas (≥1,000 people per square kilometre) is 43% higher than in less dense areas (Kosatsky et al., 2012). This effect is mainly explained by the low prevalence of residential air conditioning and the higher deprivation level of these neighbourhoods. In contrast, in Massachusetts, the heat-related mortality risk between 1990 and 2008 was not associated with urbanization measures (Hattis et al., 2012). Although population density is associated with the urban heat island phenomenon, urban sprawl increases the area with less reflective surfaces (e.g., roads, sidewalks, rooftops) and decreases in overall vegetated

3 Albedo is the ability to reflect light energy; it is measured on a unitless scale ranging from 0 (total energy absorption, such as black surfaces) to 1 (total reflection, such as a mirror).

areas. For example, U.S. cities with greater sprawl experienced a larger increase in extreme heat events between 1956 and 2005 (Stone et al., 2010). To reduce the potential for heat storage in communities and associated mortality, urban densification should be combined with measures involving greening as well as increasing shade cover and solar reflectivity (Stone et al., 2014).

The quality of housing can also affect risks to health from heat. Using reflective materials (e.g., white-roof membrane), improving the insulation and ventilation in housing (active or passive), particularly in dilapidated housing in deprived neighbourhoods, and adding solar protection to windows (shutters, curtains, etc.) can substantially reduce residents' heat exposure In addition, these measures are cost-effective in the medium and long term in terms of energy consumption (Mavrogianni et al., 2012; Porritt et al., 2012; Bélanger et al., 2014; Ngom et al., 2016).

3.5 Exposure to Ultraviolet Radiation

3.5.1 Impacts of Climate Change on Ultraviolet Light — Trends and Projections

The level and intensity of ultraviolet radiation that is reaching the surface of the earth in a particular location is influenced by numerous factors, such as the time of the day, the season, ozone layer thickness, type of cloud cover, snow reflection, altitude, and latitude. Therefore, projections of ultraviolet radiation in future climate scenarios come with several uncertainties. The Montréal Protocol ozone-depleting substances international agreement was effective in protecting the stratospheric ozone layer[4] and preventing global-scale increases in solar ultraviolet radiation (Neale et al., 2021). However, in "the Arctic, springtime episodes of stratospheric ozone depletion, identified first in the early 2010s, continue to occur. The last episode in the spring of 2020 led to the largest ozone loss measured to date and resulted in UV indices that were twice as high as typical at several Arctic locations," such as in Northern Canada (Neale et al., 2021, p. 3). Outside the Arctic region, small changes in UV radiation trends over the last 20 years were mainly influenced by clouds, aerosols, and surface reflectivity (Neale et al., 2021).

The potential impacts of climate change on stratospheric ozone levels are complex and uncertain. With climate change, changes in stratospheric ozone and cloud cover could lead to a decrease in ambient ultraviolet (UV) radiation, particularly at Northern latitudes. Cloud cover is projected to increase north of 50 degrees north latitude and consequently decrease UV radiation reaching the Earth's surface (Bais et al., 2015). Solar reflectance at ground level and concentrations of aerosols and nitrogen oxides also affect UV radiation reaching humans. In Northern Canada, warming temperatures will decrease solar reflectance at ground level and UV radiation by reducing snow and ice cover (Bais et al., 2015; Bais et al., 2018).

4 The stratosphere is the second layer of the atmosphere and contains the ozone layer, which is different from ground-level or tropospheric ozone — a source of air pollution in the lower atmosphere.

South of 50 degrees north latitude, which is where the vast majority of Canadians live, cloud cover is expected to decrease, mainly resulting from an increase in GHG concentrations (Neale et al., 2021). In addition, at mid-latitudes (Southern Canada), increased GHG emissions are expected to stimulate ozone formation in the mid- and upper stratosphere (Bais et al., 2015), decreasing lower-atmosphere UV rays. The projected reduction in anthropogenic concentrations of certain air pollutants and aerosols could, by contrast, increase the intensity of UV rays, given that they are currently partially blocked by these pollutants. In addition, risky behaviours related to sun exposure, such as increased time spent outdoors and wearing clothing with little sun protection, tend to increase as temperatures rise (Zivin & Neidell, 2014; Pinault & Fioletov, 2017). The net effect of all these factors on the intensity and level of future UV exposure, and resulting health risks to Canadians, is therefore difficult to determine.

3.5.2 Effects of Ultraviolet Radiation on Health

3.5.2.1 Skin Cancer

Overexposure to UV radiation is the leading cause of skin cancer. The World Health Organization has classified UV radiation as a Group 1 carcinogen — sufficient scientific evidence of cancer in humans (International Agency for Research on Cancer, 1992). The risk of developing malignant melanoma, the deadliest form of skin cancer, has been associated with exposure to ambient UV radiation in several countries including Canada (Watson et al., 2016; Pinault et al., 2017). Sunburns in children may increase the risk of melanoma later in life (Benedetti, 2019). UV exposure and the incidence of skin cancers are worsening as temperatures increase (Freedman et al., 2015; Kimeswenger et al., 2016; Kaffenberger et al., 2017). For example, a 2°C increase was estimated to increase the number of skin cancers by 10% annually (van der Leun et al., 2008; Kaffenberger et al., 2017). Although the incidence of melanoma in the last decade (2005–2015) has increased in many countries including Canada, a model indicates that if the Montréal Protocol would be fully implemented, about 430 million cases of keratinocyte cancer and 11 million cases of melanoma would be prevented just in the U.S., for people born between 1890 and 2100 (Neale et al., 2021).

3.5.2.2 Cataracts and Eye Tumours

UVA radiation can lead to premature aging of the eye, in turn contributing to the development of cataracts (Yam & Kwok, 2014; Delic et al., 2017; Bais et al., 2018; Ivanov et al., 2018). Repeated exposure can also lead to the development of skin cancer cells around the eye, precancerous sclera growth, conjunctival cancer, and intraocular melanoma (Yam & Kwok, 2014; Bais et al., 2018; Ivanov et al., 2018).

3.5.2.3 Immunosuppression

Excessive UV exposure can promote immunosuppression, both in the skin and throughout the body. A weakened immune system limits the body's ability to defend itself against bacteria, viruses, and serious diseases such as cancer (Hart & Norval, 2018). That said, immunomodulation by solar UV radiation may also be beneficial to certain individuals: it can reduce the incidence of autoimmune disease, such as multiple sclerosis, type 1 diabetes, chronic inflammatory bowel disease (e.g., Crohn's disease), arthritis, and allergies (Sloka et al., 2008; Gorman et al., 2010; Lucas, 2010; Holmes et al., 2015; Lu et al., 2015; Lucas et al., 2015; Bais et al., 2018; Simpson et al., 2018).

3.5.2.4 Vitamin D and Blood Pressure

Despite its harmful effects, UV exposure from the sun is the most significant source of vitamin D in humans. Considerable scientific literature has documented the benefits of vitamin D in reducing bone problems such as rickets, osteomalacia, and osteoporosis (Ross et al., 2011; Wintermeyer et al., 2016). In 2009, 10% of the Canadian population had vitamin D deficiency, and 32% had sub-optimal blood levels for bone health, with these percentages increasing significantly during the winter months. (Vieth et al., 2001; Rucker et al., 2002; Janz & Pearson, 2013). Vitamin D may also promote cardiovascular health, and heart disease is the leading cause of death in Canada. Among its effects, exposure to solar UV rays releases nitric oxide into the skin, reducing blood pressure (Juzeniene & Moan, 2012; Halliday & Byrne, 2014; Liu et al., 2014). Assessments have suggested that 30-minute exposure to sunlight reduces blood pressure by 5 to 7 mm Hg and could therefore decrease the risk of heart attack by 34% (Cabrera et al., 2016; Weller, 2017). Other suggested benefits of an adequate blood vitamin D concentration include reducing the incidence of type 2 diabetes, obesity, metabolic syndromes, and cancers, although the causal process remains to be determined (Mitchell, 2011; Pludowski et al., 2013; Shore-Lorenti et al., 2014; Gorman et al., 2017; Bais et al., 2018).

3.5.3 Populations at Increased Risk to Ultraviolet Radiation

Some subpopulations tend to be more exposed to UV rays or are less likely to protect themselves from the sun, while others may be under-exposed. In Canada, sunburns occurred more frequently from 2005 to 2014 among men, younger age groups, people who were not members of visible minority groups, people living in higher-income households, and employed individuals (Haider et al., 2007; Pinault & Fioletov, 2017). Outdoor workers often exceed recommended levels of UV exposure and are therefore at higher risk of developing skin cancer (Schmitt et al., 2011; Fartasch et al., 2012; Peters et al., 2012; Modenese et al., 2018).

Groups that may experience increased UV exposure are those with fair skin (e.g., Caucasian/White, with blond or red hair); conversely, individuals with dark skin who live in areas with low UV exposure are more likely to have a vitamin D deficiency (Jablonski & Chaplin, 2012; Correia et al., 2014). Travel to tropical climates, certain medications that make skin more sensitive, and the male sex were also factors for increased risk of UV exposure (Pinault & Fioletov, 2017; Pinault et al., 2017). The more fragile skin of young people was also a factor, especially when they play a lot outdoors without protection (The Ontario Sun Safety Working Group, 2010; Joshua, 2012). In addition, people who use certain medications or products that make skin sensitive to UV rays (such as antidepressants, antibiotics, diabetes medications, oral contraceptives, immunosuppressants, and some cosmetics) are more susceptible to photoallergic or phototoxic reactions (Monteiro et al., 2016).

3.5.4 Ultraviolet Adaptation Measures

3.5.4.1 Individual Adaptation Measures

Behaviours and Lifestyle

Applying sunscreen is known to be effective in protecting the skin from UV radiation, and wearing sunglasses is effective in protecting the eyes. The shade provided by a hat, long clothing, and infrastructure would be more effective than sunscreen in preventing sunburn and reducing UV exposure (Linos et al., 2012). Several factors can influence the adoption of protective behaviours to reduce exposure to the sun. One of the main barriers is a lack of general knowledge about the risks of solar UV exposure and the appropriate application of sunscreen (Weinstein et al., 2001; Dadlani & Orlow, 2008; Bränström et al., 2010). Other barriers include the thermal discomfort associated with wearing sun-protective (long and thick) clothing in hot temperatures, a positive attitude towards tanning for esthetic reasons, the belief that sun protection results in vitamin D deficiency, the cost of purchasing sun screen, and the perceived ineffectiveness or toxicity of sunscreen (Saraiya et al., 2004; Dadlani & Orlow, 2008; Youl et al., 2009; Bränström et al., 2010; Burnett & Wang, 2011). In practice, most people do not apply enough sunscreen, or apply it unevenly or only to certain parts of their exposed body.

3.5.4.2 Public Adaptation Measures

Awareness

Awareness campaigns have been somewhat effective in encouraging sun protection behaviours, especially when they are widespread and accompanied by more structural changes, such as building shady areas, reducing outdoor time at schools, or distributing sunscreen (Sandhu et al., 2016). This combination of large-scale interventions is associated with a median 11% increase in sunscreen use (Sandhu et al., 2016). A number of governmental and private organizations in Canada promote this type of intervention (Health Canada, 2018). For example, the Sun Safety at Work Canada project aims to support the implementation of sun protection programs in the workplace in collaboration with employers and decision makers (Kramer et al., 2015).

Environmental Monitoring

In terms of monitoring, Environment and Climate Change Canada (ECCC) created the UV Index as a tool to inform Canadians of the harmful potential of UV radiation (Fioletov et al., 2010). In 2018, ECCC began developing a new UV Index forecasting system that would provide hourly and longer-term (four days or more) forecasts, as well as regional and continental maps of UV radiation levels (Tereszchuk et al., 2018). Melanoma monitoring is also conducted by several organizations in Canada, such as the Canadian Cancer Society and the Public Health Agency of Canada (Canadian Cancer Society, 2019; Government of Canada, 2020).

3.5.4.3 Infrastructural Adaptation Measures

Several physical factors can also affect the level of solar UV exposure, such as artificial (e.g., buildings) or natural (e.g., large trees) structures that provide shady areas. Sun protection, in combination with thermal comfort, should be considered in urban planning. Green spaces, for example, can both reduce UV exposure through the shade they provide and increase it by encouraging people nearby to spend more time outdoors (Astell-Burt et al., 2014; Na et al., 2014; Porcherie et al., 2018). The City of Toronto is the first jurisdiction in Canada to include a shade policy in its planning (Kapelos & Patterson, 2014; Holman et al., 2018). Structures that provide shade can also result in reduced vitamin D production by limiting UV exposure. The vitamin D blood levels of individuals living in very dense areas with tall buildings may be up to four times lower than those of people living in an unshaded area (McKinley et al., 2011; Wai et al., 2015).

3.6 Average Cold and Extreme Cold Events

3.6.1 Impacts of Climate Change on Cold – Trends and Projections

Over the past 70 to 100 years, the average winter temperature has increased and there have been fewer extreme cold days, a trend that will continue in the future (Zhang et al., 2019). Warmer temperatures will reduce the length of the cold season across Canada and the intensity and frequency of extreme cold (Zhang et al., 2019). Compared to 1976–2000, most projected decreases in the annual number of frost days (<0°C) under a moderate climate warming scenario (RCP4.5) fall between 25 and 40 days for 2051–2080 and may reach 50 days along the Pacific coast (Prairie Climate Centre, 2019). Under a high-emission scenario (RCP8.5), these reductions are more than 45 days per year in most cases. The reductions tend to be smaller in the Prairies region and more intense in British Columbia and the Maritime provinces.

Continuing the comparison between the 2051–2080 time horizon and the 1976–2000 period, simulations project a decrease in the number of extreme cold days (< −30°C) with climate change. While regions such as Southern Ontario, the Atlantic provinces, and the Pacific coast no longer reach those temperature levels, the Northern Prairies, Northern Ontario, and Northern Quebec are expected to see the number of extreme cold days reduced by 15 to 35 days per year under a high emissions scenario (RCP8.5) (Prairie Climate Centre, 2019). The number of cold days would be virtually reduced to zero in the St. Lawrence Valley and the Southern Prairies (Prairie Climate Centre, 2019). For example, extreme cold days are projected to drop from 52 to 14 in the Northwest (e.g., Yellowknife) and from 13 to two days in the Prairies (e.g., Saskatoon). Even if the reduction was less significant under less severe climate warming, few differences would be observed in Southern Canada.

Projections for the duration of cold spells also vary widely across Canada. Under a moderate emission scenario (RCP4.5), projections for the reduction in the total duration of cold spells range from a single day in Quebec to approximately five fewer days in Northern British Columbia and the Yukon for 2081–2100 (Sillmann et al., 2013). The results under the high emissions scenario (RCP8.5) are similar; the difference between the two scenarios is less than one day for most Canadian regions.

3.6.2 Effects of Cold Weather on Health

Cold temperatures — whether they are extreme or not — are known to increase the risk of cardiovascular, respiratory, and stroke-related illness and mortality (Turner et al., 2012b; Gill et al., 2013; Phung et al., 2016; Ryti et al., 2016; Moghadamnia et al., 2017; Sun et al., 2018) as well as general mortality (Gasparrini et al., 2015; Liddell et al., 2016; Hajat, 2017; Song et al., 2017). The duration of individual cold exposure that lead to these health effects is not well known (Ryti et al., 2016); some effects can be seen up to two weeks following extreme cold, and some take even longer (Kinney et al., 2015; Liddell et al., 2016; Phung et al., 2016; Ryti et al., 2016). Humidity can also influence the effects of cold on health, as both extremes (low and high humidity) appear to exacerbate cold-related mortality and morbidity (Mäkinen et al., 2009; Barreca, 2012; Davis et al., 2016).

3.6.2.1 Mortality

According to a study conducted of 15 Canadian cities, the mortality risk associated with the minimum temperature in Vancouver, Ottawa, Edmonton, and Montréal for the time period 1981 to 2000 was between 19% and 72% higher than the optimal mortality temperature (Martin et al., 2012). In Ontario, each 5°C reduction in winter temperatures corresponded to an average 2.5% increase in fatalities from 1996 to 2010 (Chen et al., 2016). However, another study, using a 30-day lag period, found no relationship between cold temperatures and mortality in Montréal (Goldberg et al., 2011). In Quebec, all-cause mortality is not associated with average temperatures below 18°C, when seasonality and influenza are taken into account (Doyon et al., 2008). The percentage of all-cause deaths due to cold was calculated for 21 Canadian cities and ranged by city from 1.96% to 5.53% between 1986 and 2012 (Gasparrini et al., 2015).

3.6.2.2 Infections

Individuals also change their behaviour during extreme cold events, notably by increasing their time indoors. Cold temperatures thus coincide with the maximum incidence of influenza and respiratory infections such as pneumonia and bronchitis because they seem to promote the spread of such diseases (Mäkinen et al., 2009; World Health Organization, 2013b; Xu et al., 2014a; Bunker et al., 2016) (see Chapter 6: Infectious Diseases). Other infectious diseases can also be more easily transmitted in this way, although cold is also associated with a decrease in the spread of water-borne diseases, as observed in Arctic and sub-Arctic regions (Hedlund et al., 2014; Herrador et al., 2015; Bruce et al., 2016).

3.6.2.3 Hospitalizations and Emergency Department Visits

In a systematic review, the risk of hospitalization was found to increase on average by 2.8% for each degree the temperature decreased below optimal conditions (Phung et al., 2016). In Quebec, the coldest temperatures between 1989 and 2006 were associated with a maximum 12% increase in excess hospital visits for ischemic diseases in winter (Bayentin et al., 2010). There are also more emergency department visits for ischemic heart disease in Quebec in the early winter, and these decrease as the season progresses, indicating a physical and social acclimatization effect (Bayentin et al., 2010). However, cold does not appear to have any particular effect on kidney problems and mental health disorders (Wang et al., 2014; Lim et al., 2018). Furthermore, no relationship was found between extreme cold (first percentile) and emergency department visits for psychological or behavioural problems in Toronto (Wang et al., 2014).

3.6.2.4 Overall Impact on Health

Climate change is expected to have a net effect of mitigating some of the adverse health effects of the cold in Canada. Projections under an average global warming scenario for 15 Canadian cities indicated that the annual rate of deaths due to cold could decrease from three to 19 deaths per 100,000 inhabitants by 2079, compared to current rates, depending on the city (Martin et al., 2012). In addition, warmer winter temperatures encourage individuals to spend more time participating in outdoor activities, which promotes physical activity and social connections. This increased time spent outdoors could also reduce the risk of spreading infectious diseases such as colds, influenza, and lung infections (Mäkinen et al., 2009; Bunker et al., 2016). However, warmer winter temperatures may increase the number of fractures, given that temperatures near freezing and rainfall followed by a significant drop in temperature have been associated with a higher risk of falling, according to a study in Montréal (Morency et al., 2012). Since winter is often associated with increased smog and concentrations of fine particulate matter, this increase could also increase exposure to air pollutants (Jerrett et al., 2005).

3.6.3 Annual Cold and Heat Mortality Comparison

Both globally and in Canada, deaths from cold winter temperatures currently outnumber deaths from heat in summer (Martin et al., 2012; Gasparrini et al., 2015). From 1985 to 2012, 4.5% of all-cause deaths in Canada could be attributed to cold, compared to only 0.5% attributed to heat (Gasparrini et al., 2015). For Canada as a whole, this increases to 6.2% (for cold) and 0.7% (for heat) for the 2010—2019 period (Gasparrini et al., 2017), partly due to the aging of the population. This effect was also observed in Ontario, where, during summer, every 5°C increase was associated with four excess daily deaths; during the winter, every 5°C decrease was associated with seven additional daily deaths (Chen et al., 2016). The effect of cold or heat is often calculated based on the percentiles of average temperatures in a year (fifth percentile and under or first percentile for cold; 95th percentile and over or 99th percentile for heat) to estimate the effect of extreme temperatures.

3.6.3.1 Geography

Unlike heat, which affects cities more because of the presence of urban heat islands, cold appears to have a greater impact in rural areas (Bayentin et al., 2010; Conlon et al., 2011). The effects of cold on health can be felt for weeks after an extreme cold event, while the same can be said for only a week after an extreme heat event (Turner et al., 2012b; Bunker et al., 2016; Ryti et al., 2016; Moghadamnia et al., 2017; Sun et al., 2018). For both heat and cold, daily, weekly, or monthly temperature changes coincide with increased mortality and events, especially cardiac and respiratory events (Lim et al., 2012; Cheng et al., 2014; Vutcovici et al., 2014; Vanasse et al., 2016b).

3.6.3.2 Mortality Projections Up to 2100

A few studies have examined the projected net effect of climate change in Canada on mortality associated with ambient temperatures. These studies suggest that the increase in heat-related mortality is expected to outpace the reduction in cold-related mortality in most, if not all regions. In Quebec, a net increase of 3% in annual mortality was projected for 2080 compared to 1981–1999 (Doyon et al., 2006; Doyon et al., 2008). Conversely, a study of 15 Canadian cities estimated that only four would see a net increase in mortality: London, Hamilton, Regina, and Montréal (Martin et al., 2012). Thus, the net impacts of temperature on excess mortality appear to vary across geographic regions. Temperature-related excess mortality between 2090 and 2099 in Canada is expected to increase compared to the 2010–2019 period under climate change scenarios RCP4.5, RCP6.0, and RCP8.5 (Gasparrini et al., 2017; Lavigne, 2020). Figure 3.4 shows the projected net mortality change across Canada for RCP8.5. Although in simulations some regions show improvements in mortality, the vast majority of health regions, both urban and rural, are expected to experience a net negative impact on health (Gasparrini et al., 2017; Lavigne, 2020). In these two studies, the percentage of all-cause deaths due to heat is lower than those due to cold, regardless of the scenario used.

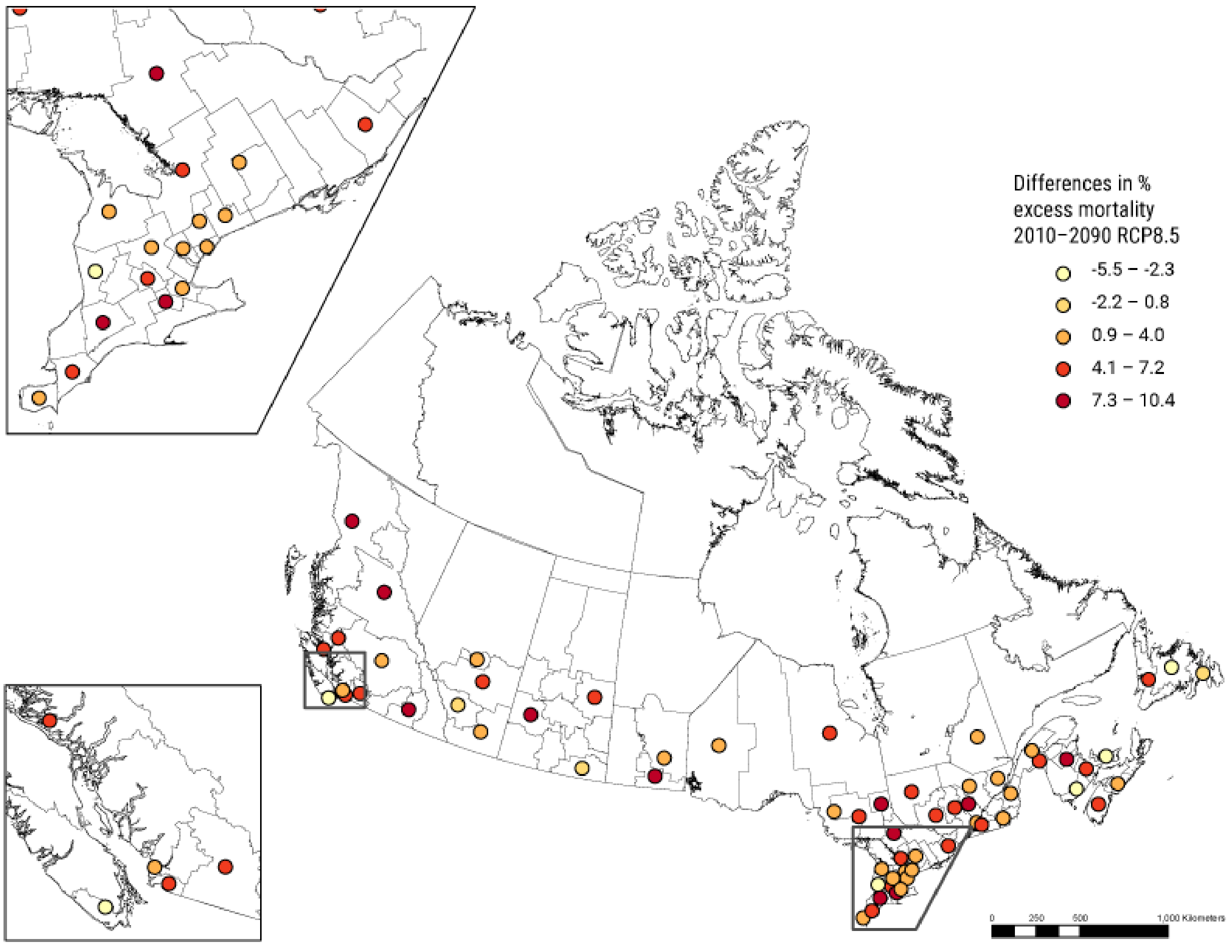


Figure 3.4 Net mortality trends 2090–2099 compared to 2010–2019 under RCP 8.5, simulated across Canadian health administrative regions. The map presents the net result of the combined changes in cold and heat mortality, mainly related to cardiovascular (+2.34% for the country) and respiratory (+7.82% for the country) disease. Source: Lavigne, 2020.

3.6.4 Populations at Increased Risk to Cold

3.6.4.1 Age, Sex, and Gender

Overall, seniors are at a higher risk of experiencing the effects of the cold (Ryti et al., 2016). A meta-analysis calculated that cardiovascular and respiratory mortality in people aged 65 and older increases by 1.7% and 2.9%, respectively, with a reduction of 1°C below optimal temperature (Bunker et al., 2016). On the other hand, some results in Canada indicate that people under 65 are more at risk than seniors. A study in Ontario found that each 5°C decrease in temperature between 1996 and 2010 increased the risk of dying from cardiovascular disease by 8% for those aged 65 and younger, and by 3% for those aged 65 years and older (Chen et al., 2016). Few studies have examined the effects of the cold on children's health (Xu et al., 2012; Song et al., 2017).

A Quebec study corroborated these results and estimated that men under age 65, particularly those aged 45 to 64, are at higher risk than those aged 65 and older and were more likely to have or die from ischemic heart disease during periods of intense cold between 1989 and 2006 (Bayentin et al., 2010). This could be explained by the fact that men generally spend more time outdoors for work or snow removal. This increases their exposure to adverse weather conditions and requires increased cardiovascular effort (Ali & Willett, 2015; Auger et al., 2017e). In Ontario, each 1°C reduction below 0°C between 2004 and 2010 led to a median 15% increase in the median number of visits to the emergency department related to outdoor work (frostbite or hypothermia) (Fortune et al., 2014).

Pregnancy and perinatal periods are critical windows of exposure to cold negative impacts to health. Cold appears to increase the likelihood of adverse effects at birth or during pregnancy, such as eclampsia, low birth weight, and premature birth (Strand et al., 2011; Poursafa et al., 2015).

3.6.4.2 Chronic Diseases

Some pre-existing diseases may also make people more susceptible to the effects of the cold. In Quebec, one study suggested that regions with higher smoking rates among those 45 to 64 years old have higher rates of hospitalization for ischemic heart disease in winter (Bayentin et al., 2010). This increase was also observed among smokers and alcohol drinkers in the United Kingdom (Sartini et al., 2016). In Toronto, people with pre-existing kidney or cardiac conditions had a higher probability of being admitted to the emergency department for cardiovascular reasons in extreme cold compared to those without this type of problem (Lavigne et al., 2014). This was observed in China among those with pre-existing respiratory diseases (Wang et al., 2016a). The impact of pre-existing morbidity on susceptibility to cold is also age-dependent.

3.6.4.3 Material and Social Deprivation

The impacts of cold on individuals with low socio-economic status has not been studied extensively. In Quebec, the effects of cold on emergency department visits for ischemic heart disease are most significant in areas of low socio-economic status (Bayentin et al., 2010). In Portugal, low socio-economic status has been associated with winter mortality, with the relative risk being 1.75 times higher among those with low socio-economic status compared to those with high socio-economic status (Almendra et al., 2017). Winter heating costs can lead low-income and even middle-class individuals to turn down the heat to meet other needs (rent, food, etc.), forcing them to live in a cold home (Liddell & Morris, 2010; Howden-Chapman et al., 2012; Rezaei, 2017). A cold home increases the risk of exposure to outdoor cold and affects the perceived mental well-being and emotional resilience of residents (Marmot Review Team, 2011). Children appear to have a higher risk of developing respiratory problems, eating fewer calories, and spending more time indoors when the home is cold, which jeopardizes their physical and cognitive development (Liddell & Morris, 2010;

Marmot Review Team, 2011). Energy insecurity in Canada averaged 8% in 2015, with peaks in the Maritimes and Saskatchewan (Canada Energy Regulator, 2017). This rate is three to four times higher than that in Scandinavian countries, but comparable to the European average (Thomson et al., 2017).

3.6.4.4 People Experiencing Homelessness

People experiencing homelessness are also very exposed to cold. A study in Paris, France, estimated that people experiencing homelessness accounted for 62% of those admitted to emergency departments for hypothermia or frostbite in winter from 2005 to 2009 (Rouquette et al., 2011). Many Indigenous peoples live in inadequate housing that require minor to major repairs (Statistics Canada, 2020), and may not be protective of cold temperatures. Indigenous peoples account for 10% to 90% of people experiencing homelessness in 18 Canadian cities, from Halifax to Vancouver (Patrick, 2014). They are therefore disproportionately affected by the effects of cold.

3.6.5 Cold Adaptation Measures

3.6.5.1 Public Warning System

Warning systems should consider wind chill and the temperature felt when setting thresholds, since these variables are associated with the cardiovascular effects of cold on health (Lin et al., 2018). It is difficult, however, to make cold thresholds operational for preventive warning systems, given that wind and humidity forecasts have limited accuracy (Laaidi et al., 2013). Forecasting models do exist, nevertheless. In Quebec, depending on the climate region and based on the 1994–2015 period, health thresholds for a 2-day forecast based upon 25% excess mortality were set at between −15°C and −23°C during the day and −20°C and −29°C at night (Yan et al., 2020). In addition, thresholds based upon a 7% excess hospitalization, were identified as between −13°C and −23°C during the day, and between −17°C and −30°C at night. The thresholds used should also consider the climatic and anthropogenic characteristics of different regions. In Ontario, for example, the temperature threshold below which emergency department visits increase is lower in the North than in the South (VanStone et al., 2017). Health authorities should also consider that intense cold periods can affect the volume of emergency department visits for at least one week and should adjust their capabilities accordingly (Ryti et al., 2016; Lin et al., 2018; Sun et al., 2018). In Canada, schools can also close in extreme cold as part of efforts to keep students safe.

3.6.5.2 Housing Insulation

The most common cold adaptation measures for individuals include wearing warm clothing and increasing time spent indoors, but people with cold homes will still be affected by staying indoors. Housing insulation reduces energy costs and makes it easier to maintain optimal indoor temperatures. Individuals who have benefited from a housing insulation program report better overall health and mental well-being after these renovations (Liddell & Morris, 2010; Howden-Chapman et al., 2012). For example, in New Zealand people aged

65 and over who had previously been hospitalized for cardiovascular or respiratory reasons were at a lower risk of death as a result of improved insulation in their homes, compared to a control group (Preval et al., 2017).

3.6.5.3 Occupational Health and Safety

The Canadian Centre for Occupational Health and Safety sets acceptable working temperature thresholds based on weather variables and the type of work (Canadian Centre for Occupational Health and Safety, 2017). All provinces and territories have adopted these measures as legal limits or guidelines. In addition, several international standards for best practices in cold weather risk assessment and prevention are available (ISO 11079, ISO 15743, etc.) (Holmer, 2009; Mäkinen et al., 2009).

3.7 Drought

3.7.1 Impacts of Climate Change on Drought – Trends and Projections

Past observations do not indicate an increasing trend in the occurrence and severity of droughts in Canada (Bonsal et al., 2019). Climate change may change this trend, however. Although annual rainfall amounts will continue to increase (mainly due to the increase in rain outside the summer months), summer precipitation is projected to decrease in Southern Canada in the late century, under the high emissions scenario (Zhang et al., 2019; see also section 3.9 Precipitation and Storms). As a result, precipitation quantities will be reduced during the season when plants and agriculture need it most, particularly in the Prairie provinces (Prairie Climate Centre, 2019). Figure 3.5 shows projected average annual precipitation for Canada for 2021–2050. In addition, warming temperatures will increase water evaporation. As a result, the impact of climate change on drought in Canada will depend on the net effect of changes in the frequency, duration, and intensity of these conflicting drivers and is therefore difficult to estimate (Bonsal et al., 2019). Still, the Southern Prairies and interior regions of British Columbia are expected to experience an increase in droughts and water shortages in the summer through the end of this century (Bonsal et al., 2019). A similar projected has been made for Southern Quebec, where the maximum number of consecutive days without precipitation is expected to increase in summer and the annual number of unusual humidity events is expected to increase (Ouranos, 2015). Environments that rely on melting snow or ice for their water supply during dry seasons are also more likely to experience an increase in the number and intensity of droughts due to decreased overall snow and ice cover (including glacier loss), and change in streamflow seasonality due to increased winter flows, earlier snow melt, and reduced summer streamflow (Bonsal et al., 2019) (see Chapter 7: Water Quality, Quantity, and Security).

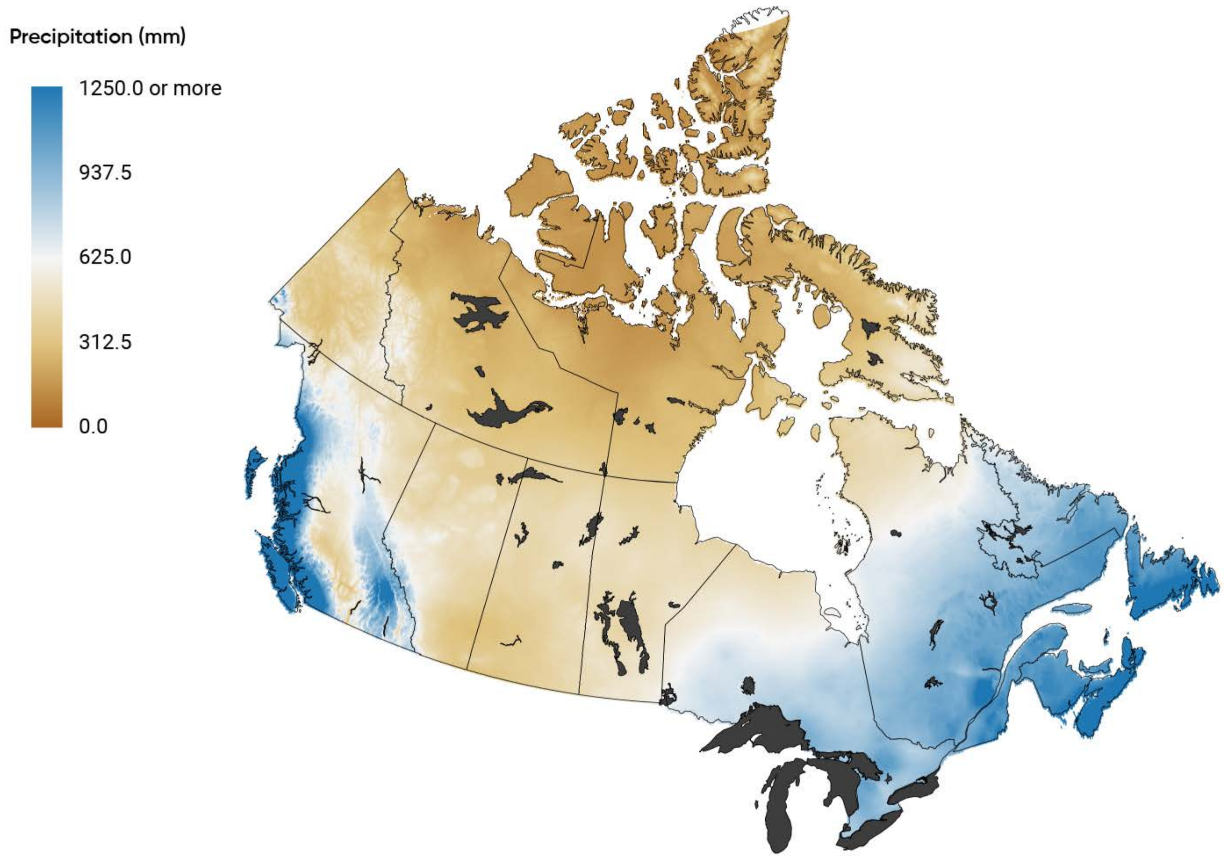


Figure 3.5 Total annual precipitation, average projected for 2021–2050, under a high emissions scenario (RCP 8.5). Blue areas correspond to areas with significant amounts of precipitation, while brown areas correspond to areas with very low precipitation, increasing the risk of drought. Source: Prairie Climate Centre, 2019.

3.7.2 Effects of Drought on Health

3.7.2.1 Indirect Health Impacts from Lower Air Quality

Drought increases the amount of dust ($PM_{2.5}$[5] and PM_{10}) in the air, as particles are more mobile when not weighed down by moisture (see Chapter 5: Air Quality). In the United States, overall $PM_{2.5}$ concentrations are projected to increase by 16% in 2100 compared to 2000, simply due to the increased number of droughts (Wang et al., 2017). Because fine particulate matter increases the risk of mortality from respiratory and cardiovascular diseases (Kim et al., 2015), the increased frequency and intensity of droughts could increase overall mortality. For example, it has been estimated that the increase in fine dust concentrations in the air

5 $PM_{2.5}$ is particulate matter (PM) with a median diameter of 2.5 microns or less. $PM_{2.5}$ can penetrate deeply into human lungs.

in the Southwestern United States could increase mortality from 24% to 130% from 2076–2095, compared to 1996–2015 (Achakulwisut et al., 2018). This trend was observed in the United States, where periods of worsening drought conditions increased the mortality rate by 1.55% between 2000 and 2013 compared to other periods (Berman et al., 2017). Droughts also indirectly affect air pollutant concentrations by increasing wildfires (see Chapter 5: Air Quality).

3.7.2.2 Infectious Diseases

Winds, combined with dry weather, can also facilitate the transport of pollens, mould, fungi, bacteria, and other organic matter (Stanke et al., 2013). Droughts can cause and exacerbate allergic and respiratory symptoms and promote the spread of infectious diseases. Related respiratory diseases include bronchitis, sinusitis, pneumonia, and asthma (Yusa et al., 2015; Doede & Davis, 2018). Some evidence points to an increase in cases of vector-borne diseases such as West Nile virus and encephalitis, during droughts, although a decrease is observed for other diseases, such as Lyme disease (Yusa et al., 2015) (see Chapter 6: Infectious Diseases).

3.7.2.3 Water-Borne Diseases

Droughts can increase pathogen concentrations in water and facilitate the transport of organic matter to water bodies during subsequent rainfall (Funari et al., 2012; Cann et al., 2013). As a result, they may increase the risk of water-borne diseases through surface water, although few studies have evaluated the effects of droughts in this regard (Levy et al., 2016) (see Chapter 7: Water Quality, Quantity, and Security). In some rural Quebec municipalities, the risk of gastrointestinal disease was at least twice as high within four weeks of very low precipitation events (Febriani et al., 2010). In Greater Vancouver, the number of *Cryptosporidium* and *Giardia* cases increased significantly up to six weeks after a heavy rainfall day following a severe drought (Chhetri et al., 2017).

3.7.2.4 Food Security

Droughts weaken crops, predisposing them to mycotoxin contamination (toxins produced by certain moulds) and making them vulnerable to insect attacks (van der Kamp, 2016; Medina et al., 2017). Declining agricultural yields can increase consumer prices and affect people experiencing food insecurity due to social disparities (see Chapter 8: Food Safety and Security).

Areas such as the Southern Prairies and Prince Edward Island, where agriculture is a significant part of their economy and identity, are more vulnerable to droughts. For example, droughts in 1980 and 2001–2002 each cost Canadians an estimated $5.8 billion, excluding health costs (Wheaton et al., 2008; Diaz et al., 2016). Droughts reduce agricultural productivity, increase personal debt for farmers, devalue land, and reduce employment opportunities in rural areas (Guiney, 2012). By reducing the economic viability of rural areas, droughts can result in rural exodus and perpetuate a vicious cycle of vulnerability (Vins et al., 2015). This loss of viability in rural areas can ultimately affect the mental and social health of the people living there.

3.7.3 Populations at Increased Risk to Drought

3.7.3.1 Rural Living

Rural populations are at increased risk to impacts of droughts compared to urban populations because they are generally more dependent on agricultural activities for their economic well-being and because their proximity to natural environments means that the deterioration of the environment affects them more directly. The resulting financial, social, and emotional stress can negatively affect the psychosocial well-being of rural populations. However, these effects have not been studied extensively in a Canadian context; most studies on the subject have been conducted in Australia and may not be representative of Canada (see Chapter 4: Mental Health and Well-Being).

3.7.3.2 Psychosocial Health

Australian farmers who report that droughts have significantly reduced their agricultural productivity have more mental health problems and a lower level of psychological well-being compared to unaffected farmers (Edwards et al., 2015). Rural children and adolescents affected by Australian droughts report higher-than-normal levels of emotional and relationship distress (Dean & Stain, 2010; Carnie et al., 2011).

Drought duration and intensity are determining factors of the impact a drought can have on the psychological distress of affected populations. In Australia, a drought of more than one year increased the incidence of psychological distress among rural residents by 6% (OBrien et al., 2014). In extreme cases, droughts may also increase the suicide rate in some population subgroups (Gunn et al., 2012; Hanigan et al., 2012). For example, rural men aged 10 to 49 had a higher risk of suicide during intense droughts (up to 15%) (Hanigan et al., 2012). On the other hand, available data are somewhat contradictory for women and seniors, who, in some cases, were at a lower risk of suffering from psychological problems or committing suicide (Hanigan et al., 2012; Powers et al., 2015; Crnek-Georgeson et al., 2017). For urban populations, mental health risks do not appear to be affected by droughts regardless of their duration or intensity (Gunn et al., 2012; Hanigan et al., 2012; OBrien et al., 2014).

3.7.3.3 Food Insecurity and Malnutrition

Drought-related stress and financial insecurity can also have a negative impact on food quality, as demonstrated by studies in Australia (see also Chapter 8: Food Safety and Security). Rural populations affected by a particularly long and intense drought between 2001 and 2008 ate more high-sugar and high-fat foods compared to those who were not affected or for whom the drought was shorter (Friel et al., 2014). Children are particularly at risk because the quality of their diet is critical to their physiological and cognitive development (Martinez Garcia & Sheehan, 2016). In addition to the agricultural sector, the economic viability of the forest industry and its workers may also be compromised by droughts, as they fuel wildfires (Bonsal et al., 2011).

3.7.3.4 Age, Sex, and Gender

People vulnerable to the effects of droughts are also vulnerable because of associated increases in pollutant concentrations in the air and water. In children, droughts can increase the risk of developing and exacerbating respiratory problems. In California, the number of emergency department visits for childhood asthma doubled in the years of severe drought from 2012 to 2016 compared to previous years, with children close to farmland at greater risk (Doede & Davis, 2018). Seniors, people with chronic diseases, fetuses during pregnancy, low-income individuals, and outdoor workers are also more exposed or sensitive to air pollutants, which can be amplified during droughts (see Chapter 5: Air Quality). In addition, children, seniors, and immunocompromised people are at higher risk of contracting water-borne diseases (Funari et al., 2012; Cann et al., 2013).

3.7.4 Drought Adaptation Measures

3.7.4.1 Awareness of Psychosocial Impacts

Rural populations are more reluctant to seek help when they need it (Berry et al., 2011; Gunn et al., 2012). In particular, the stigma attached to mental health problems decreases the likelihood of people seeking help for these types of problems. Promoting mental health literacy, organizing social events in times of drought, establishing a telephone support line, as well as creating psychosocial programs, can promote social acceptance of mental health problems and of seeking help, if necessary (Hart et al., 2011).

3.7.4.2 Financial Support Programs and Monitoring and Warning Systems

Several rural Canadian communities have implemented drought adaptation measures. Provinces such as Saskatchewan and Alberta have implemented drought monitoring systems, emergency plans for extended dry conditions, and programs to improve environmental management infrastructure (irrigation, reservoir, etc.) (Hurlbert & Gupta, 2016). A drought monitoring and reporting tool is also available across Canada (Agriculture and Agri-Food Canada, 2021). Low-labour agriculture, crop diversification and rotation, as well as the use of species more resistant to dry conditions, are other options to reduce the vulnerability of crops and people working in agriculture. These measures were used during droughts in the Prairies in 2001 and 2003, where they reduced losses (Abbasi, 2014; Diaz et al., 2016). Nevertheless, infrastructures and strategies are often implemented on the basis of past climate data and are therefore not adapted to the increasing frequency and intensity of drought (Mcmartin et al., 2018). In California, it was estimated that a water management policy using past data would not meet water demands in future droughts. It would underestimate water supply needs by up to 58% compared to an adaptive policy that takes account of future climate conditions (Georgakakos et al., 2012). Vodden & Cunsolo (2021) identify adaptation options to better prepare for future drought impacts and reduce financial stress they cause. Such options include winter water storage to feed summer irrigation, agroclimatic atlas to support the development of drought-adapted crop varieties and improved infrastructure such as dams or intake pipes (Warren & Lulham, 2021).

3.7.4.3 Monitoring the Indirect Impacts of Drought on Air and Water Quality

Monitoring air quality and water-borne diseases that may be affected by droughts makes it easier to implement preventive or reactive responses to protect health. For example, Environment and Climate Change Canada's Air Quality Health Index (AQHI) informs the public in semi-real-time about the immediate risks associated with air quality in some 60 communities across 10 Canadian provinces (Environment and Climate Change Canada, 2019a). The AQHI provides information about when certain thresholds are exceeded, including on adaptation measures for the general public and certain subgroups of vulnerable populations (Environment and Climate Change Canada, 2019a) (see Chapter 5: Air Quality). Air quality maps are also available in quasi-real-time across North America through automated analysis of satellite images (AirNow, 2021). However, pollen monitoring remains seriously lacking in several Canadian regions compared to Europe or the United States, as shown in Figure 3.6 (Buters et al., 2018). Improving water treatment facilities could also reduce the incidence of water-borne diseases in the event of drought (see Chapter 7: Water Quality, Quantity, and Security). Other strategies to restrict water consumption voluntarily or in a mandatory way during droughts can also help to better allocate water resources and limit agricultural losses (Yusa et al., 2015).

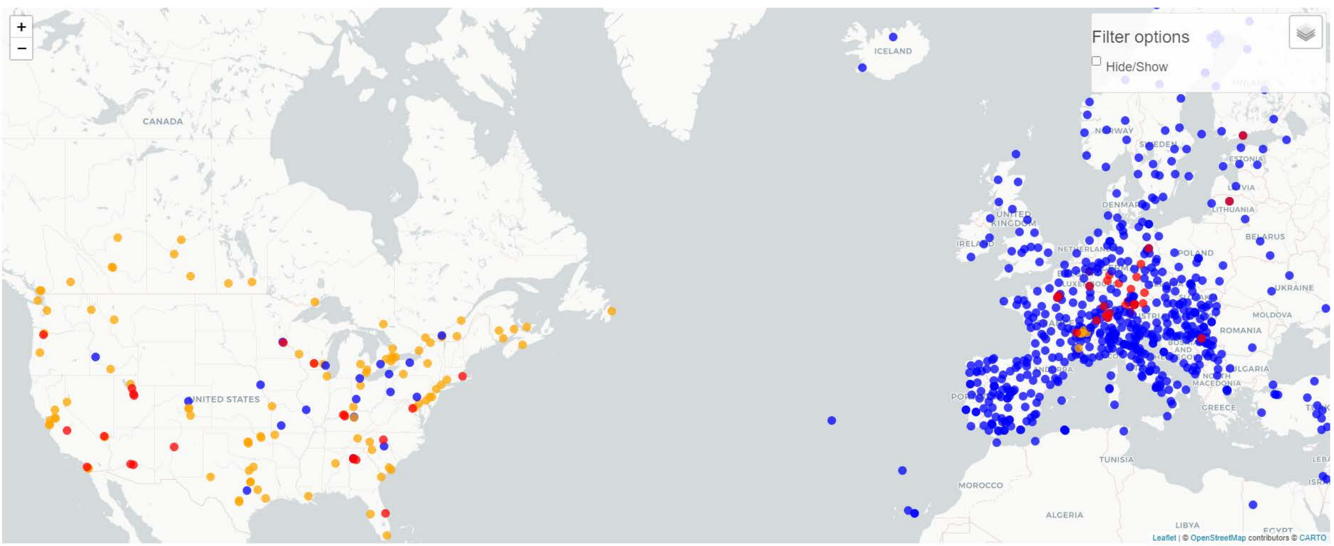


Figure 3.6 Global map of pollen and fungal spore monitoring stations. Blue points (Hirst sampling station), red (automatic sampling station), orange (other manual sampling station). Source: Buters et al., 2018 and <https://oteros.shinyapps.io/pollen_map/>.

3.8 Wildfires

3.8.1 Impacts of Climate Change on Wildfire – Trends and Projections

Forest area affected by fires doubled in Canada between the 1970s and early 2000s, mainly due to climate change (Gillett et al., 2004). One study estimated that the fire risk for 2010–2020 in Western Canada would increase more than it would have been without the anthropogenic influence of climate change (Kirchmeier-Young et al., 2017). Western Canada experienced significant increases in the number of major fires and the area burned between 1959 and 2015 (Hanes et al., 2019). Climate change has reportedly increased the area burned seven- to 11-fold during the extreme 2017 fire seasons in British Columbia (Kirchmeier-Young et al., 2019). This trend is expected to continue and grow with climate change in all regions of Canada by the end of the century (Flannigan et al., 2005; Flannigan et al., 2009). The number of days of uncontrolled wildfire could double or even triple by 2100 in British Columbia and the boreal forest (Wotton et al., 2017).

There are three reasons for these increases. First, warmer temperatures mean a longer fire season. For example, the fire season has been extended in the interior of British Columbia, Alberta, and Northern Ontario (Albert-Green et al., 2013; Hanes et al., 2019). Second, warmer conditions increase lightning strikes, driven by increased thunderstorms in a warmer/more humid environment, which increase the risk of fire (Romps et al., 2014). Third, warmer temperatures, coupled with earlier spring snow and higher spring/summer extreme temperatures, dry out forest fuels unless there is a significant increase in precipitation (Flannigan et al., 2016). Furthermore, burning forests releases GHGs that are responsible for climate change, creating a vicious cycle (Prairie Climate Centre, 2019). Most climate change scenarios in Canada do not project increases in precipitation that would offset the drying effect of warmer temperatures. Finally, climatologists do not always include behavioural factors in their projections, although humans are responsible for about 50% of bush or wildfires (Van Wagner, 2015). The greater proximity of the forests to where people live due to the expansion of urban areas and roads can also contribute to an increase in wildfires, particularly in the southern part of the country.

Air pollutant emissions from wildfires are a health concern. Four factors influence the amount of pollutant emissions from wildfires: the area burned, the amount of fuel burned, the completeness of combustion, and the amount of pollutant emissions in relation to the amount of fuel burned (emission factor). The amount of fuel burned and area burned are projected to increase in all Canadian forests by 2100 as a result of climate change (Wotton et al., 2017). Ultimately, wildfire pollutant emissions could double across Canada by the end of this century.

3.8.2 Effects of Wildfires on Health

The health risks associated with air pollution generated by wildfires are addressed more fully in Chapter 5: Air Quality, along with a discussion of populations at increased risk, and adaptation measures. A summary of pertinent information for this chapter is provided below.

3.8.2.1 Wildfire Smoke Characterization

The health burden associated with wildfires is related mainly to emissions of air pollutants such as fine particulate matter ($PM_{2.5}$), carbon monoxide, nitrogen oxides, and volatile organic compounds (Black et al., 2017). The composition of wildfire smoke is highly variable and depends on vegetation type and weather conditions. Wildfire smoke can spread over long distances, and consequently affect populations several thousand kilometres from the combustion site (Le et al., 2014; Lutsch et al., 2016). The adverse effects of wildfire smoke on human health are likely the result of similar mechanisms as for ambient fine particles, such as causing inflammation and oxidative stress as well as suppressing immune responses (Reid et al., 2016; Black et al., 2017; Cascio, 2018).

3.8.2.2 Smoke from Wildfires and Mortality

Studies have demonstrated a link between all-cause mortality and exposure to wildfire smoke (Youssouf et al., 2014; Reid et al., 2016; Cascio, 2018). Using its Air Quality Benefits Assessment Tool, Health Canada estimated 54–240 premature deaths due to short-term exposure and 570–2500 premature deaths due to long-term exposure could be attributed annually to fine particulate matter emissions from wildfires between 2013 and 2018, excluding 2016 (Matz et al., 2020). Although results vary depending on year and location and intensity of the fires, the majority of the premature deaths were associated with British Columbia and Alberta, followed by the Western provinces of Saskatchewan and Manitoba, and the Northwest Territories. For the continental United States, an estimated 1500 to 2000 and 8700 to 32,000 premature deaths per year were attributed to short-term and long-term exposure to $PM_{2.5}$ from wildfires, respectively, from 2008 to 2012 (Fann et al., 2018).

Considering both RCP4.5 and RCP8.5 climate scenarios compared to the early 21st century, premature mortality from wildfire-$PM_{2.5}$ was estimated to double for the continental United States by late 21st century, even as total premature mortality attributable to all $PM_{2.5}$ (anthropogenic emissions) is expected to decrease (Ford et al., 2018).

3.8.2.3 Wildfire Smoke and Respiratory and Cardiovascular Disease

Exposure to wildfire smoke has increased the exacerbation of respiratory diseases, particularly asthma, chronic obstructive pulmonary disease, bronchitis, and pneumonia (Henderson & Johnston, 2012; Cascio, 2018). In comparison, the relationship between wildfire smoke exposure and cardiovascular disease remains inconclusive in the literature, as some studies demonstrate an association, while others report null findings (Reid et al., 2016; Cascio, 2018).

Wildfire-related health studies in Canada have been conducted primarily in British Columbia. For the 2003 fire season, a study estimated that every 30 $\mu g/m^3$ increase in PM_{10} concentrations increased the likelihood of consulting a physician for respiratory problems by 5%, for asthma specifically by 16%, and of being admitted to the hospital for respiratory issues by 15% (Henderson et al., 2011). No association with physician visits or hospital admissions for cardiovascular outcomes was observed in this study. Another study also determined that most days with air concentrations of $PM_{2.5}$ over 25 µg/m^3 during the 2014 fire season were associated with greater than anticipated increases in doctor visits for asthma and in salbutamol (asthma medication) dispensations (McLean et al., 2015). In the Northwest Territories, primary care visits for asthma, cough, pneumonia, and salbutamol prescriptions increased in 2014 during a severe fire season, compared to 2013 and 2012 (Dodd et al., 2018a).

3.8.2.4 Direct Exposure to Wildfires and Psychosocial Health

The effects of wildfires on psychosocial health, including property loss, evacuations, and environmental degradation, have also been investigated. Six months after the 2016 Fort McMurray fires, 20% of residents surveyed met the criteria for generalized anxiety disorder (Agyapong et al., 2018). People with certain risk factors (pre-existing anxiety disorder, having witnessed the destruction of one's own home, living in other accommodations after the fires, limited family or government support, and seeking psychological counselling) were two to seven times more likely to meet the criteria for the disorder. This incidence of depression and anxiety increased with the duration of evacuation and the extent of financial loss (Cherry & Haynes, 2017). In the Northwest Territories, the 2012 and 2013 wildfires appear to have exacerbated feelings of loneliness, fear, stress, and uncertainty in the population, including in the First Nations, Inuit, and Métis Indigenous populations (Dodd et al., 2018a; Dodd et al., 2018b). Prolonged smoke episodes related to these wildfires would have increased indoor time and caused respiratory problems (Dodd et al., 2018b). Some studies in Australia and Greece have also shown that people who suffered loss or health problems, or who were evacuated as a result of wildfires, are more likely to experience trouble sleeping, anxiety, and hostile feelings as well as depressive and post-traumatic symptoms (Finlay et al., 2012; Psarros et al., 2017; Thompson et al., 2017). Wildfire smoke on its own has not been associated with hospitalizations and counselling for mental illness (Reid et al., 2016). Mixed results about the relationship between wildfire smoke exposure and cardiovascular health could be explained by the level of psychosocial impacts felt during an event; the combined effect of air pollutant inhalation and psychological stress may be conducive to adverse cardiovascular effects (Reid et al., 2016).

3.8.2.5 Water-Borne Diseases

Wildfires can also raise levels in water of organic matter, sediment, and heavy metals, such as nitrogen, phosphorus, arsenic, mercury, and manganese (Smith et al., 2011; Khan et al., 2015). Wildfires followed by heavy rainfall are particularly conducive to deteriorating water quality (see Chapter 7: Water Quality, Quantity, and Security). These increases can be harmful to people who draw their water from unfiltered sources and problematic for filtration plants during intense wildfires. Wildfires can also weaken coastal environments, making them vulnerable to erosion and flooding, which can also affect water quality.

3.8.3 Populations at Increased Risk to Wildfires

While the effects of wildfire smoke are important, there are other factors important to health that can compound the overall impacts of fire.

3.8.3.1 Pre-Existing Morbidity

Studies of populations at increased risk to wildfire smoke are rare (Reid et al., 2016). Populations at risk are often inferred from studies of the health effects of air pollutants from all sources (Rappold et al., 2017; Cascio, 2018) (see Chapter 5: Air Quality). However, several studies have suggested that people with asthma, chronic obstructive respiratory diseases, or lung infections are more likely to experience the harmful effects of smoke (Henderson & Johnston, 2012; Reid et al., 2016).

3.8.3.2 Seniors

Seniors seem more susceptible to wildfire smoke health impacts (Liu et al., 2017) and several studies, both in animal and human models and studies, suggest that oxidative stress and systemic inflammation from exposure to biomass particles could be involved (Youssouf et al., 2014). In the Northeastern United States, hospitalization rates for respiratory and cardiovascular problems in people aged 65 years and older during smoke events increased by 49.6% and 64.9%, respectively, compared to the period before smoke events (Le et al., 2014). In the Western United States, climate change could lead to a modest increase of 178 respiratory hospital admissions among people aged 65 and older from 2046 to 2051 (Liu et al., 2016b).

3.8.3.3 Children

In the 2011 wildfires near Slave Lake, Alberta, affected children experienced symptoms of post-traumatic stress six months after the event, but these symptoms disappeared after a year (Townshend et al., 2015). Younger children with several stress factors (death of a loved one, disease, academic problems, etc.) or whose home was destroyed in a wildfire were at higher risk of experiencing symptoms without resolution (Felix et al., 2015; Townshend et al., 2015). During the Fort McMurray wildfires in 2016, grades 7 to 12 students who were exposed to the wildfire showed a higher prevalence of depressive symptoms, suicidal ideation, and smoking than students the same age living in Red Deer, an Alberta city unaffected by these events (Brown et al., 2019). These children also had lower self-esteem and quality of life scores.

3.8.3.4 Social Inequities

In the United States, Black people, those with incomes below the median, and women were at a higher risk of being admitted to the emergency department for respiratory problems on smoke days (Liu et al., 2017). During a 2008 wildfire in North Carolina, rural counties with lower education, employment, income, and social capital levels presented a higher risk of emergency department admissions for asthma and heart failure compared to counties more privileged along those measures (Rappold et al., 2012). The two factors explaining the strongest correlations were income and income inequality. Women appear to be more likely than men to experience depression as a result of evacuation due to wildfire or related job loss (Cherry & Haynes, 2017).

3.8.3.5 Indigenous Populations

In addition to impacts on respiratory and cardiovascular diseases, wildfires can also disrupt traditional and subsistence activities in northern First Nations, Inuit, and Métis communities, leading to psychological impacts such as stress, anxiety, and depression (Cunsolo Willox et al., 2015; Manning & Clayton, 2018). Persistent smoke from the wildfires in summer 2014 disproportionately affected the physical, and psychosocial health of people living in First Nations communities in Northwest Territories (Dodd et al., 2018a; Dodd et al., 2018b).

3.8.3.6 Safety of Wildland Firefighters

Wildland or forest fire fighters are at greater risk of health effects from fires. They are more likely to experience decreased lung capacity as well as increased oxidative stress and respiratory symptoms, but there is little evidence to suggest that related mortality and morbidity are higher in the long term (Adetona et al., 2016; Black et al., 2017). A study in Greece also indicated that more of these workers experienced post-traumatic symptoms, particularly seasonal workers or workers fearful of dying in a fire, workers exhibiting symptoms of depression, or workers with personality characteristics of neuroticism (Psarros et al., 2018).

3.8.4 Wildfire Adaptation Measures

3.8.4.1 Individual Adaptation Measures

For clean air shelters and homes, high-performance filters can substantially reduce the amount of fine particulate matter in the air, which could mitigate effects on respiratory and cardiovascular health, depending on sources of pollution in the building, the size of the building, and the ventilation rate (Barn, 2014). To encourage people to adopt needed action to protect health, simple messages like “Don’t go outside” or “Don’t do outdoor physical activity” can be used. It is also best to not require infrastructure changes such as buying portable air filters or air conditioners (Dix-Cooper et al., 2014). The health effects of reduced time outdoors during an event have not been adequately assessed but are likely to depend on the quality of the home and its facilities. Seniors, people who do not understand the language used in messages sent out, and people who are more isolated are more difficult to reach and therefore less likely to follow these measures.

3.8.4.2 Public Adaptation Measures

Monitoring and Warning System

Given the complexity of calculating source emissions and the relative cohesion of a smoke plume over large distances, including wildfires in air quality forecasts is a significant challenge (see Chapter 5: Air Quality). Environment and Climate Change Canada has implemented Canada's Wildfire Smoke Prediction System (FireWork) to estimate wildfire smoke trajectory across North America over the coming 48 hours (Environment and Climate Change Canada, 2019b). In British Columbia, adjustments have been adopted for the AQHI to more accurately reflect the impacts of wildfire smoke on air quality, public perception of risk, and population health in British Columbia. The AQHI and the modified index (AQHI+) were both associated with all-cause mortality, physician visits for circulatory and respiratory causes, and with prescription of asthma medication. During the wildfire season, the modified index exhibited a better fit for asthma-related outcomes and, during periods with intense wildfire activity, for all respiratory outcomes (Yao et al., 2020). Air quality forecasts for wildfires continue to improve (Chen et al., 2019) and forecasts have been associated with some respiratory health outcomes (Yao et al., 2013; Yao et al., 2020). Action levels for interventions to reduce exposure can be based upon air quality indexes values or pollutant concentrations. Assuming fairly widespread adoption of measures by the public, a North Carolina simulation found that 24- or 48-hour forecasts could help reduce emergency department visits for asthma and heart failure if the threshold level is for forecasted concentrations of 20 μg/m^3 $PM_{2.5}$ compared to higher concentrations such as 50 μg/m^3 (Rappold et al., 2014).

Preparation and Action Plan

To better prepare the health care system and population for wildfires, the National Collaborating Centre for Environmental Health and British Columbia Centre for Disease Control recommended 13 priority actions based on consultations with 29 health care professionals (Maguet, 2018). These priorities relate to the following themes: documenting the experiences in implementing smoke shelters and establishing guidelines for identifying and using them; soliciting the active participation of local public health care professionals in planning emergency responses; and raising awareness among health care professionals about the effects of wildfires and associated adaptation measures. Allowing pharmacists to prescribe or renew certain medications without a physician's prescription in emergency situations could also reduce the vulnerability of some people with pre-existing diseases that need to be treated with medication (Mak & Singleton, 2017).

Evacuations

The effects on health of wildfire evacuations as an adaptation measure are mixed and should only be undertaken when public safety is not compromised. Several studies have shown that some evacuations have resulted in increased mortality and morbidity among institutionalized individuals, in spreading infectious disease in shelters, and in compromised health and mental well-being in both adults and children (Stares, 2014). Indigenous Peoples often experience disproportionate adverse impacts related to evacuation (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). The positive effects of evacuations have not been assessed and are difficult to document. These results are consistent with other studies on the health effects of evacuations (Munro et al., 2017; Thompson et al., 2017). In short, the harmful effects of wildfire smoke can be reduced by distributing high-performance filters, making smoke shelters available in affected communities, sending out simple messages encouraging people to stay indoors using communication methods that reach the most isolated people of society or those who are less likely to understand, and evacuating populations for whom the health risks of staying outweigh those associated with evacuation. High perception of risk and past property damage increases the likelihood that an individual will evacuate before and during a wildfire, which underscores the importance of raising awareness among affected populations (Thompson et al., 2017).

3.8.4.3 Infrastructural Adaptation Measures

Land-Use Planning

Containing urban sprawl is an adaptation measure that limits both direct exposure (heat) and indirect exposure (smoke) to wildfire health hazards. To limit wildfire exposure, municipalities can limit their urban perimeter and keep construction projects, as well as identifying natural buffer zones to restrict development in the wildland urban interface. Cities that now have agricultural activities in the surrounding area are also less at risk of wildfire damage because agricultural land can create a buffer zone (Darques, 2015). Planting more fire-resistant vegetation at the edge of a forest can also reduce the severity of some wildfires (Fernandes, 2013).

Built Environment

Home adaptation is also a key factor in mitigating wildfire risk. Most infrastructure losses are caused by wind-propelled ash deposited on buildings and by vegetation burning near buildings. As a result, using non-combustible materials for homes and thinning the surrounding vegetation up to 30 metres from the building are both associated with a significant decrease in infrastructure losses during a wildfire (Moritz et al., 2014). Programs, such as FireSmart (<https://firesmartcanada.ca/>), offer a variety of effective methods for adaptation.

Prescribed Burning

Prescribed burning of combustible material has been presented as an adaptation option to reduce the occurrence and intensity of wildfires (Fernandes, 2013). Results of its effectiveness are mixed, however. Since organic combustible materials renew quickly in the forest, prescribed burning is most effective as part of the initial response when a wildfire occurs or when it involves permanent reduction in combustible materials (Enright & Fontaine, 2014). Prescribed burning requires treatment of a significant portion of the forest to be effective, which incurs substantial costs. Repeated burning also increases the amount of pollutants in the air, exposing nearby residents to the associated health risks (Navarro et al., 2018). Without assessing the associated costs, a study in Europe found that systematic and widespread use of prescribed burning could reduce the projected increase in the area burned under future climate change from 200% to less than 50% in 2090, compared to the beginning of the century (Khabarov et al., 2016).

3.9 Precipitation and Storms

3.9.1 Impacts of Climate Change on Precipitation and Storms – Trends and Projections

Annual average precipitation in Canada increased by 20% between 1948 and 2012, with a larger increase in Northern Canada (Zhang et al., 2019). Heavy precipitation over a day or less can cause localized damage to infrastructure, such as roads and buildings, while multi-day episodes of precipitation can produce flooding over a large region. For Canada as a whole, no trends were detectable in extreme precipitation accumulated over periods of a day or less. More locations have experienced an increase rather than a decrease in the highest amount of one-day rainfall each year, but the direction of trends is random over the country.

Projections indicate with a high degree of confidence that both annual average precipitation and extreme precipitation events (Figure 3.7) are expected to increase over the course of the century regardless of the GHG emission scenario. In addition, changes in rainfall patterns vary according to the season (Zhang et al., 2019). Winter precipitation in the form of rain has increased, and this trend is expected to continue. The projected increase in annual mean precipitation (about 24% higher under RCP 8.5) is mainly due to increased non-summer precipitation in all regions of Canada, particularly in Northern regions. Conversely, summer precipitation is expected to decrease over Southern Canada, especially under RPC 8.5 (Zhang et al., 2019). As the climate warms, particularly in Northern Canada, there will inevitably be an increased likelihood of precipitation falling as rain rather than snow, as it is already observed (Zhang et al., 2019).

Figure 3.7 Annual number of heavy precipitation days projected for 2021–2050 in Canada, based on current GHG emission trends (RCP 8.5). Blue areas correspond to areas with more than 10 days per year of extreme precipitation, while brown areas correspond to areas with less than 4 days per year of extreme precipitation. A Heavy Precipitation Day (HPD) is a day on which a total of at least 20 mm of rain or precipitation falls. Frozen precipitation is measured by its liquid equivalent: 20 cm of snow equals about 20 mm of precipitation. Source: Prairie Climate Centre, 2019.

The effect of climate change on winds and tornadoes is uncertain. For hail events in Canada, one study projected that, by 2070, the number of hail days will decrease (compared to the 1971–2000 period); the confidence for such projections are low — the lowest among extreme event types (Brimelow et al., 2017). In contrast, large hailstones might increase in summer, creating more damage than previously, particularly in Central and Western Canada (Brimelow et al., 2017). Winds and precipitation also cause flooding, erosion, and coastal submergence, which are addressed separately in the section 3.10 Floods, Coastal Flooding, and Coastal Erosion.

3.9.2 The Effects of Precipitation and Storms on Health

3.9.2.1 Unintentional Trauma – Precipitation

Snow, rain, and freezing rain increase the risk of falling outdoors by reducing traction or creating obstacles to travel. Precipitation increases the risk of hip and wrist fractures, in particular (Ali & Willett, 2015). In Montréal, only three freezing rain or rain events, followed by significant temperature drops, caused nearly half of the falls that occurred during the months of December and January in 2008–2009 (Morency et al., 2012). Another study of people 40 years and older in Montréal indicated that snowfall could have a greater impact on hip fractures than rainfall (Modarres et al., 2014). The risk of hip fractures related to weather variables appears to increase exponentially during extreme conditions. In England, medical visits for accidental injury from 1996 to 2006 increased by 2.2% for every 10 millimetres of rain and by 7.9% on snowy days (Parsons et al., 2011). Freezing rain seems to have the greatest impact on injuries, with the effect lasting up to three days following precipitation (Modarres et al., 2014). During the ice storm that swept across Ontario in December 2013, Ottawa and Toronto residents were 2.5 times more likely to be hospitalized for environmental reasons than in previous years (Rajaram et al., 2016). In addition to injuries, snow can indirectly increase the risk of heart attack, given that snow removal and walking in the snow increases hear rate and that the cold promotes vasoconstriction (Auger et al., 2017e).

3.9.2.2 Unintentional Trauma – Storms

Despite its destabilizing effect, average wind speed does not appear to be significantly associated with an increase in the number of injuries below the storm threshold (Ali & Willett, 2015). Wind gusts of 70 km/h or more appear to increase the risk of injury (Saulnier et al., 2017). There is also an increase in injuries during the recovery effort following a storm. These include lacerations, punctures, electrocutions, and falls due to infrastructure fragility and insecurity (Goldman et al., 2014). Although precipitation generally keeps pollen on the ground, periods of extreme precipitation and storms lift massive amounts of pollen into the air through osmotic shock. This can lead to a sharp increase in asthma symptoms among those with pollen allergies (D'Amato et al., 2012).

3.9.2.3 Road Accidents – Precipitation

Precipitation increases the risk of road injuries by making the roadway slippery (Koetse & Rietveld, 2009; Ali & Willett, 2015). In the Greater Vancouver area, an estimated 17% to 28% increase in collisions is expected by 2055 due to increased maximum and total precipitation; the effect is more pronounced during heavy precipitation events (Hambly et al., 2013). However, precipitation also reduces the risk of road fatalities because drivers adjust their driving on snow-covered or wet roads by reducing speed, among other measures (Koetse & Rietveld, 2009; Ali & Willett, 2015). Across Canada, the relative risk of rainfall-related mortality decreased in 10 Canadian cities between 1984 and 2002, but there was no change for snowfall (Andrey, 2010). This trend could continue in the future, depending on precipitation patterns and improvements in vehicle and road safety. By contrast, the increase in freeze–thaw cycles and in winter thaws could make travel less safe, as a water-coated ice surface is more slippery and winter tires are less effective under these conditions (TIRF, 2012). Stronger winds could also intensify blowing snow, decrease road visibility, and reduce vehicle control of drivers (Goldman et al., 2014). The net effect of climate change on the risk of road travel injuries in Canada therefore remains to be determined.

3.9.2.4 Physical Activity

Increased summer precipitation may also influence physical activity. A study in Canada found that the number of footsteps among 8125 participants decreased by 8.3% when rainfall totals reached 14 millimetres (Chan et al., 2006). Children can spend up to 15 minutes less per day on moderate- or high-intensity physical activity on rainy days compared to dry days (Harrison et al., 2015). This plateaus, however, after which point the amount of rain no longer affects level of physical activity. As a result, an increase in heavy rainfall events rather than days of rain may not have much impact on physical activity levels.

3.9.2.5 Water-Borne Diseases

Stormwater from precipitation carries many pollutants from anthropogenic and natural environments to locations conducive to water concentration. This results in significant bacterial loads in surface water and stormwater can contaminate groundwater upon mixing (Cann et al., 2013). This increases the risk of water-borne disease agents, particularly gastrointestinal diseases such as viruses (e.g., enterovirus), bacteria (e.g., *Campylobacter*) and enteric protozoa (e.g., *Giardia*) (Levy et al., 2016; Ghazani et al., 2018) (see Chapter 6: Infectious Diseases and Chapter 7: Water Quality, Quantity, and Security). In addition, both precipitation highs (e.g., heavy precipitation) and lows (drought) increase the risk of water-borne diseases spreading, and climate change is expected to increase the frequency of these two extremes in Canada (Herrador et al., 2015; Ghazani et al., 2018).

Legionellosis cases are positively correlated with the amount of precipitation. Legionellosis is mainly transmitted through the respiratory tract, and precipitation increases the formation of bacteria-infected airborne particles (see Chapter 6: Infectious Diseases). In Connecticut, each 5 millimetre increase in rainfall was found to have raised the risk of legionellosis by 48%, which is a higher incidence than observed for changes in temperature or humidity (Cassell et al., 2018). In fact, about half of pathogens that significantly affect human or animal health are sensitive to precipitation or moisture (McIntyre et al., 2017). Extreme precipitation in particular affects some bacteria or parasites that are agents of water-borne diseases, such as *Campylobacter*, *Cryptosporidium*, *Giardia*, and *Legionnella*, but this is not the case for non-extreme precipitation (Sakamoto, 2015; Young et al., 2015). In Vancouver, days that exceed the 90th percentile of precipitation increased the number of *Cryptosporidium* and *Giardia* cases up to six weeks after the event (Chhetri et al., 2017). Heavy rainfall and storms can also increase the risk of food-borne pathogens, such as norovirus, *Campylobacter*, *Toxoplasma gondii*, and *Listeria monocytogenes* (Smith & Fazil, 2019).

Runoff from extreme precipitation also affects recreational waters (e.g., beaches), exposing users to several infectious agents of water-borne diseases (Sanborn & Takaro, 2013) (see Chapter 7: Water Quality, Quantity, and Security).

3.9.2.6 Indirect Impacts – Power Outages

Strong winds and precipitation such as freezing rain can cause power outages. A prolonged and widespread outage can cause significant social disruption and affect the psychosocial health of those affected (Silver & Grek-Martin, 2015). In winter, power outages can also force some people to live in cold homes and suffer the resulting health consequences. During winter power outages, the risk of carbon monoxide poisoning is high due to the use of portable generators and heating/cooking units (Goldman et al., 2014; Johnson-Arbor et al., 2014). Poisoning can also occur when the exhaust pipe of a running car is blocked by snow, which occurs mainly on the same day as a snowstorm (Johnson-Arbor et al., 2014).

3.9.3 Populations at Increased Risk to Storms and Precipitation

3.9.3.1 Precipitation

Sex and Gender

Heavy snowfalls have been linked to cardiovascular complications. In a Quebec study examining the period from 1981 to 2014, men were at a 16% higher risk of being hospitalized and a 34% higher risk of dying due to myocardial infarction on the day following a 20 centimetre snowfall, compared to a day without snow (Auger et al., 2017e). This could be related most likely to the increased cardiac demands of snow shovelling coupled with cold, with men being potentially more likely than women to shovel, particularly after heavy snowfalls (Auger et al., 2017e).

Age

Studies suggest that children and adults over 40 are primarily at risk of falling during precipitation and of being injured. In Montréal, freezing rain was identified as a more significant weather factor than average temperature or snow to explain the number of falls among those aged 50 and over, while other studies seem to indicate a decreasing risk beyond 75 years of age due to loss of mobility, and thus a decrease in travel when freezing rain occurs (Morency et al., 2012; Ali & Willett, 2015). A study in Quebec found that people aged 40 to 74 are more likely to be injured due to weather conditions than those aged 75 and over (Martel et al., 2010). Children in Finland were found to be 50% more likely to injure their wrists on rainy days than on dry days (Ali & Willett, 2015).

Rural Living

In Canada, residents of small towns and of rural and remote areas are also at greater risk of contracting water-borne disease, with a relatively high proportion of outbreaks estimated to have occurred in municipalities with populations of 5000 or less following unusual weather events such as drought or heavy precipitation events (Febriani et al., 2010; Moffatt & Struck, 2011). These municipalities and private well water supplies often rely on groundwater with little or no treatment to supply their residents with drinking water. Small systems and private individuals often have less means to invest sufficiently in water treatment and protection measures. In Canada, one in eight people are supplied from private supplies, most of which rely on rural groundwater sources (Charrois, 2010), and about 1.7 million (4·9%) Canadians are served by small community groundwater (3.1%) and surface water (1.8%) supplies (Murphy et al., 2016).

Indigenous Populations

Many Indigenous populations are also at greater risk of water-borne diseases, especially since most water management infrastructure in these communities are considered at moderate- or high-risk to the impacts of heavy precipitation (Neegan Burnside Ltd., 2011). In addition, many communities lack access to safe drinking water, and continue to experience boil water/drinking advisories; this increases health risks from extreme rainfall events. Inuit communities have the highest prevalence and incidence of gastrointestinal disease (Wright et al., 2018). See Chapter 2: Climate Change and Indigenous Peoples' Health in Canada and Chapter 7: Water Quality, Quantity, and Security for more discussion of the increased risks of extreme precipitation or storms for First Nations, Inuit, or Métis people and vulnerability factors that exacerbate the direct and indirect impacts of these hazards on their health.

3.9.3.2 Storms

Some population groups are more affected by storms that cause significant social disruption and have more severe health impacts. Because medications may be more difficult to obtain during and following a storm, those whose physical or mental health depends on them may be more negatively affected (McClelland et al., 2017). Seniors, men, smokers, and people who already have respiratory problems are more likely to develop legionellosis and other water-borne diseases during heavy rainfall events, usually a few weeks after the event (Hicks et al., 2007; Sakamoto, 2015; Cassell et al., 2018).

Age

Children are at risk for post-traumatic stress disorder as a result of storm events, particularly children who previously had anxiety or depressive symptoms (Furr et al., 2010). Older people are also more affected by tornadoes and high winds. For example, the 2011 tornadoes in the United States increased the number of hospitalizations and intensive care visits among seniors from 4% to 9% within 30 days after the events (Bell et al., 2018).

Perinatal Effects

Stress during pregnancy caused by a storm with prolonged effects on essential services can also have long-term consequences for the unborn child. For example, the Ice Storm Project examined the impacts of prenatal stress associated with the January 1998 ice storm that plunged 3 million people into the dark in Southern Quebec. Some homes had no electricity for up to 40 days during one of the coldest months of the year. In this study, children of pregnant women who were significantly affected (stress) by this event were at higher risk for several physical and mental health problems, including exhibiting warning signs of eating disorders (St-Hilaire et al., 2015) and autism (Walder et al., 2014). They are also more likely to have a weakened immune system (Veru et al., 2015), to develop asthma problems (Turcotte-Tremblay et al., 2014), to have a higher body mass index (Liu et al., 2016a), and, in young girls, to have their first period at an older age (Duchesne et al., 2017).

Crop and Animal Farmers

Crop and animal farmers typically have to stay on their property during power outages because they have to take care of their livestock and infrastructures. During the 1998 ice storm, 49% of Eastern Ontario farmers without electricity for a week or less reported symptoms of stress throughout the event, and this rate rose to 76% for farmers without electricity for more than 15 days (Sutherland & Glendinning, 2008). Furthermore, 13% of farmers without electricity for a week or less and 37% of those without electricity for more than 15 days experienced health effects other than persistent stress after the event, indicating an increasing impact associated with the duration of the power outage.

3.9.4 Storm and Precipitation Adaptation Measures

3.9.4.1 Public Adaptation Measures

Action Plans and Multi-Barrier Approach for Water Management

Several measures are being taken to reduce the health risks associated with precipitation, particularly in the area of drinking water. A multi-barrier approach reduces the risk of water contamination for municipalities with a drinking water treatment facility, providing multiple operational redundancies in the event of system failure (Patrick, 2018) (see Chapter 7: Water Quality, Quantity, and Security). On a smaller scale, a participatory approach involving environmental representatives and experts could help better identify drinking water contamination risks and improve knowledge of watershed-related issues (Dykman, 2013). Alberta and Saskatchewan have adopted this type of collaborative approach in their planning to protect water sources in several Indigenous communities (Patrick, 2018). Integrated watershed management, used in several provinces across Canada, adheres to the principles of Indigenous governance, community engagement, as well as inclusive decision-making (Conservation Ontario, 2010; Canadian Council of Ministers of the Environment, 2016; Regroupement des organismes de bassins versants du Québec, 2019). It is also essential that future climate change impacts be considered in identifying risks to ensure the effectiveness and sustainability of the strategies put in place, particularly with respect to drinking water (Canadian Council of Ministers of the Environment, 2016).

Evacuations During Floods or Storms

Evacuations are one of the adaptation measures to reduce post-disaster damage. On an individual level, risk perception, past evacuation behaviours, and having an evacuation plan are all factors that make individuals more likely to evacuate, whereas likelihood of evacuation generally decreases as length of residency increases (Thompson et al., 2017). Issuing a mandatory evacuation notice also provides a greater incentive for people to evacuate than a voluntary evacuation notice. In addition to the influence of family and friends, having local community representatives issue this warning increases the likelihood of evacuation. Given their significant economic and psychosocial costs, evacuations should be limited to large-scale events. Evacuations may have more negative than positive health effects (Stares, 2014; Munro et al., 2017). To reduce these negative impacts, public authorities can encourage households to purchase essential items (non-perishable food, first aid kit, flashlight, etc.) for an emergency kit. Evacuation criteria could also be reviewed to better reflect the health consequences of evacuations. For long-term care facilities, nursing homes, and retirement homes, pre-emptive evacuations during storms should be avoided: several studies show that people evacuated from these institutions have a higher risk of mortality and hospitalization than people who remain (Pierce et al., 2017; Willoughby et al., 2017). The mortality rate in nursing home residents reach 17% up to six months after the evacuation (Willoughby et al., 2017). Nursing home residents who are at increased risk of experiencing the negative impacts of an evacuation are male residents aged over 80 years, who have greater functional and cognitive impairment and a number of comorbidities (Willoughby et al., 2017).

Emergency Response and Organizational Preparedness

Several measures would reduce the impact of extreme events on patients in long-term care facilities, such as adopting a disaster management plan, training staff on responding to extreme weather events, anticipation of patient needs following the event, and implementation of redundancy systems (central generator, etc.). Implementing a municipal or provincial disaster management plan that clearly delineates the responsibilities of each department and includes predetermined shelters and services reduces response time and increases response effectiveness (Mehiriz & Gosselin, 2016). Disaster simulation activities can also provide critical insight into system shortcomings and areas for improvement in managing such events (Bayntun et al., 2012). Having adequately trained and an appropriate number of staff in health facilities has been identified as the most important factor in ensuring the resilience of health services during disasters (Ryan et al., 2016). A 2016 Quebec study of health organizations indicated that they were much less prepared for certain frequent events such as flooding than for extreme heat events (Valois et al., 2017a). In addition, two studies have shown that Level 1 trauma centres in Canada are not adequately prepared for natural or human-caused disasters (e.g., terrorist attacks). In 2011, more than 40% of these centres, critical to emergency response, had not conducted a simulation exercise in the last two years, compared to 30% in 2019 (Gomez et al., 2011; Gabbe et al., 2020).

3.9.4.2 Infrastructural Adaptation Measures

Some measures related to residential or public infrastructure can help communities adapt to extreme storms or precipitation. Upgrading infrastructure, particularly roofs, to meet Canada's building standards would reduce the vulnerability of infrastructure and its occupants to inclement weather. Other responses, such as installing weather-resistant shutters on windows, strengthening garage and front doors, and stabilizing outdoor objects, can prevent wind and the debris it carries from damaging property and endangering the people inside (Institute for Catastrophic Loss Reduction, 2012a). Regular roof repairs and maintenance ensure sufficient capacity and slope to withstand snow, ice, or sleet build-up and are therefore other options to reduce the risk of collapse (Institute for Catastrophic Loss Reduction, 2012b). However, these measures are not financially accessible to all owners.

Adaptation measures to reduce the likelihood of a power outage following a storm or heavy freezing rain include burying power lines, strengthening the support capacity of distribution poles and towers, integrating anti-cascading towers, and managing vegetation near power lines (Hydro-Québec, n.d.; Audinet et al., 2014). Restoring damaged features in disaster areas that are aesthetically and culturally significant was also proposed as a potential way to promote psychosocial health of disaster victims and the post-disaster recovery effort. In Ontario, those with a strong sense of belonging to the area were more involved in the recovery effort following a tornado that struck the rural community of Goderich in 2011, thereby fostering social cohesion (Silver & Grek-Martin, 2015).

3.10 Floods, Coastal Flooding, and Coastal Erosion

3.10.1 Impacts of Climate Change on Floods, Coastal Flooding, and Coastal Erosion — Trends and Projections

The frequency and severity of flooding, coastal flooding, and coastal erosion will be influenced by increased average and extreme precipitation, early snowmelt, higher sea levels, and reduced ice cover (Derksen et al., 2019; Greenan et al., 2019; Zhang et al., 2019). Warmer winter and spring temperatures, combined with more precipitation falling as rain rather than snow, are expected to result in earlier snowmelt in spring and earlier arrival of spring flooding, although the combined effect of this warming and of reduced snow cover on flooding is uncertain (Bonsal et al., 2019; Derksen et al., 2019). Due to changes in precipitation patterns, rainfall-related flooding is expected to increase while snowfall-related flooding is expected to decrease. In urban settings, increased extreme precipitation events will increase the risk of overflow[6] and flash flooding.

The extent of sea-level rise will vary greatly across Canada depending on regional vertical land movement in response to the retreat of the last glacial ice sheet (Greenan et al., 2019). In the Atlantic Provinces, for example, sea levels are expected to rise more than the global average due to land subsidence (downward movement). Across Canada, sea levels are expected to rise for most of the Atlantic, Pacific, and Beaufort coasts, although some specific regions, such as Hudson Bay, may see lower sea levels due to the uplift of the land as a result of the uplift being higher than the rate of global sea-level rise (Greenan et al., 2019). Inland, there is no evidence that lake and wetland levels have changed at this time (Bonsal et al., 2019). However, accelerated evapotranspiration could lower the water level of inland water bodies if it exceeds the predicted increase in precipitation. Finally, wave activity in Atlantic and Arctic Canada will increase in response to the increased extent and duration of the ice-free period (Greenan et al., 2019). Combined with rising sea levels, this is expected to increase the number of coastal floods as well as the rate of coastal retreat. There is also a higher documented risk of fluvial, pluvial, and coastal flooding in Indigenous communities across the country. A recent study of 985 communities estimated that almost 22% of residential properties were at risk of flooding, with a 100-year recurrence (Thistlethwaite et al., 2020).

6 Overflows of raw, untreated sewage into rivers and other possible sources of potable water can occur when extreme rainfall causes the capacity of combined sewers — sewers that transport both sewage and stormwater — to be exceeded (Ottawa Riverkeeper, 2020).

3.10.2 Effects of Floods, Coastal Flooding, and Coastal Erosion on Health

3.10.2.1 Floods – Physical Impacts

Floods can cause injury, infect wounds, and result in electrocution, particularly during the recovery and cleanup period (Du et al., 2010; Lowe et al., 2013). Floods can also cause drowning and hypothermia, with greater danger during flash flooding. Mortality and injury are but a small part of the health burden caused by flooding in Canada, however. More significant effects are felt on physical and mental morbidity (Bartholdson & von Schreeb, 2018).

Floods have been associated with an increased incidence of water-borne, vector-borne, and other infectious diseases because it increases the likelihood of direct contact with water, drinking water contamination, and the reproduction of pathogens and disease vectors, such as insects and some pests (Funari et al., 2012; Brown & Murray, 2013; Cann et al., 2013; McMichael, 2015; Levy et al., 2016) (see Chapter 6: Infectious Diseases). Flooding in urban areas that results in sewer overflows promotes the spread of infectious agents, moulds, and other toxic contaminants that are harmful to human health. For the St. Lawrence River, the increase in overflows upstream (e.g., from the metropolitan Montréal area) is expected to increase *Escherichia coli* concentrations up to 87% by 2070 in drinking water sources downstream, such as those in the greater Quebec City area (Jalliffier-Verne et al., 2017). Flooded houses also support the development of fungi, bacteria, and moulds that increase the risk of developing and exacerbating skin, allergy, and respiratory problems (Tempark et al., 2013; Azuma et al., 2014; Saulnier et al., 2017).

3.10.2.2 Floods – Psychosocial Impacts

Floods impair living environments, disrupt social life, and increase financial uncertainty, given the associated material costs and economic disruption, often over many months. Flooding is therefore associated with compromised psychosocial impacts and quality of life (Turner et al., 2012a; Fernandez et al., 2015; French et al., 2019) (see Chapter 4: Mental Health and Well-Being). Among its manifestations, flooding increases the incidence of symptoms of post-traumatic stress, depression, and anxiety in addition to suicidal ideation in exposed individuals (Alderman et al., 2012; Turner et al., 2012a; Warsini et al., 2014; Fernandez et al., 2015; Munro et al., 2017; Graham et al., 2019). According to some studies, the prevalence of post-traumatic stress in populations exposed to flooding in the previous two years ranges from 9% to 53% (Alderman et al., 2012). Repeated flooding does not necessarily increase the level of post-traumatic stress and depression; however, little research has been done on its health effects (French et al., 2019). According to a 2017 survey of 200 households, 67% of the Eastern Montréal population affected by flooding reported feeling anxious or having trouble sleeping or concentrating, and that percentage was highest among evacuated individuals (CIUSSS du Centre-Sud-de-l'Île-de-Montréal, 2017). In addition, 24% of respondents felt that their mental health was fair or poor; that is nearly five times the prevalence of mental ill health than in Montréal's population overall. Other studies using indices of psychological well-being have also observed an inverse relationship between these indices and the level of exposure to flooding (Fernandez et al., 2015). A study of approximately 100 residents affected by the 2014 floods in Burlington, Ontario, found that these residents experienced high levels of stress even three years after the flood (Decent, 2018). Nevertheless, the prevalence of psychological disorders can decrease and eventually resolve over time (Fernandez et al., 2015; Johal & Mounsey, 2016; Jermacane et al., 2018).

Exposure to flooding appears to increase excessive use of drugs, alcohol, or medication, and to decrease the sense of safety and belonging to the area (Tapsell & Tunstall, 2008; Fernandez et al., 2015). Relationships with neighbours, friends, and family can also deteriorate after a flood, as seen among seniors up to six months after the 1996 Saguenay flood (Maltais, 2006). The opposite can also be true, however. A survey of 963 people after the 2013 Calgary flood found that those who supported others during or after the flood had a higher sense of social cohesion (Hetherington et al., 2018).

The stress from flooding can also affect physical health (Saulnier et al., 2017). For example, during the flooding of the Richelieu River in Quebec in 2011, exposed individuals were 25% more likely to have a cardiac event afterward, although this increase was not seen in the 1996 Saguenay flooding (Vanasse et al., 2015; Vanasse et al., 2016a). Indeed, these two floods were very different in terms of the number of people affected and the duration of the event. Complications associated with diabetes as well as high blood pressure and nutrition also increase post-flood (Saulnier et al., 2017).

3.10.2.3 Coastal Flooding

The impacts of coastal flooding on the health of populations are different than the consequences of flooding and of storms. It is less likely than flooding to spread vector- or water-borne diseases, although related precipitation may increase the risk. Like regular flooding, coastal flooding may require prolonged evacuations and cause significant damage to public infrastructure and property. The psychosocial and physical impacts associated with financial stress and social disruption therefore theoretically apply as much to coastal flooding as they do to freshwater flooding (Lane et al., 2013; Manuel et al., 2015). That said, few studies have actually examined the health effects of this hazard outside the context of hurricanes or tropical storms, which do not really apply to Canada other than the Atlantic provinces, which can experience the tail-end of hurricanes (Lane et al., 2013; Hung et al., 2016; Ryan et al., 2016; Saulnier et al., 2017).

3.10.2.4 Coastal Erosion

Unless landslides occur, there is little or no risk of injury from coastal erosion. However, it has the potential to cause psychosocial impacts and damage property. The effects of coastal erosion on health are more difficult to assess, as they are felt in the medium to long term and, in theory, they allow for preventive responses. Like coastal flooding, little research has been done on the health effects of coastal erosion. In some areas, however, it is clear that coastal erosion and flooding will increase the isolated nature of regions by making roads impassable and damaging other infrastructures along the coastline (Drejza et al., 2015; Manuel et al., 2015). By reducing the habitability of affected regions, they could also lead to a permanent community breakdown and encourage the exodus of populations.

3.10.2.5 Indirect Impacts – Power Outages

Regular and coastal flooding can also cause power outages. Although the effects of power outages in warmer weather are less of a threat, given that dangers are mainly associated with using backup heating and being exposed to the cold (Lane et al., 2013; Klinger et al., 2014), power outages during shoulder seasons could increase these risks compared to a normal situation, since outdoor temperatures are not optimal during those seasons. Flooding has been associated with an increase in carbon monoxide poisoning before and during the event and even in the recovery phase (Waite et al., 2014). In addition, a lack of air conditioning due to a power outage could increase heat exposure during periods of intense heat.

3.10.3 Populations at Increased Risk to Floods, Coastal Flooding, and Coastal Erosion

3.10.3.1 Age

Children and adolescents are also likely to experience symptoms of post-traumatic stress after a disaster, although it is unclear how much more affected they are than adults (Furr et al., 2010; Garcia & Sheehan, 2016; Lai et al., 2017). Based on two literature reviews, the risk appears to be higher for young girls than for young boys and for children and adolescents who lack social support (Garcia & Sheehan, 2016; Lai et al., 2017). Most related studies show that children tolerate low levels of post-traumatic stress over a long period of time (Lai et al., 2017). They seem to be less likely than adults to have post-traumatic stress symptoms worsen after an extreme event. In any case, this stress may have a significant impact on the child's long-term development. Post-traumatic stress disorders in children have been associated with cognitive impairments, alcohol and drug problems, immunodeficiency, asthma, as well as learning, sleep, and behavioural problems (Garcia & Sheehan, 2016). Prenatal stress from flooding has also been associated with weight status in children (Dancause et al., 2015).

Seniors over 65 affected by a flood disproportionately experience symptoms of anxiety, depression and post-traumatic stress compared to prime-age adults (Leyva et al., 2017; Decent, 2018). Based on a systematic review, the risk of mortality and morbidity during and after a flood is particularly high among adolescents and young adults (aged 10 to 29) and among those over the age of 60 (Lowe et al., 2013).

3.10.3.2 Sex and Gender

After a flood, women appear to have an increased risk of experiencing psychological impacts, while men seem to be more likely to experience physical impacts, such as cardiac events (Lowe et al., 2013). Following the 2011 Calgary floods, new prescriptions for anti-anxiety medications and sleep aids increased by a factor of 1.64 and 2.32, respectively, among women (Sahni et al., 2016). In addition, women are more likely to experience domestic violence as a result of extreme events such as flooding, and women who experience post-flood violence are more likely to report depression (First et al., 2017).

3.10.3.3 Presence of Pre-Existing Diseases

People with pre-existing health problems are more susceptible to the effects of flooding (Lowe et al., 2013). During the 2011 flooding of the Richelieu River in Quebec, people with a history of cardiovascular disease were 70% more likely to experience a cardiac event following flooding, compared with 25% for all those affected (Vanasse et al., 2016a). Individuals taking medications are also at greater risk because access to them could be compromised during significant social disruptions such as flooding (Gaskin et al., 2017). Access to essential care for people with pre-existing physical or mental health problems could also be problematic. For post-traumatic stress, people with high levels of anxiety are more likely to experience high levels after extreme weather events, as seen after the 2011 floods in Calgary (Hetherington et al., 2018).

3.10.3.4 Indigenous Populations

First Nations and Métis peoples are particularly vulnerable to extreme events such as flooding, as they often live in isolated areas, with infrastructure in poor condition, and in low socio-economic settings (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). For example, between 2006 and 2016, nearly 67 First Nations communities experienced close to 100 flood events, causing substantial property and infrastructure damage, community service failures, and individual health and wellness impacts.

3.10.3.5 Rural Living and Low Socio-Economic Status

Municipalities with combined sewers (e.g., sewers that deliver both wastewater and storm water to a sewage treatment plant) are at increased risk of regular and wastewater overflows (Fortier, 2013). Areas affected by coastal erosion are also often remote or rural communities with low socio-economic status. These communities do not always have the financial or human resources to adapt to coastal hazards and therefore need external support (Chouinard et al., 2008). The proportion of seniors is also generally higher, and the current rural exodus and the aging population will continue to challenge the resilience of these communities (Manuel et al., 2015; Rapaport et al., 2015), while higher social cohesion and the ability to cope may lessen the psychological effects of flooding (Greene et al., 2015). In addition to residents, volunteers and emergency responders are also at risk to flood health effects during the recovery phase (Johanning et al., 2014).

3.10.3.6 Insurance

People without insurance are more likely to experience the psychosocial impacts of floods (Tunstall et al., 2006; Mulchandani et al., 2019). People without specific flood insurance often have a higher economic deprivation profile, given the costs of flood protection (Poussin et al., 2015; Koerth et al., 2017). The time it takes to contact insurance companies can also increase stress among people whose homes have been flooded (Maltais, 2006).

3.10.4 Floods, Coastal Flooding, and Coastal Erosion Adaptation Measures

3.10.4.1 Individual Adaptation Measures

Adaptation Behaviours

At the individual level, infrastructure adaptation measures to protect against the consequences of floods include elevation of the house (e.g., electricity meter, doors, furniture, baseboards and electrical outlets), moving objects from the basement to upper levels, and waterproofing foundations in the home (Poussin et al., 2015; Koerth et al., 2017; Valois et al., 2020a). However, it is important to choose measures adapted to the characteristics of the home and its environment to avoid unintended consequences and damage (e.g., uplift during very significant floods due to waterproofing of foundations). Staying informed about whether one's home is in a flood zone, and about flooding-related consequences and adaptation measures, taking stock of assets, and obtaining flood insurance are non-infrastructure measures that can be beneficial. According to a nationwide survey, however, only 6% of people were aware they are living in flood-risk area, while 30% have implemented measures to protect their property from flooding (Thistlethwaite et al., 2017). Insured individuals may feel they can engage in more risky behaviours or take fewer actions to protect themselves less from insured hazards. Insurance is also an unaffordable option for some low-income households. Making insurance premiums dependent on implementation of protection measures would provide an incentive for insured individuals to protect themselves further (Botzen et al., 2009). In any case, financial incentives are essential to encourage individual adaptation measures because exposed individuals may be aware of the risk without having means to adapt to it (Wachinger et al., 2013; Poussin et al., 2014). Support programs should be tailored to reduce the financial burden on low socio-economic and at-risk households.

Risk Perception

Several factors associated with individual perceptions can also influence the adoption of adaptation measures for coastal hazards. These include risk perception, the perceived effectiveness of an adaptation measure, the perception of control over implementing that measure, the estimated cost of implementing that measure, and the perceived individual responsibility for taking action (Bubeck et al., 2012; Kellens et al., 2013; Poussin et al., 2014; Valois et al., 2020a). The number of floods an individual has experienced in the past, factual knowledge of risks and adaptation measures, status as a homeowner, residing in a single-family home, and living permanently in a house increase an individual's likelihood of adopting adaptation measures in a coastal environment (Koerth et al., 2017; Valois et al., 2019; Valois et al., 2020a). A sense of belonging to a living environment also intensifies risk perception for relatively frequent events (Bonaiuto et al., 2016). On the other hand, such a sense decreases the likelihood that an individual will move or evacuate, in addition to exacerbating any psychosocial impacts that might occur. Some people will also accept exposure to a risk because of habituation to the risk, or because they feel that the benefits of living in an at-risk nearshore area outweigh potential costs (Wachinger et al., 2013; Poussin et al., 2014; Koerth et al., 2017). A flood adaptation index is available that that can measure the extent of adaptation by linking pre- and post-flood adaptation and variables such as income, household type, and perception (Valois et al., 2019).

3.10.4.2 Public Adaptation Measures

Evacuations

Evacuations are often mandated by public authorities when flooding is expected or occurs. However, similar to other hazards discussed in this chapter, evacuations are not always an appropriate adaptation measure: several studies show adverse effects for evacuees compared to those who remained in place. In the United Kingdom, flood-affected people who remained at home were at lower risk of depression than evacuees (Munro et al., 2017). Evacuees had higher rates of depression, anxiety, and post-traumatic stress. The intensity of mental health effects varies with the duration of separation from the living environment and with income — low-income individuals were at higher risk (Lowe et al., 2013; Lamond et al., 2015; Munro et al., 2017). It is more difficult for people with reduced mobility or sensory and cognitive disabilities to evacuate or to prepare for and cope with flooding. As a result, there is a significant risk of injury and mortality among seniors during or after evacuation (Gamble et al., 2013; Thompson et al., 2017; Willoughby et al., 2017). These health consequences should be taken into account when public authorities make decisions about whether evacuation is the optimal solution. If evacuations are necessary, issuing an evacuation notice at least 12 hours in advance appears to reduce the psychosocial impacts of flooding. A study showed that people who did not receive a warning or who received one less than 12 hours' notice before the event had a higher level of psychological distress (Munro et al., 2017).

Permanent evacuation, or relocation, may also be considered as a preventive measure. The health impacts of voluntary or forced relocation outside of an at-risk area are more significant for people with a strong sense of belonging to the area and community or with a strong local social network (Uscher-Pines, 2009; Lowe et al., 2013; Munro et al., 2017). Employment stability and the costs associated with moving are important issues related to the vulnerability of lower-income individuals. A move within the same community limits effects on social connections, while public financial support for low-income people mitigates the consequences for this segment of the population. In the La Mitis region of Quebec, which was affected by major flooding in 2011, the government covered the costs of moving residents in areas at risk of coastal flooding or erosion to a nearby area specially built for that purpose, with a citizens' support program managed by local authorities (Radio-Canada, 2018).

Preparation and Action Plan

Public weather alerts and other tools are available for individuals and public health authorities in Canada to use to prepare and plan for storms and floods (Government of Canada, 2019b). In terms of response, front-line and emergency management workers can increase their awareness of the relationships between domestic violence and disasters and of how to take action to help victims, including children (First et al., 2017). For people with physical or mental disabilities, involvement in emergency planning and response through organizations working with these groups increases their ability to adapt (Gaskin et al., 2017). Health services in municipalities at flood risk should have disaster contingency plans and strategies, particularly for flooding (Burton et al., 2016). These plans should include measures to train staff, anticipate patients' medical needs during a disaster, a decision-making process that considers evacuations as a last resort, and systematic evaluation of disaster response effectiveness (Pierce et al., 2017). Social workers and other psychosocial health professionals should also be better trained to better respond to feelings of loss and grief caused by weather events (Fulton & Drolet, 2018). In addition, increased monitoring of infectious diseases by public health authorities during and after flooding would also be beneficial (McMichael, 2015; Burton et al., 2016).

3.10.4.3 Infrastructural Adaptation Measures

Regular updating of maps of flood-prone areas, flood-vulnerable areas, and coastal erosion zones is key to managing these risks. Alterations to the built environment can reduce the risks of floods and overflows. Rainwater management measures such as retention ponds and making the urban environment more permeable to runoff can decrease these risks by reducing the burden on water treatment systems and encouraging the absorption of rainwater, thereby decreasing the risk of overflows (Houghton & Castillo-Salgado, 2017). Requirements for such measures are found in some green building or neighbourhood development certifications, such as LEED, but not always. One study found that scenarios of moderately and intensely impervious urban surfaces can increase the risk of flooding two-fold and the risk of overflows four-fold, before taking climate change into account (Zimmermann et al., 2016). Making soil more permeable via green infrastructure are among the measures that could stabilize or reduce these risks (Farrugia et al., 2013; Lennon et al., 2014; Zimmermann et al., 2016). Increasing riparian planting by 20% to 40% can also reduce river peak flow levels by up to 19%, while increasing planting by 10% to 15% can reduce levels by up to 6% (Dixon et al., 2016) and reduce erosion as well as the loss of property values (Moudrak et al., 2018). Prohibiting building in at-risk coastal areas through zoning bylaws or other legal means could progressively reduce exposure to coastal hazards, with the gradual loss of acquired rights and mitigation of urban expansion into high-risk areas. Green infrastructure is also an effective measure to prevent or slow coastal erosion (Keesstra et al., 2018).

3.10.4.4 Evaluation of Floods, Coastal Flooding, and Coastal Erosion Adaptation Measures

Unfortunately, the effectiveness of floods, coastal flooding, and coastal erosion adaptation measures on health has not been assessed in the Canadian context and has undergone very limited assessment internationally (Burton et al., 2016). Actions taken by municipalities and provinces are still largely reactive rather than proactive, although a reverse trend is beginning to emerge (Manuel et al., 2015; Burton et al., 2016; Hurlbert & Gupta, 2016). Some adaptation measures may not be advantageous to implement in that their costs may exceed the benefits, especially in areas where the potential damage and likelihood of occurrence are relatively low. To be better able to assess costs and benefits, programs like the Flood Ready platform, the National Disaster Mitigation Program and organizations like FloodSmart Canada (<http://floodsmartcanada.ca>) are gathering detailed information to assist individuals, businesses, and the public sector to optimize investments in coastal hazard adaptation measures (Government of Canada, 2019a; Public Safety Canada, 2019). Assessing, mapping, and updating coastal risks to account for climate trends is also essential to better focus interventions. In Canada, this mapping predates the turn of the century and would benefit from an update (Henstra & Thistlethwaite, 2018). In Quebec, a number of impact and cost-benefit studies of coastal adaptation options led the provincial government and municipalities to implement a relevant adaptation program for the entire St. Lawrence River, Gulf, and Estuary (Bernatchez et al., 2015; Circé et al., 2016). This program includes stricter regulations and construction standards, along with compensation and relocation measures.

3.11 Landslides, Avalanches, and Thawing Permafrost

3.11.1 Impacts of Climate Change on Landslides, Avalanches, and Thawing Permafrost — Trends and Projections

A warmer, wetter climate generally increases the occurrence of landslides (Gariano & Guzzetti, 2016). Studies in Canada on the effects of climate change on landslides have mainly been conducted in British Columbia and seem to confirm that warming temperatures and increased precipitation have increased the frequency and magnitude of landslides over the past century (Jakob & Lambert, 2009; Geertsema, 2013; Gariano & Guzzetti, 2016).

The net effect of climate change on avalanches in Canada is unclear. Between 1981 and 2011, the number of avalanches reportedly decreased in Western Canada, while there does not appear to be a trend in Southern Quebec (Hetu et al., 2015; Sinickas et al., 2016). Warming temperatures, snow accumulation, freezing rain, wind strength, and the formation of a layer of frost or ice crystals at the beginning of the season affect the likelihood of avalanches and their intensity, which complicates projections of future impacts (Germain et al., 2009; Bellaire et al., 2016; Sinickas et al., 2016).

Permafrost covers nearly 40% of Canada's land mass and extends under the Arctic Ocean. Projected warming of ground temperatures is expected to promote thawing of permafrost over large areas — up to 20% in Northern regions by 2090 (compared to 1990) (Derksen et al., 2019). A few regional observations indicate that permafrost temperature has increased by 0.1°C to 1°C per decade, with warming being greater in Arctic Canada than in sub-Arctic regions. Thermokarst[7] formation has also been observed over large areas in Northern Canada, an environment characterized by subsidence due to thawing permafrost. The land area supported by permafrost in Canada could decrease by 16% to 20% under low-to-moderate GHG emission scenarios (IPCC AR4 scenarios A2 and B2, used in 2007) compared to 1990, with some estimates being even more pessimistic (Derksen et al., 2019). The circumpolar Northern region of permafrost contains carbon reserves equivalent to the total amount of carbon already in the atmosphere (Derksen et al., 2019). The projected thawing of permafrost could release massive amounts of GHGs into the atmosphere, contributing to the acceleration of climate change and its consequences.

7 Thermokarst refers to irregular topographies related to ice-rich thawing permafrost (Derksen et al., 2019).

3.11.2 Effects of Landslides, Avalanches, and Thawing Permafrost on Health

3.11.2.1 Impacts of Landslides on Health

The risk of dying from a landslide is quite low in Canada and has decreased over the years while landslides seem to be increasing in number. From 1990 to 2018, 23 landslides caused fatalities across Canada, resulting in a total of 39 deaths, with an average of one to two deaths per year (Blais-Stevens et al., 2018). The probability of death is greater when landslides develop rapidly and when they affect people inside a building (Kennedy et al., 2015). Landslides can also result in some physical injuries and trauma, including cuts, bruises, concussions, and fractures. Some studies conducted outside of Canada (Italy, Greece, Puerto Rico, etc.) have also associated landslide exposure with an increased incidence of post-traumatic stress and deterioration of social cohesion up to two years after the event (Kennedy et al., 2015). However, these effects are generally observed during large-scale landslides, which are rare in Canada.

3.11.2.2 Impacts of Avalanches on Health

Physical Health

Avalanche-related health risks are primarily associated with the injuries and deaths they can cause. Across Canada, 123 people died as a result of an avalanche from 2009 to 2018 (Avalanche Canada, 2018). Avalanches pose a particular risk in Western Canada, with 102 of those 123 deaths occurring in British Columbia and 16 in Alberta, because mountain slopes in Western Canada are much steeper than the rest of the country. Asphyxia, severe trauma, and hypothermia account for the bulk of avalanche-related deaths (Boyd et al., 2009; Kornhall & Martens-Nielsen, 2016). In fact, one study found that avalanches were lethal in 23% of cases, with a 50% mortality rate when the victim was completely covered by snow (Kornhall & Martens-Nielsen, 2016).

Psychosocial Health

Avalanches can also have short- and long-term effects on the psychosocial health of affected people. A study in Iceland considered the psychosocial impacts on populations in two villages affected by deadly avalanches (Thordardottir et al., 2015). Some 16% of villagers affected by avalanches directly or indirectly had symptoms of post-traumatic stress related to the event 16 years after the event. Villagers were also at higher risk for sleep disorders and post-traumatic hyper-reactivity compared to a similar, unexposed population.

3.11.2.3 Effects of Thawing Permafrost on Health

Thawing permafrost is a hazard specific to Northern environments. The related health risks are more indirect than for avalanches and landslides — hazards that develop rapidly. Thawing permafrost is compromising the integrity of houses, public buildings, roads, and other infrastructures and Northern communities, such as many First Nations and Inuit communities, are already lacking infrastructure. They also depend on air transport to bring in food and essential goods such as medicine (Allard et al., 2012; Ford et al., 2014; Durkalec et al., 2015). In addition, thawing permafrost could affect the risk of water-borne disease by releasing infectious agents and significant concentrations of heavy metals such as mercury (Moquin & Wrona, 2015; Vonk et al., 2015; Schuster et al., 2018) (see Chapter 6: Infectious Diseases and Chapter 8: Food Safety and Security).

Across Canada, many Indigenous communities face serious water safety challenges due to inadequate water and wastewater systems, a lack of trained staff, and higher exposure to pollutants or environmental contaminants and many face short- and long-term boil water advisories (Wright et al., 2018; Indigenous Services Canada, 2020a; Indigenous Services Canada, 2020b). Thawing permafrost can increase exposure to health risks from contaminated water by further weakening water supply systems or water sources (Neegan Burnside Ltd., 2011). Finally, thawing permafrost can compromise the food security of Arctic communities, which use ice cellars dug from permafrost to safely store food, such as in the community of Inupiat, Alaska (U.S. Climate Resilience Toolkit, 2017). Biodiversity, and thus access to traditional food, will also be negatively affected by thawing permafrost, which may further affect local populations (Berteaux et al., 2016).

3.11.3 Populations at Increased Risk to Landslides, Avalanches, and Thawing Permafrost

People living on clay soil or near steep slopes are at increased risk of landslides (Porter & Morgenstern, 2013; Macciotta & Lefsrud, 2018). Some international studies have also shown that women are more likely to experience symptoms of post-traumatic stress following a major landslide (Kennedy et al., 2015). People who practise snowmobiling, skiing, snowshoeing, winter hiking, and any other winter activities on mountainous terrain are the most exposed to avalanches (Boyd et al., 2009). Almost half of all avalanche deaths between 2009 and 2018 involved snowmobilers, and just over one-third involved skiers (Avalanche Canada, 2018); 88% of fatalities were males, a situation similar to most countries with snow (Page et al., 1999; Jamieson et al., 2010; Berlin et al., 2019).

For thawing permafrost, Northern and Indigenous populations are at increased risk given their highly exposed infrastructure (such as roads, drinking water systems, buildings, pipelines) and limited access to some essential resources due to remoteness. In particular, Indigenous Peoples living in areas vulnerable to thawing permafrost are at increased risk of negative health and social impacts, given existing social and health inequities, such as poverty, poor quality of housing and infrastructure, and disproportionate burden of disease (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). In addition, their proximity to nature and close connection to the land means that these climate change impacts affect their way of life and can destroy places that have cultural significance (Government of Nunavut, 2012). For example, in Inuit Nunangat,[8] natural disturbances such as thawing permafrost, melting or thinning ice, and changes in sea level exacerbated the loss of Indigenous knowledge and skills related to hunting, road transportation, weather forecasting, and wildlife movement. These changes increase the risk of unintentional injury or death and the need for search-and-rescue missions, reduced access to traditional food, and impacts on mental health.

8 Inuit Nunangat is the Inuit homeland in Canada and is comprised for four regions: the Inuvialuit Settlement Region (northern Northwest Territories), Nunavut, Nunavik (northern Quebec) and Nunatsiavut (northern Labrador).

3.11.4 Landslides, Avalanches, and Thawing Permafrost Adaptation Measures

One of the first adaptation measures for landslides, avalanches, and permafrost melt is the production and updating of risk and vulnerability maps. Monitoring these events (e.g., avalanche) is also critical (Canadian Space Agency, 2016; Avalanche Canada, 2018; MFFP, 2019).

3.11.4.1 Landslide Adaptation Measures

Given the low risk of death from landslides, major adaptation measures such as relocation would only be warranted in the most at-risk areas (Macciotta & Lefsrud, 2018). Natural Resources Canada offers a best-practices guide for assessing landslide risks based on physical, legal, economic, and risk acceptance criteria (Porter & Morgenstern, 2013). In addition, preventive warning systems that take account of the hydrological and physical properties of soils and precipitation forecasts have been developed in other countries and may be an option for limiting the exposure of populations to this risk in some cases (Chae et al., 2017).

3.11.4.2 Avalanches Adaptation Measures

The assessment of avalanche risk areas and the consequent adaptation of land-use planning have significantly reduced the number of deaths inside buildings (Hetu et al., 2015; Germain, 2016). In addition to choosing building locations strategically, the reforestation of the slopes is another management measure that reduces the risk of avalanche by obstructing the wind and avalanche corridor (Hetu et al., 2015). A downward trend in the risk of mortality has also been observed since avalanche-related weather monitoring organizations were created to raise public awareness of avalanche-related risks and provide mountain safety training (Avalanche Canada, 2018). Avalanches can be activated pre-emptively in a controlled manner before they become a threat, or when the risk becomes too high, as in Glacier National Park in the Canadian Rockies (Parks Canada, 2018).

3.11.4.3 Thawing Permafrost Adaptation Measures

Work by Natural Resources Canada has made it possible to characterize and determine temperature thresholds for thawing permafrost (Labbé et al., 2017). Adaptation measures such as using surfaces with high albedo, placing ventilation ducts or heat sinks below infrastructure, installing adjacent air convection levees or thermosyphons, and building an overhead solar shelter can cool the soil and thereby mitigate infrastructure damage (Calmels et al., 2016; Doré et al., 2016). Many of these measures have been implemented in Northern Canadian communities, although there is no national adaptation strategy to direct such activities (Labbé et al., 2017). The Alaska Highway in the Yukon is a well-documented example of risk characterization and subsequent infrastructure stabilization through adaptation (Stephani et al., 2014; Calmels et al., 2016). Characterizing permafrost-related risks can also better inform land-use planning. In Arviat, Nunavut, for example, an assessment has increased decision makers' awareness of the risks posed by thawing permafrost and facilitated adaptation cooperation among stakeholders (Flynn et al., 2018). The ArcticNet Network of Centres of Excellence of Canada has been conducting a major research program on these impacts and applicable solutions for the past 15 years (ArcticNet, 2021). For example, a 2013 mapping of discontinuous permafrost areas in Nunavik allowed for risk-informed planning for infrastructure and health facilities for all levels of government involved (L'Hérault et al., 2013).

3.12 Gaps in the Literature and Uncertainty of Scientific Evidence Related to the Impacts on Health of Natural Hazards Influenced by Climate Change

This section details the main gaps in the scientific literature and the uncertainties that remain about the impacts of natural hazards on health, individuals most at risk, and how they can protect themselves as the climate continues to warm in Canada.

3.12.1 Health and Natural Hazards Data

Several uncertainties persist in the literature about the impacts on health of natural hazards influenced by climate change. The projected health effects are highly dependent on GHG emission scenarios, demographic changes, and the future levels of adaptation by individuals, communities, and institutions, for example, health systems and facilities (see Chapter 10: Adaptation and Health System Resilience). These projections must therefore be interpreted with caution, since significant variability is to be expected, based on these factors. The literature also contains some conflictual findings regarding natural hazard impacts on health in the context of climate change. They are included in this chapter when applicable. The processes leading to health effects are also often indirect and complex. Some effects may not be evident or explored in studies because of the large number of variables and their complex interactions. Experimental (e.g., clinical studies) or quasi-experimental[9] designs are particularly difficult — and in some cases impossible — to implement to assess the effects of climate change. Designs are often observational or cross-sectional and are therefore offer slightly less robust evidence, although still acceptable for understanding risks and adaptation planning. In contrast, several rigorous meta-analyses and literature reviews have been documented. There exists an imbalance in researched topics and in the quality of documented studies, and a number of gaps remain. Nevertheless, the number of studies available for most natural hazards influenced by climate change is substantial and for the most part sufficient to provide a clear characterization of current health impacts in the short term.

9 A quasi-experimental design describes pre-post, non-randomized studies (i.e., participants were not assigned randomized treatments, for example, unlike clinical studies).

However, climate impact models do not yet, or rarely, take health into account in their impact simulations, leading to uncertainty about projected global impacts (Gosling et al., 2017). In addition, these models do not take adaptation measures into account, resulting in additional uncertainty (Gosling et al., 2017).

3.12.2 Type of Natural Hazards Considered

There are a number of gaps in the scientific literature regarding the health effects of natural hazards in Canada. First, a number of natural hazards are under-represented. Health effects not directly associated with temperature, infectious diseases, or air quality are generally less well studied. Research on droughts, coastal erosion, coastal flooding, landslides, and thawing permafrost typically focuses on assessment methods or economic and ecological damage, and not on health impacts. The small size of the affected populations also makes health impact and vulnerability studies more difficult to conduct methodologically.

3.12.3 Direct and Indirect Impacts on Health

Most of the direct, but especially indirect, effects of these hazards on health, as described in this chapter, should be analyzed in more detail and for their specific characteristics. Although mental health impacts (post-traumatic stress, depression, etc.) are being studied more and more, the impacts of various hazards on social cohesion, environmental degradation, population movements, and financial insecurity are unknown and remain to be discovered. It is important to assess these psychosocial health effects, as they indirectly affect the physical health and adaptive capacity of affected individuals (see Chapter 4: Mental Health and Well-Being).

3.12.4 Impacts of Combined Natural Hazard Events

In Canada, very few studies have focused on the effect of combined natural hazards occurring simultaneously or successively on population health. Assessing the health and social impacts associated with the repeated exposure to extreme events on the same populations is rare and should be prioritized given that climate change is expected to increase the frequency of many extreme weather events and disasters, thereby increasing the probability of combined and/or successive events. Examples of past events in Canada include the successive exposure to floods (2017 and 2019) and tornadoes or high winds (2018) in the Gatineau/Ottawa area (CRC, 2020a), and wildfires (2016) and floods (2020) in Fort McMurray, Alberta (CRC, 2020b). The successive extreme heat events that struck Eastern Canada in 2020 are another example. Not only are more studies of the health effects of such combined events needed, but expected future trends also need to be projected. Traditional risk assessment assesses one danger/hazard at a time, which can lead to an underestimated risk for natural hazards events that often depend on each other (e.g., extreme heat and wildfires), are fed by the same hydro-meteorological variables (Zscheischler et al., 2018), or combine to overwhelm adaptive capacities that protect health. Climate projections would also benefit from the analysis of compound events, such as combined (or repeated) extreme heat event projections, which are expected to be amplified (Baldwin et al., 2019).

3.12.5 Cascading Impacts of Hazards and Health System Impacts

Little research has yet been conducted on the cumulative impacts of natural hazards that can affect health, such as the likelihood of a power outage causing a water or medication shortage or road accidents due to a traffic light outage. Assessing the health system's ability to cope with natural hazards is also essential, albeit poorly documented, to avoid disrupting services or overloading equipment or staff, particularly in areas that are rural or remote from urban centres. A health system that is itself vulnerable to natural hazards could exacerbate the health effects of at risk populations by being unable to meet the demand for care, medication, and social services (see Chapter 10: Adaptation and Health System Resilience). The current COVID-19 pandemic also illustrates a situation in which an already overloaded health system may have to simultaneously deal with the effects of a hurricane or extreme heat events.

3.12.6 Behaviours and Lifestyle

The effects of climate change on behaviour and lifestyle should require further study. For example, an analysis of the effects of heat and precipitation on physical activity, outdoor activity, travel habits, eating, social interactions, criminal behaviour, emotional strain, cognitive ability, and choice of living area are essential for a full and representative assessment of the consequences of climate change, but little related data are available for Canada and elsewhere in the world.

3.12.7 Assessment of Adaptation Measures

Retrospective assessment of the health effects of measures to adapt to natural hazards is also lacking, with the exception of greening. The scientific literature focuses more on health effects based on exposure and vulnerability to hazards. In the absence of a more accurate assessment, health effects must be inferred from the impacts of adaptation measures on the frequency, location, intensity, and timing of the natural hazards, which have been studied more extensively. Even in this literature, studies rarely control for implemented adaptation measures and individual or social adaptive abilities, or else do so indirectly through socio-economic factors, such as income and education. Individuals respond in one way or another to extreme heat, intense cold, smog episodes, humidity, and precipitation by reducing their time outdoors, for example, which influences observed health effects.

3.12.8 Economic Impacts of Health Effects and Adaptation and Mitigation Measures

Although there are cost-benefit analyses for select climate change adaptation and mitigation measures, they fail to take into account health benefits associated with them. Estimates of the monetary value of the health benefits of proposed measures, including avoided health care costs, could help justify their adoption and implementation. Decision makers require information about whether costly adaptation measures would have sufficient economic payback, for example, the benefits of reducing fossil fuel combustion (less GHGs, less air pollution) compared to the costs of building infrastructure (bicycle path, tram) or setting up a monitoring system for health impacts. As well, there are very few studies that highlight the level of climate change adaptation and preparedness, and effectiveness of specific measures, whether at the municipal, provincial, or national level; yet these preparations and adaptations can greatly reduce the medical costs associated with natural disasters, in particular.

3.12.9 Relative Importance of Vulnerability and Protection Factors

Although vulnerability is central to the literature on the health impacts of natural hazards and adaptation to climate change, further research is needed to better understand and rank vulnerability factors in order to effectively prioritize adaptation measures. The assessment of the interactions between these factors and their cumulative effects on health outcomes in a climate change context is also lacking. The same applies to protective factors and their interactions with vulnerability factors. Currently, the way vulnerability is conceptualized is misunderstood, especially regarding social cohesion, sense of belonging, education, and certain cultural or cognitive factors.

3.12.10 Equitable Representation in the Literature

Some populations at higher risk from the health effects of natural hazards are studied less than others, particularly those already experiencing health inequities (see Chapter 9: Climate Change and Health Equity). People experiencing homelessness, people who have pre-existing chronic diseases or mental illness, people with reduced mobility, racialized populations, and socially isolated individuals are less represented in the literature compared to men, women, low-income individuals, children, workers, and seniors.

Sex is often included in impact studies,[10] and each sex may have different vulnerability factors, but it is not clear whether one particular sex is more vulnerable overall. Consideration for gender[11] and 2SLGBTQQIA+ populations are almost completely absent from the scientific literature on climate change (see Chapter 9: Climate Change and Health Equity).

3.12.11 Indigenous Populations

The literature on how climate change will impact Indigenous populations living in Canada is uneven in terms of population and geographic focus. Most research is on Inuit populations and the Canadian Arctic, while studies of people living in Southern Canadian or urban areas, and of Métis peoples across Canada, are sparse. While there is more research on Northern Indigenous populations, they are less documented than

10 In Western science, sex is typically considered binary (male and female), which overlooks intersex individuals.

11 Gender refers to the socially constructed roles assigned to men and women. In Western science, gender is commonly conflated with sex, and presented as binary (man and woman), overlooking non-binary individuals.

the general populations living in Southern Canada. In addition, significant research gaps exist about climate change impacts on the health of First Nations communities in the Prairies and the Atlantic provinces.

The vulnerability factors that increase risks of health impacts of First Nations, Inuit, and Métis peoples and the impacts of hazards may differ in important aspects from non-Indigenous populations (e.g., pervasive health inequalities, inequities, and determinants of health, including a shared history of colonization) and require more research, as do the factors on the determinants of adaptive capacity needed to build greater resilience to future impacts. Furthermore, research on Indigenous communities is seldom Indigenous-led, which can contribute to a sometimes biased interpretation of research findings on impacts or vulnerability to natural hazards.

3.12.12 Factors Supporting Adaptation

Political, societal, and structural factors that support effective adaptation to natural hazards, although studied elsewhere, have not been thoroughly assessed in a Canadian context. Factors influencing whether and how decision makers within and outside the health sector implement climate change adaptation measures are not well documented in a Canadian context. Legal and administrative organization, strategic planning, communication between different sectors and departments, resource allocation, windows of opportunity, the role of public opinion, as well as assessment and prioritization methods, are all relevant topics that should be studied more in-depth to facilitate adaptation to climate change and encourage optimal governance.

3.12.13 Communication on Climate Change

Strategies and measures to communicate climate change also requires further study in Canada. Knowledge of risk and adaptation measures influences the adoption of preventive behaviours. Thus, the use of the most effective communication tools and messages to reach populations at increased risk, who generally have less means to adapt, and the tailoring of messages according to each subpopulation are essential. Communication efforts related to climate change and health are not currently being assessed in Canada. Evaluation of such efforts would make it possible to optimize the impacts of awareness campaigns. Social marketing approaches and techniques are a potentially powerful tool to improve the effectiveness of climate change and health communication, but are not currently being widely utilized (Daignault et al., 2018). A better understanding of the psychological processes that lead individuals to adopt adaptation measures would help in efforts by public health officials to better tailor messages such as, for example, framing the issue to emphasize opportunities and benefits to encourage action. Several social psychology models, such as the theory of planned behaviour or the protection motivation theory, can be used for this purpose.

In summary, analysis of the impacts of natural hazards on health, risk factors, and vulnerability factors, as well as adaptation measures, need to successfully plan for climate change, is still piecemeal in Canada, despite more than 15 years of work and growing interest in this area. More research should be undertaken to fill these gaps.

3.13 Conclusion

This chapter discusses the impacts of natural hazards influenced by climate change on the health of Canadians with a special focus on populations at increased risk. All of the natural hazards identified already have significant impacts on people's health, some major, and these impacts are expected to become more intense in the coming years in the absence of further adaptation measures.

A few years ago, an external assessment noted that, while several provinces have adopted climate change action plans that recognize the impacts of climate change on population health, most remained in the early stages of adapting to the health impacts of climate change, with responses that are fragmented or focused on a limited number of hazards, particularly heat (Austin et al., 2015). Moreover, a provincial and federal auditors general report in 2018 criticized the limited progress on risk assessment and the lack of detailed adaptation plans across the country, despite some tangible successes (Office of the Auditor General of Canada, 2018). As extreme meteorological events constitute the most important element of climate change risks, this conclusion remains relevant for natural hazards.

Several adaptation measures do exist and some are being implemented by health authorities; they can be adopted more widely to reduce the effects of hazards on the health of Canadians, as this chapter has shown. However, monitoring and evaluation of these measures as they are implemented should be undertaken in the coming years to gain more evidence of their effectiveness and efficiency in diverse contexts and populations. Documenting and evaluating on a regular basis our health system risk levels and preparedness for natural hazards events should thus become a top priority, along with monitoring the implementation of preventive measures to reduce risks, especially for vulnerable populations. Preparing detailed adaptation plans, region by region throughout the country, would constitute an important first step towards improved preparedness.

A very similar conclusion emerged from a recent international review that suggested inclusion of vulnerable subpopulations is low across all actions and diffusion of adaptation across sectors remains underdeveloped (Berrang-Ford et al., 2019). These authors also argue that an important disconnection exists between adaptation goals and the instruments and means proposed for implementation and reporting, including in Canada. Typically, preliminary actions (scenarios, conceptual tools, guides, assessment of potential impacts, etc.) far outweigh the systematic implementation of practical measures (financial support, technology, assessment of measures, etc.) by health authorities (Lesnikowski et al., 2015; Lesnikowski et al., 2016). Furthermore, significant regional differences exist in efforts to understand and adapt to the health impacts of national hazards in Canada.

At the municipal level, an assessment of the climate change plans for the 63 most-populated cities in Canada found that GHG mitigation rather than adaptation measures were being prioritized, while the assessment of both types of measures in the plans, their implementation, and the involvement of a variety of stakeholders were lacking (Guyadeen et al., 2019). Ultimately, the current pace of implementation of adaptation measures to reduce the health impacts of natural hazards may be insufficient to substantially mitigate the future effects of climate change, as highlighted by recent dramatic events such as the 2021 summer extreme heat and severe wildfires in Western Canada, and their effects. Redoubling efforts to prepare for climate change is therefore essential to ensure sustainable health in all Canadian communities and regions.

3.14 References

Abbasi, S. (2014). *Adaptation to drought in Saskatchewan rural communities : A case study of Kindersley and Maidstone, Saskatchewan* [Master's Thesis, University of Saskatchewan]. University of Saskatchewan. Retrieved from <http://hdl.handle.net/10388/ETD-2014-01-1385>

Achakulwisut, P., Mickley, L., & Anenberg, S. (2018). Drought-sensitivity of fine dust in the US Southwest : Implications for air quality and public health under future climate change. *Environmental Research Letters, 13*(5), 054025.

Acharya, P., Boggess, B., & Zhang, K. (2018). Assessing heat stress and health among construction workers in a changing climate : A review. *International Journal of Environmental Research and Public Health, 15*(2). <https://doi.org/10.3390/ijerph15020247>

Adam-Poupart, A., Smargiassi, A., Busque, M.-A., Duguay, P., Fournier, M., Zayed, J., & Labreche, F. (2014). Summer outdoor temperature and occupational heat-related illnesses in Quebec (Canada). *Environmental Research, 134*, 339-344. <https://doi.org/10.1016/j.envres.2014.07.018>

Adam-Poupart, A., Smargiassi, A., Busque, M.-A., Duguay, P., Fournier, M., Zayed, J., & Labrèche, F. (2015). Effect of summer outdoor temperatures on work-related injuries in Quebec (Canada). *Occupational & Environmental Medicine, 72*(5), 338-345.

Adam-Poupart, A., Nicolakakis, N., Anassour Laouan Sidi, E., Berry, P., Campagna, C., Chaumont, D., Hamel, D., Labrèche, F., Sassine, M.-P., Smargiassi, A., Zayed, J. (2021). *Climate change and heat vulnerabilities of Canadian workers: Focus on the Central and Western provinces of Canada.* Institut national de santé publique du Québec.

Adetona, O., Reinhardt, T. E., Domitrovich, J., Broyles, G., Adetona, A. M., Kleinman, M. T., Ottmar, R. D., & Naeher, L. P. (2016). Review of the health effects of wildland fire smoke on wildland firefighters and the public. *Inhalation Toxicology, 28*(3), 95-139.

Advisory Committee on Homelessness. (2018). *Final Report of the Advisory Committee on Homelessness on the Homelessness Partnering Strategy*. Employment and Social Development Canada.

Agriculture and Agri-Food Canada (2021). *Canadian Canadian Drought Monitor*. Retrieved from <https://www-ep.agr.gc.ca/en/agriculture-and-environment/drought-watch-and-agroclimate/canadian-drought-monitor>

Agyapong, V. I. O., Hrabok, M., Juhas, M., Omeje, J., Denga, E., Nwaka, B., Akinjise, I., Corbett, S. E., Moosavi, S., Brown, M., Chue, P., Greenshaw, A. J., & Li, X.-M. (2018). Prevalence rates and predictors of generalized anxiety disorder symptoms in residents of Fort McMurray six months after a wildfire. *Frontiers in Psychiatry, 9,* 345. <https://doi.org/10.3389/fpsyt.2018.00345>

AirNow. (2021). *AirNow.* Retrieved from <https://airnow.gov/>

Alberini, A., Gans, W., Alhassan, M. (2011). Individual and public-program adaptation : Coping with heat waves in five cities in Canada. *International Journal of Environmental Research and Public Health, 8*(12), 4679-4701. <https://doi.org/10.3390/ijerph8124679>

Alberta Health Service. (2020). *Use of Portable Bedside Fans and Air Conditioners in Healthcare during the COVID-19 Pandemic*. Infection and Prevention Control Continuing Care Working Group. Retrieved from <https://www.albertahealthservices.ca/assets/healthinfo/ipc/if-hp-ipc-info-sheet-portable-fans.pdf>

Albert-Green, A., Dean, C. B., Martell, D. L., & Woolford, D. G. (2013). A methodology for investigating trends in changes in the timing of the fire season with applications to lightning-caused forest fires in Alberta and Ontario, Canada. *Canadian Journal of Forest Research, 43*(1), 39-45. <https://doi.org/10.1139/cjfr-2011-0432>

Alderman, K., Turner, L. R., & Tong, S. (2012). Floods and human health : A systematic review. *Environment International, 47*, 37-47. https://doi.org/10.1016/j.envint.2012.06.003

Ali, A. M., & Willett, K. (2015). What is the effect of the weather on trauma workload? A systematic review of the literature. *Injury, 46*(6), 945-953. https://doi.org/10.1016/j.injury.2015.03.016

Allard, M., Lemay, M., Barrette, C., L'Hérault, E., Sarrazin, D., Bell, T., & Doré, G. (2012). Permafrost and climate change in Nunavik and Nunatsiavut : Importance for municipal and transportation infrastructures. In M. Allard, & M. Lemay (Eds.), N*unavik and Nunatsiavut: From science to policy. An Integrated Regional Impact Study (IRIS) of climate change and modernization,* 171-197. Quebec City, QC.

Almendra, R., Santana, P., & Vasconcelos, J. (2017). Evidence of social deprivation on the spatial patterns of excess winter mortality. *International Journal of Public Health, 62*(8), 849-856.

Andrey, J. (2010). Long-term trends in weather-related crash risks. *Journal of Transport Geography, 18*(2), 247-258. <https://doi.org/10.1016/j.jtrangeo.2009.05.002>

Arbuthnott, K., Hajat, S., Heaviside, C., & Vardoulakis, S. (2016). Changes in population susceptibility to heat and cold over time : Assessing adaptation to climate change. *Environmental Health, 15*(1), S33.

ArcticNet. (2021). *ArcticNet.* Retrieved from <http://www.arcticnet.ulaval.ca/>

Askew, A. E., & Bowker, J. M. (2018). Impacts of climate change on outdoor recreation participation : Outlook to 2060. *Journal of Park & Recreation Administration, 36*(2), 97-120.

Astell-Burt, T., Feng, X., & Kolt, G. S. (2014). Neighbourhood green space and the odds of having skin cancer : Multilevel evidence of survey data from 267072 Australians. *Journal of Epidemiology and Community Health, 68*(4), 370-374. <https://doi.org/10.1136/jech-2013-203043>

Audinet, P., Amado, J.-C., & Rabb, B. (2014). Climate risk management approaches in the electricity sector : Lessons from early adapters. In A. Troccoli, L. Dubus, & S. E. Haupt (Eds.), *Weather Matters for Energy* (p. 17-64). New York, NY: Springer. <https://doi.org/10.1007/978-1-4614-9221-4_2>

Auger, N., Bilodeau-Bertrand, M., Labesse, M. E., & Kosatsky, T. (2017a). Association of elevated ambient temperature with death from cocaine overdose. *Drug and Alcohol Dependence, 178,* 101-105. <https://doi.org/10.1016/j.drugalcdep.2017.04.019>

Auger, N., Fraser, W. D., Arbour, L., Bilodeau-Bertrand, M., & Kosatsky, T. (2017b). Elevated ambient temperatures and risk of neural tube defects. *Occupational and Environmental Medicine, 74*(5), 315-320. <https://doi.org/10.1136/oemed-2016-103956>

Auger, N., Fraser, W. D., Sauvé, R., Bilodeau-Bertrand, M., & Kosatsky, T. (2017c). Risk of congenital heart defects after ambient heat exposure early in pregnancy. *Environmental Health Perspectives, 125*(1), 8-14. <https://doi.org/10.1289/EHP171>

Auger, N., Fraser, W. D., Smargiassi, A., Bilodeau-Bertrand, M., & Kosatsky, T. (2017d). Elevated outdoor temperatures and risk of stillbirth. *International Journal of Epidemiology, 46*(1), 200-208. <https://doi.org/10.1093/ije/dyw077>

Auger, N., Fraser, W. D., Smargiassi, A., & Kosatsky, T. (2015). Ambient heat and sudden infant death : A case-crossover study spanning 30 years in Montreal, Canada. *Environmental Health Perspectives, 123*(7), 712-716. <https://doi.org/10.1289/ehp.1307960>

Auger, N., Naimi, A. I., Smargiassi, A., Lo, E., & Kosatsky, T. (2014). Extreme heat and risk of early delivery among preterm and term pregnancies. *Epidemiology, 25*(3), 344. <https://doi.org/10.1097/EDE.0000000000000074>

Auger, N., Potter, B. J., Smargiassi, A., Bilodeau-Bertrand, M., Paris, C., & Kosatsky, T. (2017e). Association between quantity and duration of snowfall and risk of myocardial infarction. *CMAJ: Canadian Medical Association Journal, 189*(6), E235-E242. <https://doi.org/10.1503/cmaj.161064>

Auger, N., Rhéaume, M.-A., Bilodeau-Bertrand, M., Tang, T., & Kosatsky, T. (2017f). Climate and the eye : Case-crossover analysis of retinal detachment after exposure to ambient heat. *Environmental Research, 157*, 103-109. <https://doi.org/10.1016/j.envres.2017.05.017>

Austin, S. E., Ford, J. D., Berrang-Ford, L., Araos, M., Parker, S., & Fleury, M. D. (2015). Public health adaptation to climate change in Canadian jurisdictions. *International Journal of Environmental Research and Public Health, 12*(1), 623-651. <https://doi.org/10.3390/ijerph120100623>

Avalanche Canada. (2018). *2017-2018 Annual report.* Retrieved from <https://issuu.com/avalancheca/docs/ac_2018_annual_reportissuu>

Azuma, K., Ikeda, K., Kagi, N., Yanagi, U., Hasegawa, K., & Osawa, H. (2014). Effects of water-damaged homes after flooding : Health status of the residents and the environmental risk factors. *International Journal of Environmental Health Research, 24*(2), 158-175. <https://doi.org/10.1080/09603123.2013.800964>

BC Centre for Disease Control (BC CDC). (2020). *Warm weather safety in a time of COVID-19*. Retrieved from <http://www.bccdc.ca/about/news-stories/stories/2020/warm-weather-safety-in-a-time-of-covid-19>

Baert, V., Gorus, E., Mets, T., Geerts, C., & Bautmans, I. (2011). Motivators and barriers for physical activity in the oldest old : A systematic review. *Ageing Research Reviews, 10*(4), 464-474. <https://doi.org/10.1016/j.arr.2011.04.001>

Bai, L., Li, Q., Wang, J., Lavigne, É., Gasparrini, A., Copes, R., Yagouti, A., Burnett, R. T., Goldberg, M. S. & Cakmak, S. (2017). Increased coronary heart disease and stroke hospitalisations from ambient temperatures in Ontario. *Heart*, *104*(8), 673-679.

Bai, L., Li, Q., Wang, J., Lavigne, E., Gasparrini, A., Copes, R., Yagouti, A., Burnett, R. T., Goldberg, M. S., Villeneuve, P. J., Cakmak, S., & Chen, H. (2016). Hospitalizations from hypertensive diseases, diabetes, and arrhythmia in relation to low and high temperatures : Population-based study. *Scientific Reports, 6*, 30283. <https://doi.org/10.1038/srep30283>

Bais, A. F., Lucas, R. M., Bornman, J. F., Williamson, C. E., Sulzberger, B., Austin, A. T., Wilson, S. R., Andrady, A. L., Bernhard, G., & McKenzie, R. L. (2018). Environmental effects of ozone depletion, UV radiation and interactions with climate change : UNEP Environmental Effects Assessment Panel, update 2017. *Photochemical & Photobiological Sciences, 17*(2), 127-179.

Bais, A. F., McKenzie, R., Bernhard, G., Aucamp, P., Ilyas, M., Madronich, S., & Tourpali, K. (2015). Ozone depletion and climate change : Impacts on UV radiation. *Photochemical & Photobiological Sciences, 14*(1), 19-52.

Baldwin, J. W., Dessy, J. B., Vecchi, G. A., & Oppenheimer, M. (2019). Temporally compound heat wave events and global warming: An emerging hazard. *Earth's Future, 7*(4), 411-427.

Barn, P. (2014). *Evidence review: Home and community clean air shelters to protect public health during wildfire smoke events* (C. Elliott, & K. Rideout, eds). BC Centre for Disease Control.

Barnett, A. G., Tong, S., & Clements, A. (2010). What measure of temperature is the best predictor of mortality? *Environmental research, 110*(6), 604-611. <https://doi.org/10.1016/j.envres.2010.05.006>

Barreca, A. I. (2012). Climate change, humidity, and mortality in the United States. *Journal of Environmental Economics and Management, 63*(1), 19-34. <https://doi.org/10.1016/j.jeem.2011.07.004>

Bartholdson, S., & von Schreeb, J. (2018). Natural Disasters and Injuries: What Does a Surgeon Need to Know? *Current Trauma Reports*, *4*(2), 103–108. <https://doi.org/10.1007/s40719-018-0125-3>

Basu, R., Pearson, D., Malig, B., Broadwin, R., & Green, R. (2012). The effect of high ambient temperature on emergency room visits. *Epidemiology, 23*(6), 813. <https://doi.org/10.1097/EDE.0b013e31826b7f97>

Bayentin, L., El Adlouni, S., Ouarda, T. B., Gosselin, P., Doyon, B., & Chebana, F. (2010). Spatial variability of climate effects on ischemic heart disease hospitalization rates for the period 1989-2006 in Quebec, Canada. *International Journal of Health Geographics, 9,* 5. <https://doi.org/10.1186/1476-072X-9-5>

Bayntun, C., Rockenschaub, G., & Murray, V. (2012). Developing a health system approach to disaster management: A qualitative analysis of the core literature to complement the WHO Toolkit for assessing health-system capacity for crisis management. PLoS Currents, 4, e5028b6037259a. <https://doi.org/10.1371/5028b6037259a>

Beaudoin, M., & Gosselin, P. (2016). An effective public health program to reduce urban heat islands in Québec, Canada. *Revista Panamericana de Salud Publica = Pan American Journal of Public Health*, *40*(3), 160–166.

Beaudoin, M., & Levasseur, M.-È. (2017). *Verdir les villes pour la santé de la population.* Institut national de santé publique du Québec.

Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z. J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P., Nieuwenhuijsen, M., Vineis, P., Xun, W. W., Katsouyanni, K., Dimakopoulou, K., Oudin, A., Forsberg, B., Modig, L., Havulinna, A. S., Lanki, T., … Hoek, G. (2014). Effects of long-term exposure to air pollution on natural-cause mortality : An analysis of 22 European cohorts within the multicentre ESCAPE project. *The Lancet, 383*(9919), 785-795. <https://doi.org/10.1016/S0140-6736(13)62158-3>

Bélanger, D., Abdous, B., Valois, P., Gosselin, P., & Sidi, E. (2016). A multilevel analysis to explain self-reported adverse health effects and adaptation to urban heat: a cross-sectional survey in the deprived areas of 9 Canadian cities. *BMC public health*, *16*, 144. <https://doi.org/10.1186/s12889-016-2749-y>

Bélanger, D., Gosselin, P., Valois, P., & Abdous, B. (2014). Perceived adverse health effects of heat and their determinants in deprived neighbourhoods : A cross-sectional survey of nine cities in Canada. *International Journal of Environmental Research and Public Health, 11*(11), 11028-11053. <https://doi.org/10.3390/ijerph111111028>

Bélanger, D., Gosselin, P., Valois, P., & Abdous, B. (2015). *Caractéristiques et perceptions du quartier et du logement associées aux impacts sanitaires néfastes autorapportés lorsqu'il fait très chaud et humide en été dans les secteurs urbains les plus défavorisés : Étude transversale dans 9 villes du Québec.* INRS, Institut National de Santé Publique, & Centre Eau Terre Environnement.

Bélanger, D., Gosselin, P., Bustinza., R., & Campagna, C. (2019). *Changements climatiques et santé : prévenir, soigner et s'adapter*. Québec, QC: Presses de l'Université Laval.

Bell, S. A., Abir, M., Choi, H., Cooke, C., & Iwashyna, T. (2018). All-cause hospital admissions among older adults after a natural disaster. *Annals of Emergency Medicine, 71*(6), 746-754.

Bellaire, S., Jamieson, B., Thumlert, S., Goodrich, J., & Statham, G. (2016). Analysis of long-term weather, snow and avalanche data at Glacier National Park, B.C., Canada. *Cold Regions Science and Technology, 121*, 118-125. <https://doi.org/10.1016/j.coldregions.2015.10.010>

Benedetti, J. (2019). *Sunburn.* Merck Manuals. Retrieved from <https://www.merckmanuals.com/>

Benmarhnia, T., Bailey, Z., Kaiser, D., Auger, N., King, N., & Kaufman, J. S. (2016). A difference-in-differences approach to assess the effect of a heat action plan on heat-related mortality, and differences in effectiveness according to sex, age, and socioe-conomic status (Montreal, Quebec). *Environmental Health Perspectives, 124*(11), 1694-1699. <https://doi.org/10.1289/EHP203>

Benmarhnia, T., Deguen, S., Kaufman, J. S., & Smargiassi, A. (2015). Review article : Vulnerability to heat-related mortality - a systematic review, meta-analysis, and meta-regression analysis. *Epidemiology, 26*(6), 781. <https://doi.org/10.1097/EDE.0000000000000375>

Berardi, U., & Jafarpur, P. (2020). Assessing the impact of climate change on building heating and cooling energy demand in Canada. *Renewable and Sustainable Energy Reviews, 121*, 109681. <https://doi.org/10.1016/j.rser.2019.109681>

Berlin, C., Techel, F., Moor, B. K., Zwahlen, M., Hasler, R. M., & Swiss National Cohort study group. (2019). Snow avalanche deaths in Switzerland from 1995 to 2014—Results of a nation-wide linkage study. *PloS One*, *14*(12), e0225735.

Berman, J. D., Ebisu, K., Peng, R. D., Dominici, F., & Bell, M. L. (2017). Drought and the risk of hospital admissions and mortality in older adults in western USA from 2000 to 2013 : A retrospective study. *The Lancet Planetary Health, 1*(1), e17-e25. <https://doi.org/10.1016/S2542-5196(17)30002-5>

Bernatchez, P., Dugas, S., Fraser, C., & Da Silva, L. (2015). Évaluation économique des impacts potentiels de l'érosion des côtes du Québec maritime dans un contexte de changements climatiques. Ouranos. <https://www.ouranos.ca/publication-scientifique/RapportBernatchez2015_FR.pdf>

Berrang-Ford, L., Biesbroek, R., Ford, J. D., Lesnikowski, A., Tanabe, A., Wang, F. M., Chen, C., Hsu, A., Hellmann, J. J., Pringle, P., Grecequet, M., Amado, J. C., Huq, S., Lwasa, S. & Heymann, S. J. (2019). Tracking global climate change adaptation among governments. Nature Climate Change, 9(6), 440-449.

Berry, H. L., Hogan, A., Owen, J., Rickwood, D., & Fragar, L. (2011). Climate change and farmers' mental health : Risks and responses. *Asia Pacific Journal of Public Health, 23*(2 Suppl), 119S-132S. <https://doi.org/10.1177/1010539510392556>

Berteaux, D., Gauthier, G., Domine, F., Ims, R. A., Lamoureux, S. F., Lévesque, E., & Yoccoz, N. (2016). Effects of changing permafrost and snow conditions on tundra wildlife: critical places and times. *Arctic Science*, *3*(2), 65-90. <https://doi.org/10.1016/j.etap.2017.08.022>

Black, C., Tesfaigzi, Y., Bassein, J. A., & Miller, L. A. (2017). Wildfire smoke exposure and human health : Significant gaps in research for a growing public health issue. *Environmental Toxicology and Pharmacology, 55*, 186-195. <https://doi.org/10.1016/j.etap.2017.08.022>

Blais-Stevens, A., Behnia, O., & Castagner, A. (2018). *Historical landslides that have resulted in fatalities in Canada (1771-2018).* Natural Resources Canada.

Bobb, J. F., Peng, R. D., Bell, M. L., & Dominici, F. (2014). Heat-related mortality and adaptation to heat in the United States. *Environmental Health Perspectives, 122*(8), 811-816.

Boeckmann, M., & Rohn, I. (2014). Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. *BMC Public Health, 14*, 1112. <https://doi.org/10.1186/1471-2458-14-1112>

Bolitho, A., & Miller, F. (2017). Heat as emergency, heat as chronic stress : Policy and institutional responses to vulnerability to extreme heat. *Local Environment, 22*(6), 682-698.

Bonaiuto, M., Alves, S., De Dominicis, S., & Petruccelli, I. (2016). Place attachment and natural hazard risk : Research review and agenda. *Journal of Environmental Psychology, 48*, 33-53.

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

Bonsal, B. R., Wheaton, E. E., Chipanshi, A. C., Lin, C., Sauchyn, D. J., & Wen, L. (2011). Drought research in Canada : A review. *Atmosphere-Ocean, 49*(4), 303-319. <https://doi.org/10.1080/07055900.2011.555103>

Botzen, W. J. W., Aerts, J. C. J. H., & van den Bergh, J. C. J. M. (2009). Willingness of homeowners to mitigate climate risk through insurance. *Ecological Economics, 68*(8), 2265-2277. <https://doi.org/10.1016/j.ecolecon.2009.02.019>

Boyd, J., Haegeli, P., Abu-Laban, R. B., Shuster, M., & Butt, J. C. (2009). Patterns of death among avalanche fatalities : A 21-year review. *Canadian Medical Association Journal, 180*(5), 507-512. <https://doi.org/10.1503/cmaj.081327>

Boyer, T. A., Melstrom, R. T., & Sanders, L. D. (2017). Effects of climate variation and water levels on reservoir recreation. *Lake and Reservoir Management, 33*(3), 223-233. <https://doi.org/10.1080/10402381.2017.1285375>

Bränström, R., Kasparian, N. A., Chang, Y., Affleck, P., Tibben, A., Aspinwall, L. G., Azizi, E., Baron-Epel, O., Battistuzzi, L., Bergman, W., Bruno, W., Chan, M., Cuellar, F., Dębniak, T., Pjanova, D., Ertmański, S., Figl, A., Gonzalez, M., Hayward, N. K., … Brandberg, Y. (2010). Predictors of sun protection behaviors and severe sunburn in an international online study. *Cancer Epidemiology and Prevention Biomarkers, 19*(9), 2199-2210. <https://doi.org/10.1158/1055-9965.EPI-10-0196>

Brimelow, J. C., Burrows, W. R., & Hanesiak, J. M. (2017). The changing hail threat over North America in response to anthropogenic climate change. *Nature Climate Change, 7*(7), 516-522.

Brown, L., & Murray, V. (2013). Examining the relationship between infectious diseases and flooding in Europe. *Disaster Health, 1*(2), 117-127. <https://doi.org/10.4161/dish.25216>

Brown, M., Agyapong, V., Greenshaw, A. J., Cribben, I., Brett-MacLean, P., Drolet, J., McDonald-Harker, C., Omeje, J., Mankowsi, M., Noble, S., Kitching, D., & Silverstone, P. H. (2019). After the Fort McMurray wildfire there are significant increases in mental health symptoms in grade 7-12 students compared to controls. *BMC Psychiatry, 19*(1), 18. <https://doi.org/10.1186/s12888-018-2007-1>

Bruce, M., Zulz, T., & Koch, A. (2016). Surveillance of infectious diseases in the Arctic. *Public health, 137,* 5-12.

Bubeck, P., Botzen, W. J., & Aerts, J. C. (2012). A review of risk perceptions and other factors that influence flood mitigation behavior. *Risk Analysis: An International Journal, 32*(9), 1481-1495.

Bunker, A., Wildenhain, J., Vandenbergh, A., Henschke, N., Rocklöv, J., Hajat, S., & Sauerborn, R. (2016). Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly; a systematic review and meta-analysis of epidemiological evidence. *EBioMedicine, 6*, 258-268. <https://doi.org/10.1016/j.ebiom.2016.02.034>

Burnett, M. E., & Wang, S. Q. (2011). Current sunscreen controversies : A critical review. *Photodermatology, Photoimmunology & Photomedicine, 27*(2), 58-67. <https://doi.org/10.1111/j.1600-0781.2011.00557.x>

Burton, H., Rabito, F., Danielson, L., & Takaro, T. K. (2016). Health effects of flooding in Canada : A 2015 review and description of gaps in research. *Canadian Water Resources Journal = Revue canadienne des ressources hydriques, 41*(1-2), 238-249. <https://doi.org/10.1080/07011784.2015.1128854>

Bush, E. & Lemmen, D. S. (Eds.). (2019). *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019>

Bustinza, R. (2020). *COVID-19 : Adaptation des recommandations de santé publique lors de chaleur extrême conformément aux recommandations de distanciation physique*. INSPQ. <https://www.inspq.qc.ca/sites/default/files/covid/3024-chaleur-extreme-recommandations-distanciation-physique-covid19.pdf> (version anglaise disponible)

Bustinza, R., Lebe,l G., Gosselin, P., Bélanger, D., & Chebana, F. (2013). Health impacts of the July 2010 heat wave in Québec, Canada. *BMC Public Health, 13*, 56. <https://doi.org/10.1186/1471-2458-13-56>

Buters, J. T. M., Antunes, C., Galveias, A., Bergmann, K. C., Thibaudon, M., Galán, C., Schmidt-Weber, C., & Oteros, J. (2018). Pollen and spore monitoring in the world. *Clinical and Translational Allergy, 8*(1), 9. <https://doi.org/10.1186/s13601-018-0197-8>

Cabrera, S. E., Mindell, J. S., Toledo, M., Alvo, M., & Ferro, C. J. (2016). Associations of Blood Pressure With Geographical Latitude, Solar Radiation, and Ambient Temperature : Results From the Chilean Health Survey, 2009–2010. *American Journal of Epidemiology, 183*(11), 1071-1073. <https://doi.org/10.1093/aje/kww037>

Calmels, F., Doré, G., Kong, X., & Roy, L. P. (2016). *Vulnerability of the north Alaska Highway to permafrost thaw : Design options and climate change adaptation.* Whitehorse, YT: Northern Climate ExChange, Yukon Research Centre.

Canada Energy Regulator. (2017). *Market Snapshot: Fuel poverty across Canada – lower energy efficiency in lower income households*. Retrieved from <https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2017/market-snapshot-fuel-poverty-across-canada-lower-energy-efficiency-in-lower-income-households.html>

Canadian Cancer Society. (2019). *Publications*. Retrieved from <https://action.cancer.ca/en/cancer-information/resources/publications>

Canadian Centre for Occupational Health and Safety. (2017). *Temperature conditions - Legislation.* Retrieved from <https://www.ccohs.ca/oshanswers/phys_agents/temp_legislation.html>

Canadian Council of Ministers of the Environment. (2016). *Summary of Integrated Watershed Management Approaches Across Canada*. Retrieved from <https://ccme.ca>

Canadian Institute for Health Information (CICH). (2007). *Improving the Health of Canadians: Mental Health and Homelessness*. Ottawa, ON. Retrieved from <https://cpa.ca/cpasite/UserFiles/Documents/Practice_Page/mental_health_homelessness_en.pdf>

Canadian Red Cross (CRC). (2020a). *Quebec Major Responses.* Retrieved from <https://www.redcross.ca/in-your-community/quebec/quebec-major-responses>

Canadian Red Cross (CRC). (2020b). *Alberta Major Disaster Responses.* Retrieved from <https://www.redcross.ca/in-your-community/alberta/alberta-major-disaster-responses>

Canadian Space Agency. (2016). *Detecting landslide risks on a wide scale*. Retrieved from <https://www.asc-csa.gc.ca/eng/blog/2016/11/24/detecting-landslide-risks-on-a-wide-scale.asp>

Cann, K., Thomas, D. R., Salmon, R., Wyn-Jones, A., & Kay, D. (2013). Extreme water-related weather events and water-borne disease. *Epidemiology & Infection, 141*(4), 671-686.

Canuel, M., Gosselin, P., Duhoux, A., Brunet, A. & Lesage, A. (2019). Surveillance and Prevention of the Impacts of Extreme Meteorological Events on Public Health System (SUPREME). In *Post-Disaster Mental Health Impacts Surveillance Toolkit*. Institut national de santé publique du Québec. Retrieved from <https://www.inspq.qc.ca/en/publications/2676>

Carnie, T.-L., Berry, H. L., Blinkhorn, S. A., & Hart, C. R. (2011). In their own words : Young people's mental health in drought-affected rural and remote NSW. *Australian Journal of Rural Health, 19*(5), 244-248. <https://doi.org/10.1111/j.1440-1584.2011.01224.x>

Cascio, W. E. (2018). Wildland fire smoke and human health. *Science of the Total Environment, 624*, 586-595. <https://doi.org/10.1016/j.scitotenv.2017.12.086>

Cassell, K., Gacek, P., Warren, J. L., Raymond, P. A., Cartter, M., & Weinberger, D. M. (2018). Association Between Sporadic Legionellosis and River Systems in Connecticut. *The Journal of Infectious Diseases, 217*(2), 179-187. <https://doi.org/10.1093/infdis/jix531>

Centers for Disease Control and Prevention (CDC). (2020). *COVID-19 and cooling centers.* Retrieved from <https://www.cdc.gov/coronavirus/2019-ncov/php/cooling-center.html>

Chae, B.-G., Park, H.-J., Catani, F., Simoni, A., & Berti, M. (2017). Landslide prediction, monitoring and early warning : A concise review of state-of-the-art. *Geosciences Journal, 21*(6), 1033-1070. <https://doi.org/10.1007/s12303-017-0034-4>

Chan, C. B., Ryan, D. A., & Tudor-Locke, C. (2006). Relationship between objective measures of physical activity and weather : A longitudinal study. *International Journal of Behavioral Nutrition and Physical Activity, 3*(1), 21. <https://doi.org/10.1186/1479-5868-3-21>

Chapra, S. C., Boehlert, B., Fant, C., Bierman, V. J., Henderson, J., Mills, D., Mas, D. M. L., Rennels, L., Jantarasami, L., Martinich, J., Strzepek, K. M., & Paerl, H. W. (2017). Climate change impacts on harmful algal blooms in US freshwaters : A screening-level assessment. *Environmental Science & Technology, 51*(16), 8933-8943. <https://doi.org/10.1021/acs.est.7b01498>

Charrois, J. W. (2010). Private drinking water supplies : Challenges for public health. *Canadian Medical Association Journal, 182*(10), 1061-1064.

Chen, H., Wang, J., Li, Q., Yagouti, A., Lavigne, E., Foty, R., Burnett, R. T., Villeneuve, P. J., Cakmak, S., & Copes, R. (2016). Assessment of the effect of cold and hot temperatures on mortality in Ontario, Canada : A population-based study. *CMAJ Open, 4*(1), E48-E58. <https://doi.org/10.9778/cmajo.20150111>

Chen, J., Anderson, K., Pavlovic, R., Moran, M. D., Englefield, P., Thompson, D. K., Munoz-Alpizar, R., Landry, H. (2019). The FireWork v2. 0 air quality forecast system with biomass burning emissions from the Canadian Forest Fire Emissions Prediction System v2.03. *Geoscientific Model Development, 12*(7), 3283-310. <https://doi.org/10.5194/gmd-12-3283-2019>

Cheng, J., Xu, Z., Zhu, R., Wang, X., Jin, L., Song, J., & Su, H. (2014). Impact of diurnal temperature range on human health : A systematic review. *International Journal of Biometeorology, 58*(9), 2011-2024.

Cherry, N., & Haynes, W. (2017). Effects of the Fort McMurray wildfires on the health of evacuated workers : Follow-up of 2 cohorts. *CMAJ Open, 5*(3), E638-E645. <https://doi.org/10.9778/cmajo.20170047>

Chhetri, B. K., Takaro, T. K., Balshaw, R., Otterstatter, M., Mak, S., Lem, M., Zubel, M., Lysyshyn, M., Clarkson, L., Edwards, J., Fleury, M. D., Henderson, S. B., & Galanis, E. (2017). Associations between extreme precipitation and acute gastro-intestinal illness due to cryptosporidiosis and giardiasis in an urban Canadian drinking water system (1997–2009). *Journal of Water and Health, 15*(6), 898-907. <https://doi.org/10.2166/wh.2017.100>

Chief Public Health Officer. (2016). *Health Status of Canadians 2016: Report of the Chief Public Health Officer.* Public Health Agency of Canada. Retrieved from <https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/2016-health-status-canadians.html>

Chouinard, O., Plante, S., & Martin, G. (2008). The community engagement process : A governance approach in adaptation to coastal erosion and flooding in Atlantic Canada. *Canadian Journal of Regional Science, 31*(3), 507-520.

Chu, A., Han, L., Roifman, I., Lee, D. S., Green, M. E., Jacklin, K., Walker, J., Sutherland, R., Khan, S., Frymire, E. & Tu, J. V. (2019). Trends in cardiovascular care and event rates among First Nations and other people with diabetes in Ontario, Canada, 1996–2015. *CMAJ, 191*(47), E1291-E1298.

Circé, M., Da Silva, L., Boyer-Villemaire, U., Duff, G., Desjarlais, C., & Morneau, F. (2016). *Analyse couts-avantages des options d'adaptation en zone côtière au Québec.* Ouranos.

Centre intégré universitaire de santé et de services sociaux (CIUSSS) du Centre-Sud-de-l'Île-de-Montréal. (2017). *Le Directeur de santé publique de Montréal présente les principaux constats de l'enquête réalisée auprès des victimes des inondations.* Retrieved from <https://santemontreal.qc.ca/population/actualites/nouvelle/le-directeur-de-sante-publique-de-montreal-presente-les-principaux-constats-de-lenquete-sant/>

Clark, D. G., Ford, J. D., Berrang-Ford, L., Pearce, T., Kowal, S., & Gough, W. A. (2016a). The role of environmental factors in search and rescue incidents in Nunavut, Canada. *Public Health, 137,* 44-49. <https://doi.org/10.1016/j.puhe.2016.06.003>

Clark, D. G., Ford, J. D., Pearce, T., & Berrang-Ford, L. (2016b). Vulnerability to unintentional injuries associated with land-use activities and search and rescue in Nunavut, Canada. *Social Science & Medicine, 169*, 18-26. <https://doi.org/10.1016/j.socscimed.2016.09.026>

Conlon, K. C., Rajkovich, N. B., White-Newsome, J. L., Larsen, L., & Neill, M. S. O. (2011). Preventing cold-related morbidity and mortality in a changing climate. *Maturitas, 69*(3), 197-202. <https://doi.org/10.1016/j.maturitas.2011.04.004>

Conservation Ontario. (2010). *Overview of Integrated Watershed Management in Ontario*. Retrieved from https://conservationontario.ca/fileadmin/pdf/policy-priorities_section/IWM_OverviewIWM_PP.pdf

Conway, T., & Scott, J. L. (2020). *Urban Forests in a Changing Climate*. The Greenbelt Foundation. Retrieved from https://d3n8a8pro7vhmx.cloudfront.net/greenbelt/pages/14604/attachments/original/1600457503/UrbanForestsChangingClimate_REPORT_E-ver_REV.pdf?1600457503

Correia, A., Azevedo, M., Gondim, F., & Bandeira, F. (2014). Ethnic aspects of vitamin D deficiency. *Arquivos Brasileiros de Endocrinologia e Metabologia*, *58*(5), 540–544. <https://doi.org/10.1590/0004-2730000003320>

Crnek-Georgeson, K. T., Wilson, L. A., & Page, A. (2017). Factors influencing suicide in older rural males : A review of Australian studies. *Rural & Remote Health, 17*(4), 1-11.

Crouse, D. L., Pinault, L., Balram, A., Hystad, P., Peters, P. A., Chen, H., van Donkelaar, A., Martin, R. V., Ménard, R., Robichaud, A., & Villeneuve, P. J. (2017). Urban greenness and mortality in Canada's largest cities : A national cohort study. *The Lancet Planetary Health, 1*(7), e289-e297. <https://doi.org/10.1016/S2542-5196(17)30118-3>

Cunsolo Willox, A., Stephenson, E., Allen, J., Bourque, F., Drossos, A., Elgarøy, S., Kral, M. J., Mauro, I., Moses, J., Pearce, T., MacDonald, J. P., & Wexler, L. (2015). Examining relationships between climate change and mental health in the Circumpolar North. *Regional Environmental Change*, *15*(1), 169-82.

Curtis, S., Fair, A., Wistow, J., Val, D. V., & Oven, K. (2017). Impact of extreme weather events and climate change for health and social care systems. *Environmental Health, 16*(1), 128.

Cusack, L., van Loon, A., Kralik, D., Arbon, P., & Gilbert, S. (2013). Extreme weather-related health needs of people who are homeless. *Australian Journal of Primary Health, 19*(3), 250-255. <https://doi.org/10.1071/PY12048>

Dadlani, C., & Orlow, S. J. (2008). Planning for a brighter future : A review of sun protection and barriers to behavioral change in children and adolescents. *Dermatology Online Journal, 14*(9). <https://escholarship.org/uc/item/6vs1r0r9>

D'Amato, G., Cecchi, L., & Annesi-Maesano, I. (2012). A trans-disciplinary overview of case reports of thunderstorm-related asthma outbreaks and relapse. *European Respiratory Review, 21*(124), 82-87. <https://doi.org/10.1183/09059180.00001712>

Daignault, P., Boivin, M., & Champagne St-Arnaud, V. (2018). Communiquer l'action en changements climatiques au Québec: une étude de segmentation. *VertigO: la revue électronique en sciences de l'environnement, 18*(3). <https://www.erudit.org/en/journals/vertigo/1900-v1-n1-vertigo04929/1065313ar/abstract/>

Dancause, K. N., Laplante, D. P., Hart, K. J., O'Hara, M. W., Elgbeili, G., Brunet, A., & King, S. (2015). Prenatal stress due to a natural disaster predicts adiposity in childhood : The Iowa Flood Study. *Journal of Obesity, 2015,* 570541-570541. >https://doi.org/10.1155/2015/570541>

Darques, R. (2015). Mediterranean cities under fire. A critical approach to the wildland–urban interface. *Applied Geography, 59*, 10-21.

Davis, R. E., McGregor, G. R., & Enfield, K. B. (2016). Humidity : A review and primer on atmospheric moisture and human health. *Environmental Research, 144,* 106-116. <https://doi.org/10.1016/j.envres.2015.10.014>

Dean, J. G., & Stain, H. J. (2010). Mental health impact for adolescents living with prolonged drought. *Australian Journal of Rural Health, 18*(1), 32-37.

Decent, D. (2018). *The mental and physical human health impacts of residential basement Flooding and associated financial costs : Interviews with households in Southern Ontario, Canada.* UWSpace. Retrieved from <http://hdl.handle.net/10012/13366>

Delic, N. C., Lyons, J. G., Di Girolamo, N., & Halliday, G. M. (2017). Damaging Effects of Ultraviolet Radiation on the Cornea. *Photochemistry and Photobiology, 93*(4), 920-929. <https://doi.org/10.1111/php.12686>

de Munck, C., Pigeon, G., Masson, V., Meunier, F., Bousquet, P., Tréméac, B., Merchat, M., Poeuf, P., & Marchadier, C. (2013). How much can air conditioning increase air temperatures for a city like Paris, France? *International Journal of Climatology, 33*(1), 210-227. <https://doi.org/10.1002/joc.3415>

Derksen, C., Burgess, D., Duguay, C., Howell, S., Mudryk, L., Smith, S., Thackeray, C., & Kirchmeier-Young, M. (2019). Changes in snow, ice, and permafrost across Canada. In E. Bush, & D.S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada.

Diaz, H., Hurlbert, M., & Warren, J. (2016). *Vulnerability and adaptation to drought : The Canadian Prairies and South America.* University of Calgary.

Dix-Cooper, L., Johnston, F., Hasselback, P., & Rideout, K. (2014). *Evidence review : Reducing time outdoors during wildfire smoke events : Advice to stay indoors, advice to reduce outdoor physical activity and cancelling.* BC Centre for Disease Control.

Dixon, S. J., Sear, D. A., Odoni, N. A., Sykes, T., & Lane, S. N. (2016). The effects of river restoration on catchment scale flood risk and flood hydrology. *Earth Surface Processes and Landforms, 41*(7), 997-1008. <https://doi.org/10.1002/esp.3919>

Dodd, W., Howard, C., Rose, C., Scott, C., Scott, P., Cunsolo, A., & Orbinski, J. (2018a). The summer of smoke : Ecosocial and health impacts of a record wildfire season in the Northwest Territories, Canada. *The Lancet Global Health, 6,* S30. <https://doi.org/10.1016/S2214-109X(18)30159-1>

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018b). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *109*(3), 327–337. <https://doi.org/10.17269/s41997-018-0070-5>

Doede, A., & Davis, R. (2018). Use of airborne PM10 concentrations at air quality monitoring sites in Imperial County, California, as an indication of geographical influences on lung health during drought periods : A time-series analysis. *The Lancet Planetary Health, 2,* S10.

Doré, G., Niu, F., & Brooks, H. (2016). Adaptation methods for transportation infrastructure built on degrading permafrost. *Permafrost and Periglacial Processes, 27*(4), 352-364. <https://doi.org/10.1002/ppp.1919>

Doyon, B., Bélanger, D., & Gosselin, P. (2006). Effets du climat sur la mortalité au Québec méridional de 1981 à 1999 et simulations pour des scénarios climatiques futures. Institut national de santé publique Québec.

Doyon, B., Belanger, D., & Gosselin, P. (2008). The potential impact of climate change on annual and seasonal mortality for three cities in Quebec, Canada. *International Journal of Health Geographics, 7*, 23. <https://doi.org/10.1186/1476-072X-7-23>

Drejza, S., Friesinger, S., & Bernatchez, P. (2015). *Vulnérabilité des infrastructures routières de l'Est du Québec à l'érosion et à la submersion côtière dans un contexte de changements climatiques : Développement d'une approche et d'un indice pour quantifier la vulnérabilité des infrastructures routières à l'érosion et à la submersion côtière dans un contexte de changements climatiques sur 9 sites témoins*. Volume III. Projet X008.1. Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski.

Du, W., FitzGerald, G. J., Clark, M., & Hou, X.-Y. (2010). Health impacts of floods. *Prehospital and Disaster Medicine, 25*(3), 265-272. <https://doi.org/10.1017/S1049023X00008141>

Duchesne, A., Liu, A., Jones, S. L., Laplante, D. P., & King, S. (2017). Childhood body mass index at 5.5 years mediates the effect of prenatal maternal stress on daughters' age at menarche : Project Ice Storm. *Journal of Developmental Origins of Health and Disease, 8*(2), 168-177. <https://doi.org/10.1017/S2040174416000726>

Durkalec, A., Furgal, C., Skinner, M. W., & Sheldon, T. (2014). Investigating Environmental Determinants of Injury and Trauma in the Canadian North. *International Journal of Environmental Research and Public Health, 11*(2), 1536-1548. <https://doi.org/10.3390/ijerph110201536>

Durkalec, A., Furgal, C., Skinner, M. W., & Sheldon, T. (2015). Climate change influences on environment as a determinant of Indigenous health : Relationships to place, sea ice, and health in an Inuit community. *Social Science and Medicine, 136*, 17-26. <https://doi.org/10.1016/j.socscimed.2015.04.026>

Dykman, K. R. J. (2013). *Integrated watershed management planning in Manitoba : A platform for social learning* [Master's Thesis, University of Manitoba]. University of Manitoba. Retrieved from <https://mspace.lib.umanitoba.ca/bitstream/handle/1993/23231/dykman_kate.pdf?sequence=1&isAllowed=y>

Edwards, B., Gray, M., & Hunter, B. (2015). The impact of drought on mental health in rural and regional Australia. *Social Indicators Research, 121*(1), 177-194.

Enright, N. J., & Fontaine, J. B. (2014). Climate change and the management of fire-prone vegetation in southwest and southeast Australia. *Geographical Research, 52*(1), 34-44. <https://doi.org/10.1111/1745-5871.12026>

Environment and Climate change Canada. (2019a). *Air Quality Health Index*. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index.html>

Environment and Climate Change Canada. (2019b). *Canada's Wildfire Smoke Prediction System (FireWork)*. Retrieved from <https://weather.gc.ca/firework/>

Fann, N., Alman, B., Broome, R. A., Morgan, G. G., Johnston, F. H., Pouliot, G., & Rappold, A. G. (2018). The health impacts and economic value of wildland fire episodes in the U.S. : 2008–2012. *The Science of the Total Environment, 610-611*, 802-809. <https://doi.org/10.1016/j.scitotenv.2017.08.024>

Farrugia, S., Hudson, M. D., & McCulloch, L. (2013). An evaluation of flood control and urban cooling ecosystem services delivered by urban green infrastructure. *International Journal of Biodiversity Science, Ecosystem Services & Management, 9*(2), 136-145. <https://doi.org/10.1080/21513732.2013.782342>

Fartasch, M., Diepgen, T. L., Schmitt, J., & Drexler, H. (2012). The relationship between occupational sun exposure and non-melanoma skin cancer : Clinical basics, epidemiology, occupational disease evaluation, and prevention. *Deutsches Ärzteblatt International, 109*(43), 715.

Febriani, Y., Levallois, P., Gingras, S., Gosselin, P., Majowicz, S. E., & Fleury, M. D. (2010). The association between farming activities, precipitation, and the risk of acute gastrointestinal illness in rural municipalities of Quebec, Canada : A cross-sectional study. *BMC Public Health, 10*(1), 48. <https://doi.org/10.1186/1471-2458-10-48>

Felix, E., Afifi, T., Kia-Keating, M., Brown, L., Afifi, W., & Reyes, G. (2015). Family functioning and posttraumatic growth among parents and youth following wildfire disasters. *American Journal of Orthopsychiatry, 85*(2), 191.

Fernandes, P. M. (2013). Fire-smart management of forest landscapes in the Mediterranean basin under global change. *Landscape and Urban Planning, 110*, 175-182. <https://doi.org/10.1016/j.landurbplan.2012.10.014>

Fernandez, A., Black, J., Jones, M., Wilson, L., Salvador-Carulla, L., Astell-Burt, T., & Black, D. (2015). Flooding and mental health : A systematic mapping review. *PLOS ONE, 10*(4), e0119929. <https://doi.org/10.1371/journal.pone.0119929>

Findlay, L. C., Arim, R., & Kohen, D. (2020). Understanding the perceived mental health of Canadians during the COVTD-19 pandemic. *Health reports, 31*(4), 22-27. (disponible en français également)

Finlay, S. E., Moffat, A., Gazzard, R., Baker, D., & Murray, V. (2012). Health impacts of wildfires. *PLoS Currents*, *4*, e4f959951cce2c. <https://doi.org/10.1371/4f959951cce2c>

Fioletov, V., Kerr, J. B., & Fergusson, A. (2010). The UV Index : Definition, distribution and factors affecting It. *Canadian Journal of Public Health, 101*(4), I5-I9. <https://doi.org/10.1007/BF03405303>

First, J. M., First, N. L., & Houston, J. B. (2017). Intimate partner violence and disasters : A framework for empowering women experiencing violence in disaster settings. *Affilia, 32*(3), 390-403.

First Nations Information Governance Centre. (2018). *National report of the First Nations Regional Health Survey*. Phase 3: Volume One. Ottawa, ON. Retrieved from <https://fnigc.ca/wp-content/uploads/2020/09/713c8fd606a8eeb021debc927332938d_FNIGC-RHS-Phase-III-Report1-FINAL-VERSION-Dec.2018.pdf>

Fisk, W. J. (2015). Review of some effects of climate change on indoor environmental quality and health and associated no-regrets mitigation measures. *Building and Environment, 86*, 70-80. <https://doi.org/10.1016/j.buildenv.2014.12.024>

Flannigan, M. D., Krawchuk, M. A., Groot, W. J. de, Wotton, B. M., & Gowman, L. M. (2009). Implications of changing climate for global wildland fire. *International Journal of Wildland Fire, 18*(5), 483-507. <https://doi.org/10.1071/WF08187>

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic Change, 72*(1), 1-16. <https://doi.org/10.1007/s10584-005-5935-y>

Flannigan, M. D., Wotton, B. M., Marshall, G. A., de Groot, W. J., Johnston, J., Jurko, N., & Cantin, A. S. (2016). Fuel moisture sensitivity to temperature and precipitation : Climate change implications. *Climatic Change, 134*(1), 59-71. <https://doi.org/10.1007/s10584-015-1521-0>

Flynn, M., Ford, J. D., Labbé, J., Schrott, L., & Tagalik, S. (2018). Evaluating the effectiveness of hazard mapping as climate change adaptation for community planning in degrading permafrost terrain. *Sustainability Science*, *14*(4), 1041–1056. <https://doi.org/10.1007/s11625-018-0614-x>

Ford, B., Val Martin, M., Zelasky, S., Fischer, E., Anenberg, S., Heald, C., & Pierce, J. (2018). Future fire impacts on smoke concentrations, visibility, and health in the contiguous United States. *GeoHealth, 2*(8), 229-247.

Ford, J. D., Willox, A. C., Chatwood, S., Furgal, C., Harper, S., Mauro, I., & Pearce, T. (2014). Adapting to the Effects of Climate Change on Inuit Health. *American Journal of Public Health, 104*(S3), e9-e17. <https://doi.org/10.2105/AJPH.2013.301724>

Fortier, C. (2013). *Impact des changements climatiques sur les débordements des réseaux d'égouts unitaires*. Institut national de la recherche scientifique.

Fortune, M., Mustard, C., & Brown, P. (2014). The use of Bayesian inference to inform the surveillance of temperature-related occupational morbidity in Ontario, Canada, 2004-2010. *Environmental Research, 132*, 449-456. <https://doi.org/10.1016/j.envres.2014.04.022>

Freeman, S., & Eykelbosh, A. (2020). *COVID-19 and outdoor safety: Considerations for use of outdoor recreational spaces.* National Collaborating Centre for Environmental Health. Retrieved from <https://ncceh.ca/documents/guide/covid-19-and-outdoor-safety-considerations-use-outdoor-recreational-spaces>

Freedman, D. M., Kitahara, C. M., Linet, M. S., Alexander, B. H., Neta, G., Little, M. P., & Cahoon, E. K. (2015). Ambient temperature and risk of first primary basal cell carcinoma : A nationwide United States cohort study. *Journal of Photochemistry and Photobiology B: Biology, 148*, 284-289. <https://doi.org/10.1016/j.jphotobiol.2015.04.025>

French, C. E., Waite, T. D., Armstrong, B., Rubin, G. J., Group, E. N. S. of F. and H. S., Beck, C. R., & Oliver, I. (2019). Impact of repeat flooding on mental health and health-related quality of life : A cross-sectional analysis of the English National Study of Flooding and Health. *BMJ Open, 9*(11). <https://doi.org/10.1136/bmjopen-2019-031562>

Friel, S., Berry, H., Dinh, H., O'Brien, L., & Walls, H. L. (2014). The impact of drought on the association between food security and mental health in a nationally representative Australian sample. *BMC Public Health, 14*(1), 1102.

Fulton, A. E., & Drolet, J. (2018). Responding to disaster-related loss and grief : Recovering from the 2013 flood in Southern Alberta, Canada. *Journal of Loss & Trauma, 23*(2), 140-158. <https://doi.org/10.1080/15325024.2018.1423873>

Funari, E., Manganelli, M., & Sinisi, L. (2012). Impact of climate change on water-borne diseases. *Annali dell'Istituto superiore di sanita, 48*, 473-487.

Furr, J. M., Corner, J. S., Edmunds, J. M., & Kendall, P. C. (2010). Disasters and youth : A meta-analytic examination of posttraumatic stress. *Journal of Consulting and Clinical Psychology, 78*(6), 765-780. <https://doi.org/10.1037/a0021482>

Gabbe, B. J., Veitch, W., Curtis, K., Martin, K., Gomez, D., Civil, I., ... & Fitzgerald, M. (2020). Survey of major trauma centre preparedness for mass casualty incidents in Australia, Canada, England and New Zealand. *EClinicalMedicine, 21*, 100322. <https://doi.org/10.1016/j.eclinm.2020.100322>

Gabriel, K. M., & Endlicher, W. R. (2011). Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany. *Environmental Pollution, 159*(8-9), 2044-2050.

Gachon, P., Bussières, L., Gosselin, P., Raphoz, M., Bustinza, R., Martin, P., Dueymes, G., Gosselin, D., Labrecque, S., Jeffers, S., & Yagouti, A. (2016). *Guide to identifying alert thresholds for heat waves in Canada based on evidence*. Université du Québec à Montréal, Environment and Climate Change Canada, Institut National de Santé Publique du Québec, and Health Canada. Retrieved from <https://archipel.uqam.ca/9073/1/Gachon_et_al_2016_Guide_Heat_Waves_EN.pdf>

Gagnon, D., Romero, S. A., Cramer, M. N., Jay, O., & Crandall, C. G. (2016). Cardiac and thermal strain of elderly adults exposed to extreme heat and humidity with and without electric fan use. *JAMA, 316*(9), 989-991. <https://doi.org/10.1001/jama.2016.10550>

Gamble, J. L., Hurley, B. J., Schultz, P. A., Jaglom, W. S., Krishnan, N., & Harris, M. (2013). Climate change and older Americans : State of the science. *Environmental Health Perspectives, 121*(1), 15.

Garcia, D. M., & Sheehan, M. C. (2016). Extreme weather-driven disasters and children's health. *International Journal of Health Services*, *46*(1), 79-105. doi :10.1177/0020731415625254

Gariano, S. L., & Guzzetti, F. (2016). Landslides in a changing climate. *Earth-Science Reviews, 162*, 227-252. <https://doi.org/10.1016/j.earscirev.2016.08.011>

Gaskin, C. J., Taylor, D., Kinnear, S., Mann, J., Hillman, W., & Moran, M. (2017). Factors associated with the climate change vulnerability and the adaptive capacity of people with disability : A systematic review. *Weather, Climate, and Society, 9*(4), 801-814.

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., De Sario, M., Bell, M. L., Guo, Y.-L. L., Wu, C., Kan, H., Yi, S.-M., de Sousa Zanotti Stagliorio Coelho, M., Saldiva, P. H. N., … Armstrong, B. (2015). Mortality risk attributable to high and low ambient temperature : A multicountry observational study. *The Lancet, 386*(9991), 369-375. <https://doi.org/10.1016/S0140-6736(14)62114-0>

Gasparrini, A., Guo, Y., Sera, F., Vicedo-Cabrera, A. M., Huber, V., Tong, S., de Sousa Zanotti Stagliorio Coelho, M., Nascimento Saldiva, P. H., Lavigne, E., Matus Correa, P., Valdes Ortega, N., Kan, H., Osorio, S., Kyselý, J., Urban, A., Jaakkola, J. J. K., Ryti, N. R. I., Pascal, M., Goodman, P. G., … Armstrong, B. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health, 1*(9), e360-e367. <https://doi.org/10.1016/S2542-5196(17)30156-0>

Geertsema, M. (2013). Quick clay landslides, landscape evolution, and climate change : A perspective from British Columbia. In C. Margottini, P. Canuti, & K. Sassa (Eds.), *Landslide Science and Practice : Volume 4 : Global Environmental Change* (p. 115-120). Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-642-31337-0_15>

Georgakakos, A., Yao, H., Kistenmacher, M., Georgakakos, K., Graham, N., Cheng, F.-Y., Spencer, C., & Shamir, E. (2012). Value of adaptive water resources management in Northern California under climatic variability and change : Reservoir management. *Journal of Hydrology, 412*, 34-46.

Germain, D. (2016). Snow avalanche hazard assessment and risk management in northern Quebec, eastern Canada. *Natural Hazards, 80*(2), 1303-1321. <https://doi.org/10.1007/s11069-015-2024-z>

Germain, D., Filion, L., & Hétu, B. (2009). Snow avalanche regime and climatic conditions in the Chic-Choc Range, eastern Canada. *Climatic Change, 92*(1), 141-167. <https://doi.org/10.1007/s10584-008-9439-4>

Ghazani, M., FitzGerald, G., Hu, W., & Xu, Z. (2018). Temperature variability and gastrointestinal infections : A review of impacts and future perspectives. *International Journal of Environmental Research and Public Health, 15*(4), 766. <https://doi.org/10.3390/ijerph15040766>

Giguère, M. (2012). *Urban Heat Island Mitigation Strategies*. Institut national de santé publique. Retrieved from <https://www.inspq.qc.ca/en/publications/1513>

Gill, R. S., Hambridge, H. L., Schneider, E. B., Hanff, T., Tamargo, R. J., & Nyquist, P. (2013). Falling temperature and colder weather are associated with an increased risk of aneurysmal subarachnoid hemorrhage. *World Neurosurgery, 79*(1), 136-142.

Gillett, N. P., Weaver, A. J., Zwiers, F. W., & Flannigan, M. D. (2004). Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters, 31*(18). <https://doi.org/10.1029/2004GL020876>

Goldberg, M. S., Gasparrini, A., Armstrong, B., & Valois, M.-F. (2011). The short-term influence of temperature on daily mortality in the temperate climate of Montreal, Canada. *Environmental research, 111*(6), 853-860.

Goldman, A., Eggen, B., Golding, B., & Murray, V. (2014). The health impacts of windstorms : A systematic literature review. *Public health, 128*(1), 3-28.

Gomez, D., Haas, B., Ahmed, N., Tien, H., & Nathens, A. (2011). Disaster preparedness of Canadian trauma centres: the perspective of medical directors of trauma. *Canadian Journal of Surgery, 54*(1), 9.

Gorman, S., Lucas, R. M., Allen-Hall, A., Fleury, N., & Feelisch, M. (2017). Ultraviolet radiation, vitamin D and the development of obesity, metabolic syndrome and type-2 diabetes. *Photochemical & Photobiological Sciences, 16*(3), 362-373. <https://doi.org/10.1039/c6pp00274a>

Gorman, S., McGlade, J. P., Lambert, M. J., Strickland, D. H., Thomas, J. A., & Hart, P. H. (2010). UV exposure and protection against allergic airways disease. *Photochemical & Photobiological Sciences, 9*(4), 571-577.

Gosling, S. N., Hondula, D. M., Bunker, A., Ibarreta, D., Liu, J., Zhang, X., & Sauerborn, R. (2017). Adaptation to climate change: a comparative analysis of modeling methods for heat-related mortality. *Environmental health perspectives, 125*(8), 087008.

Government of Canada. (2019a). *Flood Ready*. Retrieved from <https://www.canada.ca/en/campaign/flood-ready.html>

Government of Canada (2019b). *Severe weather*. Retrieved from <https://www.canada.ca/en/services/environment/weather/severeweather.html>

Government of Canada. (2020). *Public health infobase.* Retrieved from <https://sante-infobase.canada.ca/>

Government of Nunavut. (2012). *Changing times: Climate change impacts and adaptation in Nunavut.* Iqaluit, NU. Retrieved from <http://www.climatechangenunavut.ca/sites/default/files/summer_2012_newsletter.pdf>

Graham, D. A., Vanos, J. K., Kenny, N. A., & Brown, R. D. (2016). The relationship between neighbourhood tree canopy cover and heat-related ambulance calls during extreme heat events in Toronto, Canada. *Urban Forestry & Urban Greening, 20*, 180-186. <https://doi.org/10.1016/j.ufug.2016.08.005>

Graham, H., White, P., Cotton, J., & McManus, S. (2019). Flood- and weather-damaged homes and mental health : An analysis using England's mental health survey. *International Journal of Environmental Research and Public Health, 16*(18), 3256. <https://doi.org/10.3390/ijerph16183256>

Greenan, B. J. W., James, T. S., Loder, J. W., Pepin, P., Azetsu-Scott, K., Ianson, D., Hamme, R. C., Gilbert, D., Tremblay, J.-É., Wang, X. L., & Perrie, W. (2019). Changes in oceans surrounding Canada. In E. Bush & D.S. Lemmen (Eds.), *Canada's Changing Climate Report.* Ottawa, ON: Government of Canada.

Greene, C. S., Robinson, P. J., & Millward, A. A. (2018). Canopy of advantage: Who benefits most from city trees? *Journal of Environmental Management*, *208*(15), 24-35. https://doi.org/10.1016/j.jenvman.2017.12.015

Greene, G., Paranjothy, S., & Palmer, S. R. (2015). Resilience and vulnerability to the psychological harm from flooding : The role of social cohesion. *American Journal of Public Health, 105*(9), 1792-1795. <https://doi.org/10.2105/AJPH.2015.302709>

Gronlund, C. J. (2014). Racial and socioe-conomic disparities in heat-related health effects and their mechanisms : A review. *Current Epidemiology Reports, 1*(3), 165-173. <https://doi.org/10.1007/s40471-014-0014-4>

Guiney, R. (2012). Farming suicides during the Victorian drought : 2001–2007. *Australian journal of rural health, 20*(1), 11-15.

Gunn, K. M., Kettler, L. J., Skaczkowski, G. L., & Turnbull, D. A. (2012). Farmers' stress and coping in a time of drought. *Rural & Remote Health, 12*(4).

Guo, Y., Gasparrini, A., Li, S., Sera, F., Vicedo-Cabrera, A. M., Coelho, M. de S. Z. S., Saldiva, P. H. N., Lavigne, E., Tawatsupa, B., & Punnasiri, K. (2018). Quantifying excess deaths related to heatwaves under climate change scenarios : A multicountry time series modelling study. *PLoS Medicine, 15*(7), e1002629.

Gupta, S., Carmichael, C., Simpson, C., Clarke, M. J., Allen, C., Gao, Y., Chan, E. Y., & Murray, V. (2012). Electric fans for reducing adverse health impacts in heatwaves. *The Cochrane Database of Systematic Reviews*, *2012*(7), CD009888. <https://doi.org/10.1002/14651858.CD009888.pub2>

Guyadeen, D., Thistlethwaite, J., & Henstra, D. (2019). Evaluating the quality of municipal climate change plans in Canada. *Climatic Change, 152*(1), 121-143. <https://doi.org/10.1007/s10584-018-2312-1>

Haider, A., Mamdani, M., & Shear, N. H. (2007). Socioeconomic status and the prevalence of melanoma in Ontario, Canada. *Journal of Cutaneous Medicine and Surgery*, *11*(1), 1–3. <https://doi.org/10.2310/7750.2007.00001>

Hajat, S. (2017). Health effects of milder winters : A review of evidence from the United Kingdom. *Environmental Health, 16*(1), 109.

Hajat, S., Haines, A., Sarran, C., Sharma, A., Bates, C., & Fleming, L. E. (2017). The effect of ambient temperature on type-2-diabetes: case-crossover analysis of 4+ million GP consultations across England. *Environmental Health : A Global Access Science Source*, *16*(1), 73. <https://doi.org/10.1186/s12940-017-0284-7>

Halliday, G. M., & Byrne, S. N. (2014). An unexpected role : UVA-induced release of nitric oxide from skin may have unexpected health benefits. *Journal of Investigative Dermatology, 134*(7), 1791-1794. <https://doi.org/10.1038/jid.2014.33>

Hambly, D., Andrey, J., Mills, B., & Fletcher, C. (2013). Projected implications of climate change for road safety in Greater Vancouver, Canada. *Climatic Change, 116*(3-4), 613-629. <https://doi.org/10.1007/s10584-012-0499-0>

Hanes, C. C., Wang, X., Jain, P., Parisien, M.-A., Little, J. M., & Flannigan, M. D. (2019). Fire-regime changes in Canada over the last half century. *Canadian Journal of Forest Research, 49*(3), 256-269. <https://doi.org/10.1139/cjfr-2018-0293>

Hanigan, I. C., Butler, C. D., Kokic, P. N., & Hutchinson, M. F. (2012). Suicide and drought in New South Wales, Australia, 1970–2007. *Proceedings of the National Academy of Sciences, 109*(35), 13950-13955. <https://doi.org/10.1073/pnas.1112965109>

Harrison, F., van Sluijs, E. M., Corder, K., Ekelund, U., & Jones, A. (2015). The changing relationship between rainfall and children's physical activity in spring and summer: a longitudinal study. *The International Journal of Behavioral Nutrition and Physical Activity*, *12*, 41. <https://doi.org/10.1186/s12966-015-0202-8>

Hart, C. R., Berry, H. L., & Tonna, A. M. (2011). Improving the mental health of rural New South Wales communities facing drought and other adversities. *Australian Journal of Rural Health, 19*(5), 231-238. <https://doi.org/10.1111/j.1440-1584.2011.01225.x>

Hart, P. H., & Norval, M. (2018). Ultraviolet radiation-induced immunosuppression and its relevance for skin carcinogenesis. *Photochemical & Photobiological Sciences*, 17(12), 1872-1884. doi: 10.1039/C7PP00312A

Hattis, D., Ogneva-Himmelberger, Y., & Ratick, S. (2012). The spatial variability of heat-related mortality in Massachusetts. *Applied Geography, 33*, 45-52. <https://doi.org/10.1016/j.apgeog.2011.07.008>

He, S., Kosatsky, T., Smargiassi, A., Bilodeau-Bertrand, M., & Auger, N. (2018). Heat and pregnancy-related emergencies : Risk of placental abruption during hot weather. *Environment International, 111*, 295-300. <https://doi.org/10.1016/j.envint.2017.11.004>

Health Canada. (2011). *Extreme heat events guidelines: technical guide for health care workers*. Retrieved from <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/climate-change-health/extreme-heat-events-guidelines-technical-guide-health-care-workers.html>

Health Canada. (2012). *Heat alert and response systems to protect health: best practices guidebook*. Retrieved from <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/climate-change-health/heat-alert-response-systems-protect-health-best-practices-guidebook.html>

Health Canada. (2018). *Sun Safety*. Retrieved from <https://www.canada.ca/en/health-canada/services/sun-safety.html>

Health Canada. (2020a). *Extreme heat and COVID-19 : Considerations for Heat Health Programing in the Context of COVID-19*. Advice for Public Health Officials.

Health Canada. (2020b). *Reducing urban heat islands to protect health in Canada - An introduction for public health professionals*. Retrieved from <https://www.canada.ca/en/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada.html>

Hedlund, C., Blomstedt, Y., & Schumann, B. (2014). Association of climatic factors with infectious diseases in the Arctic and subarctic region—A systematic review. *Global Health Action, 7*, 1-16. <https://doi.org/10.3402/gha.v7.24161>

Henderson, S. B., Brauer, M., MacNab, Y. C., & Kennedy, S. M. (2011). Three measures of forest fire smoke exposure and their associations with respiratory and cardiovascular health outcomes in a population-based cohort. *Environmental Health Perspectives, 119*(9), 1266-1271.

Henderson, S. B., & Johnston, F. H. (2012). Measures of forest fire smoke exposure and their associations with respiratory health outcomes. *Current Opinion in Allergy and Clinical Immunology, 12*(3), 221-227.

Henderson, S. B., Wan, V., & Kosatsky, T. (2013). Differences in heat-related mortality across four ecological regions with diverse urban, rural, and remote populations in British Columbia, Canada. *Health & Place, 23*, 48-53.

Henstra, D., & Thistlethwaite, J. (2018). *Flood risk mapping in Canada : Moving forward on a national priority*. Centre for International Governance Innovation. Retrieved from <https://www.cigionline.org/publications/flood-risk-mapping-canada-moving-forward-national-priority/>

Herrador, B. R. G., De Blasio, B. F., MacDonald, E., Nichols, G., Sudre, B., Vold, L., Semenza, J. C., & Nygård, K. (2015). Analytical studies assessing the association between extreme precipitation or temperature and drinking water-related water-borne infections : A review. *Environmental Health, 14*(1), 29.

Hetherington, E., McDonald, S., Wu, M., & Tough, S. (2018). Risk and protective factors for mental health and community cohesion after the 2013 Calgary flood. *Disaster Medicine and Public Health Preparedness, 12*(4), 470-477. <https://doi.org/10.1017/dmp.2017.91>

Hetu, B., Fortin, G., & Brown, K. (2015). Winter climate, land settlement and avalanche dynamics in southern Quebec : An analysis from the known accidents since 1825. *Canadian Journal of Earth Sciences, 52*(5), 307-321. <https://doi.org/10.1139/cjes-2014-0205>

Hicks, L. A., Rose, C. E., Fields, B. S., Drees, M. L., Engel, J. P., Jenkins, P. R., Rouse, B. S., Blythe, D., Khalifah, A. P., Feikin, D. R., & Whitney, C. G. (2007). Increased rainfall is associated with increased risk for legionellosis. *Epidemiology & Infection, 135*(5), 811-817. <https://doi.org/10.1017/S0950268806007552>

Ho, H. C., Knudby, A., Xu, Y., Hodul, M., & Aminipouri, M. (2016). A comparison of urban heat islands mapped using skin temperature, air temperature, and apparent temperature (Humidex), for the greater Vancouver area. *The Science of the Total Environment, 544*, 929-938.

Holman, D. M., Kapelos, G. T., Shoemaker, M., & Watson, M. (2018). Shade as an environmental design tool for skin cancer prevention. *American Journal of Public Health, 108*(12), 1607-1612. <https://doi.org/10.2105/AJPH.2018.304700>

Holmer, I. (2009). Evaluation of cold workplaces : An overview of standards for assessment of cold stress. *Industrial Health, 47*(3), 228-234.

Holmes, E. A., Xiang, F., & Lucas, R. M. (2015). Variation in incidence of pediatric Crohn's disease in relation to latitude and ambient ultraviolet radiation : A systematic review and analysis. *Inflammatory Bowel Diseases, 21*(4), 809-817. <https://doi.org/10.1097/MIB.0000000000000320>

Houghton, A., & Castillo-Salgado, C. (2017). Health Co-Benefits of Green Building Design Strategies and Community Resilience to Urban Flooding: A Systematic Review of the Evidence. *International Journal of Environmental Research and Public Health*, *14*(12), 1519. <https://doi.org/10.3390/ijerph14121519>

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivan, K., Telfar Barnard, L., & Lloyd, B. (2012). Tackling cold housing and fuel poverty in New Zealand : A review of policies, research, and health impacts. *Energy Policy, 49*, 134-142. <https://doi.org/10.1016/j.enpol.2011.09.044>

Hsu, A., Sheriff, G., Chakraborty, T., & Manya, D. (2021). Disproportionate exposure to urban heat island intensity across major US cities. *Nature Communications*, *12*(1), 1-11.

Hu, X. F., Singh, K., Kenny, T. A., & Chan, H. M. (2019). Prevalence of heart attack and stroke and associated risk factors among Inuit in Canada: A comparison with the general Canadian population. *International Journal of Hygiene and Environmental Health, 222*(2), 319-326.

Huang, C., Barnett, A. G., Wang, X., Vaneckova, P., FitzGerald, G., & Tong, S. (2011). Projecting future heat-related mortality under climate change scenarios : A systematic review. *Environmental Health Perspectives, 119*(12), 1681-1690. <https://doi.org/10.1289/ehp.1103456>

Hung, L.-S., Wang, C., & Yarnal, B. (2016). Vulnerability of families and households to natural hazards : A case study of storm surge flooding in Sarasota County, Florida. *Applied Geography, 76*, 184-197. <https://doi.org/10.1016/j.apgeog.2016.09.021>

Hurlbert, M., & Gupta, J. (2016). Adaptive governance, uncertainty, and risk : Policy framing and responses to climate change, drought, and flood. *Risk Analysis, 36*(2), 339-356.

Huynen, M. M., & Martens, P. (2015). Climate change effects on heat-and cold-related mortality in the Netherlands : A scenario-based integrated environmental health impact assessment. *International Journal of Environmental Research and Public Health, 12*(10), 13295-13320.

Hydro-Québec. (n.d.). *L'après 1998 : Un réseau plus robuste*. Retrieved from <http://www.hydroquebec.com/verglas-1998/apres-la-tempete.html>

Indigenous Services Canada. (2020a). *Short-term drinking water advisories.* Ottawa, ON. Retrieved from <http://www.fnha.ca/what-we-do/environmental-health/drinking-water-advisories>

Indigenous Services Canada. (2020b). *Ending long-term drinking water advisories*. Ottawa, ON. Retrieved from <https://www.sac-isc.gc.ca/eng/1506514143353/1533317130660>

International Agency for Research on Cancer. (1992). *Monographs on the evaluation of carcinogenic risks to humans: Solar and ultraviolet radiation.* Lyon, France. Retrieved from >https://publications.iarc.fr/Book-And-Report-Series/Iarc-Monographs-On-The-Identification-Of-Carcinogenic-Hazards-To-Humans/Solar-And-Ultraviolet-Radiation-1992>

Institut national de santé publique du Québec (INSPQ). (2020a). *Mesures de prévention et contrôle des infections pour l'utilisation des climatiseurs mobiles et des ventilateurs sur pied en milieux de soins dans un contexte de COVID-19*. Retrieved from <https://www.inspq.qc.ca/publications/3011-climatiseurs-mobiles-ventilateurs-milieux-soin-covid19>

Institut national de santé publique du Québec (INSPQ). (2020b). *COVID-19 : Climatisation et ventilation portative en milieu de travail.* Groupe de travail SAT-COVID-19. Retrieved from <https://www.inspq.qc.ca/publications/3021-ventilation-portative-travail-covid19>

Institut national de santé publique du Québec (INSPQ). (2020c). *Utilisation des climatiseurs et des ventilateurs électriques dans les milieux scolaires, les milieux de garde et les camps de jour lors des vagues de chaleur dans un contexte de COVID-19.* Retrieved from <https://www.inspq.qc.ca/publications/3034-climatiseurs-ventilateurs-milieux-scolaires-garde-camps-jour-covid19>

Institut national de santé publique du Québec (INSPQ). (2020d). *COVID-19 : utilisation sécuritaire des parcs et espaces verts urbains en contexte de déconfinement graduel.* Retrieved from <https://www.inspq.qc.ca/publications/3043-utilisation-parcs-espaces-verts-covid19>

Institute for Catastrophic Loss Reduction. (2012a). *Protect your home from severe wind*. Retrieved from <https://www.iclr.org/wp-content/uploads/PDFS/ICLR_Severe-wind_2018.pdf>

Institute for Catastrophic Loss Reduction. (2012b). *Your insurance broker's guide to snow & ice storms*. Retrieved from <https://www.ibans.com/_Library/Home_Owner_Safety_Brochures/IBAC_ICLR_Snow-Ice_Book-E_Spreads.pdf>

Ivanov, I. V., Mappes, T., Schaupp, P., Lappe, C., & Wahl, S. (2018). Ultraviolet radiation oxidative stress affects eye health. *Journal of Biophotonics*, *11*(7), e201700377. <https://doi.org/10.1002/jbio.201700377>

Jablonski, N. G., & Chaplin, G. (2012). Human skin pigmentation, migration and disease susceptibility. *Philosophical Transactions of the Royal Society B, 367*(1590), 785-792.

Jakob, M., & Lambert, S. (2009). Climate change effects on landslides along the southwest coast of British Columbia. *Geomorphology, 107*(3), 275-284. <https://doi.org/10.1016/j.geomorph.2008.12.009>

Jalliffier-Verne, I., Leconte, R., Huaringa-Alvarez, U., Heniche, M., Madoux-Humery, A.-S., Autixier, L., Galarneau, M., Servais, P., Prevost, M., & Dorner, S. (2017). Modelling the impacts of global change on concentrations of *Escherichia coli* in an urban river. *Advances in Water Resources, 108*, 450-460. <https://doi.org/10.1016/j.advwatres.2016.10.001>

Jamieson, J. B., Haegeli, P. & Gauthier, D. (2010). *Avalanche Accidents in Canada (Volume 5, 1996-2007).* Canadian Avalanche Association. Retrieved from <www.avalancheassociation.ca>

Janz, T., & Pearson, C. (2013). *Vitamin D blood levels of Canadians.* Statistics Canada. Retrieved from <http://www.statcan.gc.ca/pub/82-624-x/2013001/article/11727-eng.pdf>

Jay, O., Cramer, M. N., Ravanelli, N. M., & Hodder, S. G. (2015). Should electric fans be used during a heat wave? *Applied ergonomics*, *46*, 137-143.

Jeong, D. I., Sushama, L., Diro, G. T., Khaliq, M. N., Beltrami, H., & Caya, D. (2016). Projected changes to high temperature events for Canada based on a regional climate model ensemble. *Climate Dynamics, 46*(9-10), 3163-3180.

Jermacane, D., Waite, T. D., Beck, C. R., Bone, A., Amlôt, R., Reacher, M., Kovats, S., Armstrong, B., Leonardi, G., James Rubin, G., & Oliver, I. (2018). The English National Cohort Study of Flooding and Health : The change in the prevalence of psychological morbidity at year two. *BMC Public Health, 18*(1), 330. <https://doi.org/10.1186/s12889-018-5236-9>

Jerrett, M., Arain, A., Kanaroglou, P., Beckerman, B., Potoglou, D., Sahsuvaroglu, T., Morrison, J., & Giovis, C. (2005). A review and evaluation of intraurban air pollution exposure models. *Journal of Exposure Science and Environmental Epidemiology, 15*(2), 185-204. <https://doi.org/10.1038/sj.jea.7500388>

Johal, S., & Mounsey, Z. (2016). A research-based primer on the potential psychosocial impacts of flooding. *Disaster Prevention and Management, 25*(1), 104-110. <https://doi.org/10.1108/DPM-09-2015-0206>

Johanning, E., Auger, P., Morey, P. R., Yang, C. S., & Olmsted, E. (2014). Review of health hazards and prevention measures for response and recovery workers and volunteers after natural disasters, flooding, and water damage : Mold and dampness. *Environmental Health and Preventive Medicine, 19*(2), 93-99. <https://doi.org/10.1007/s12199-013-0368-0>

Johnson-Arbor, K. K., Quental, A. S., & Li, D. (2014). A comparison of carbon monoxide exposures after snowstorms and power outages. *American Journal of Preventive Medicine, 46*(5), 481-486. <https://doi.org/10.1016/j.amepre.2014.01.006>

Joshua, A. M. (2012). Melanoma prevention : Are we doing enough? A Canadian perspective. *Current Oncology, 19*(6), e462-e467. <https://doi.org/10.3747/co.19.1222>

Juzeniene, A., & Moan, J. (2012). Beneficial effects of UV radiation other than via vitamin D production. *Dermato-Endocrinology, 4*(2), 109-117. <https://doi.org/10.4161/derm.20013>

Kaffenberger, B. H., Shetlar, D., Norton, S. A., & Rosenbach, M. (2017). The effect of climate change on skin disease in North America. *Journal of the American Academy of Dermatology, 76*(1), 140-147. <https://doi.org/10.1016/j.jaad.2016.08.014>

Kampe, E. O. I., Kovats, S., & Hajat, S. (2016). Impact of high ambient temperature on unintentional injuries in high-income countries : A narrative systematic literature review. *BMJ Open, 6*(2), e010399. <https://doi.org/10.1136/bmjopen-2015-010399>

Kapelos, G. T., & Patterson, M. R. S. (2014). Health, planning, design, and shade : A critical review. *Journal of Architectural and Planning Research, 31*(2), 91-111. <https://www.jstor.org/stable/43031028>

Keesstra, S., Nunes, J., Novara, A., Finger, D., Avelar, D., Kalantari, Z., & Cerdà, A. (2018). The superior effect of nature based solutions in land management for enhancing ecosystem services. *The Science of the Total Environment, 610*, 997-1009.

Kellens, W., Terpstra, T., & Maeyer, P. D. (2013). Perception and communication of flood risks : A systematic review of empirical research. *Risk Analysis, 33*(1), 24-49. <https://doi.org/10.1111/j.1539-6924.2012.01844.x>

Kennedy, I. T., Petley, D. N., Williams, R., & Murray, V. (2015). A systematic review of the health impacts of mass Earth movements (landslides). *PLoS Currents*, *7*, ecurrents.dis.1d49e84c8bbe678b0e70cf7fc35d0b77. <https://doi.org/10.1371/currents.dis.1d49e84c8bbe678b0e70cf7fc35d0b77>

Khabarov, N., Krasovskii, A., Obersteiner, M., Swart, R., Dosio, A., San-Miguel-Ayanz, J., Durrant, T., Camia, A., & Migliavacca, M. (2016). Forest fires and adaptation options in Europe. *Regional Environmental Change, 16*(1), 21-30. <https://doi.org/10.1007/s10113-014-0621-0>

Khan, S. J., Deere, D., Leusch, F. D. L., Humpage, A., Jenkins, M., & Cunliffe, D. (2015). Extreme weather events : Should drinking water quality management systems adapt to changing risk profiles? *Water Research, 85*, 124-136. <https://doi.org/10.1016/j.watres.2015.08.018>

Kim, K.-H., Kabir, E., & Kabir, S. (2015). A review on the human health impact of airborne particulate matter. *Environment International, 74*, 136-143. <https://doi.org/10.1016/j.envint.2014.10.005>

Kim, Y., Kim, H., Gasparrini, A., Armstrong, B., Honda, Y., Chung, Y., Ng, C. F. S., Tobias, A., Íñiguez, C., & Lavigne, E. (2019). Suicide and ambient temperature : A multi-country multi-city study. *Environmental Health Perspectives, 127*(11), 117007.

Kimeswenger, S., Schwarz, A., Födinger, D., Müller, S., Pehamberger, H., Schwarz, T., & Jantschitsch, C. (2016). Infrared A radiation promotes survival of human melanocytes carrying ultraviolet radiation-induced DNA damage. *Experimental Dermatology, 25*(6), 447-452. <https://doi.org/10.1111/exd.12968>

Kinney, P. L., Schwartz, J., Pascal, M., Petkova, E., Le Tertre, A., Medina, S., & Vautard, R. (2015). Winter season mortality : Will climate warming bring benefits? *Environmental Research Letters, 10*(6), 064016.

Kirchmeier-Young, M. C., Gillett, N. P., Zwiers, F. W., Cannon, A. J., & Anslow, F. S. (2019). Attribution of the influence of human-induced climate change on an extreme fire season. *Earth's Future, 7*(1), 2-10. <https://doi.org/10.1029/2018EF001050>

Kirchmeier-Young, M. C., Zwiers, F. W., Gillett, N. P., & Cannon, A. J. (2017). Attributing extreme fire risk in Western Canada to human emissions. *Climatic Change, 144*(2), 365-379. <https://doi.org/10.1007/s10584-017-2030-0>

Klinger, C., Landeg, O., & Murray, V. (2014). Power outages, extreme events and health: a systematic review of the literature from 2011-2012. *PLoS Currents, 6*, ecurrents.dis.04eb1dc5e73dd1377e05a10e9edde673. <https://doi.org/10.1371/currents.dis.04eb1dc5e73dd1377e05a10e9edde673>

Koerth, J., Vafeidis, A. T., & Hinkel, J. (2017). Household-level coastal adaptation and its drivers : A systematic case study review. *Risk Analysis, 37*(4), 629-646. <https://doi.org/10.1111/risa.12663>

Koetse, M. J., & Rietveld, P. (2009). The impact of climate change and weather on transport : An overview of empirical findings. *Transportation Research Part D: Transport and Environment, 14*(3), 205-221. <https://doi.org/10.1016/j.trd.2008.12.004>

Kornhall, D. K., & Martens-Nielsen, J. (2016). The prehospital management of avalanche victims. *Journal of the Royal Army Medical Corps, 162*(6), 406-412. <https://doi.org/10.1136/jramc-2015-000441>

Kosatsky, T., Dufresne, J., Richard, L., Renouf, A., Giannetti, N., Bourbeau, J., Julien, M., Braidy, J., & Sauvé, C. (2009). Heat awareness and response among Montreal residents with chronic cardiac and pulmonary disease. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique, 100*(3), 237–240. <https://doi.org/10.1007/BF03405548>

Kosatsky, T., Henderson, S. B., & Pollock, S. L. (2012). Shifts in mortality during a hot weather event in Vancouver, British Columbia : Rapid assessment with case-only analysis. *American journal of public health, 102*(12), 2367-2371.

Kramer, D. M., Tenkate, T., Strahlendorf, P., Kushner, R., Gardner, A., & Holness, D. L. (2015). Sun Safety at Work Canada : A multiple case-study protocol to develop sun safety and heat protection programs and policies for outdoor workers. *Implementation Science, 10*(1), 97. <https://doi.org/10.1186/s13012-015-0277-2>

Laaidi, K., Economopoulou, A., Wagner, V., Pascal, M., Empereur-Bissonnet, P., Verrier, A., & Beaudeau, P. (2013). Cold spells and health : Prevention and warning. *Public Health, 127*(5), 492-499. <https://doi.org/10.1016/j.puhe.2013.02.011>

Labbé, J., Ford, J. D., Araos, M., & Flynn, M. (2017). The government-led climate change adaptation landscape in Nunavut, Canada. *Environmental Reviews, 25*(1), 12-25. doi:10.1139/er-2016-0032

Lai, B. S., Lewis, R., Livings, M. S., La Greca, A. M., & Esnard, A. (2017). Posttraumatic stress symptom trajectories among children after disaster exposure : A review. *Journal of Traumatic Stress, 30*(6), 571-582.

Lamond, J. E., Joseph, R. D., & Proverbs, D. G. (2015). An exploration of factors affecting the long term psychological impact and deterioration of mental health in flooded households. *Environmental Research, 140*, 325-334. <https://doi.org/10.1016/j.envres.2015.04.008>

Lane, K., Charles-Guzman, K., Wheeler, K., Abid, Z., Graber, N., & Matte, T. (2013). Health effects of coastal storms and flooding in urban areas : A review and vulnerability assessment. *Journal of Environmental and Public Health, 2013*(913064), 13. <https://doi.org/10.1155/2013/913064>

Liang, K. E., & Kosatsky, T. (2020). Protecting rural Canadians from extreme heat. *CMAJ, 192*(24), E657-E658. <https://doi.org/10.1503/cmaj.200004>

Laverdière, É., Généreux, M., Gaudreau, P., Morais, J. A., Shatenstein, B., & Payette, H. (2015). Prevalence of risk and protective factors associated with heat-related outcomes in Southern Quebec : A secondary analysis of the NuAge study. *Canadian Journal of Public Health, 106*(5), e315-e321. <https://doi.org/10.17269/cjph.106.5029>

Laverdière, É., Payette, H., Gaudreau, P., Morais, J. A., Shatenstein, B., & Généreux, M. (2016). Risk and protective factors for heat-related events among older adults of Southern Quebec (Canada) : The NuAge study. *Canadian Journal of Public Health-Revue Canadienne De Sante Publique, 107*(3), E258-E265. <https://doi.org/10.17269/CJPH.107.5599>

Lavigne, E., Gasparrini, A., Wang, X., Chen, H., Yagouti, A., Fleury, M. D., & Cakmak, S. (2014). Extreme ambient temperatures and cardiorespiratory emergency room visits : Assessing risk by comorbid health conditions in a time series study. *Environmental Health, 13*(1), 5. <https://doi.org/10.1186/1476-069X-13-5>

Lavigne, E. (2020). *Temperature-related mortality under climate change scenarios in health regions of Canada* [Video]. Air Health Science Division of Health Canada. Presented at the NOAA-ECCC webinar. Retrieved from <https://www.youtube.com/watch?v=JD-3rVL_5lY>

Le, G., Breysse, P., McDermott, A., Eftim, S., Geyh, A., Berman, J., & Curriero, F. (2014). Canadian forest fires and the effects of long-range transboundary air pollution on hospitalizations among the elderly. *ISPRS International Journal of Geo-Information, 3*(2), 713-731.

Lebel, G., Dubé, M. & Bustinza, R. (2015). *Évaluation du Fichier hebdomadaire des décès pour l'estimation des impacts des vagues de chaleur: rapport*. Institut national de santé publique du Québec. Retrieved from <https://www.inspq.qc.ca/publications/1962>

Lebel, G., Dubé, M. & Bustinza, R. (2017). *Analyse des impacts des vagues régionales de chaleur extrême sur la santé au Québec de 2010 à 2015*. Institut national de santé publique du Québec. Retrieved from <https://www.inspq.qc.ca/publications/2221>

Lebel, G., Dubé, M. & Bustinza, R. (2019). *Surveillance des impacts des vagues de chaleur extrême sur la santé au Québec à l'été 2018*. Institut national de santé publique du Québec. Retrieved from <https://www.inspq.qc.ca/bise/surveillance-des-impacts-des-vagues-de-chaleur-extreme-sur-la-sante-au-quebec-l-ete-2018>

Lennon, M., Scott, M., & O'Neill, E. (2014). Urban design and adapting to flood risk : The role of green infrastructure. *Journal of Urban Design, 19*(5), 745-758. <https://doi.org/10.1080/13574809.2014.944113>

Lesnikowski, A., Ford, J., Berrang-Ford, L., Barrera, M., & Heymann, J. (2015). How are we adapting to climate change ? A global assessment. *Mitigation and Adaptation Strategies for Global Change, 20*(2), 277-293.

Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., & Heymann, S. J. (2016). National-level progress on adaptation. *Nature Climate Change, 6*(3), 261-264. <https://doi.org/10.1038/nclimate2863>

Lévesque, B., Gervais, M.-C., Chevalier, P., Gauvin, D., Anassour-Laouan-Sidi, E., Gingras, S., Fortin, N., Brisson, G., Greer, C., & Bird, D. (2014). Prospective study of acute health effects in relation to exposure to cyanobacteria. *The Science of the Total Environment, 466-467,* 397-403. <https://doi.org/10.1016/j.scitotenv.2013.07.045>

Levi, M., Kjellstrom, T., & Baldasseroni, A. (2018). Impact of climate change on occupational health and productivity : A systematic literature review focusing on workplace heat. *Medicina Del Lavoro, 109*(3), 163-179. <https://doi.org/10.23749/mdl.v109i3.6851>

Levy, K., Woster, A. P., Goldstein, R. S., & Carlton, E. J. (2016). Untangling the impacts of climate change on water-borne diseases : A systematic review of relationships between diarrheal diseases and temperature, rainfall, flooding, and drought. E*nvironmental Science & Technology, 50*(10), 4905-4922.

Leyva, E. W. A., Beaman, A., & Davidson, P. M. (2017). Health impact of climate change in older people : An integrative review and implications for nursing. *Journal of Nursing Scholarship, 49*(6), 670-678. <https://doi.org/10.1111/jnu.12346>

L'Hérault, E., Allard, M., Fortier, D., Carbonneau, A., Doyon-Robitaille, J., Lachance, M. P., Ducharme, M.A., Larrivée, K., Grandmont, K., & Lemieux, C. (2013). *Production de cartes des caractéristiques du pergélisol afin de guider le développement de l'environnement bâti pour quatre communautés du Nunavik*. Centre d'études nordiques, Université Laval. Montréal, QC.

Liddell, C., & Morris, C. (2010). Fuel poverty and human health : A review of recent evidence. *Energy Policy, 38*(6), 2987-2997. <https://doi.org/10.1016/j.enpol.2010.01.037>

Liddell, C., Morris, C., Thomson, H., & Guiney, C. (2016). Excess winter deaths in 30 European countries 1980-2013 : A critical review of methods. *Journal of Public Health, 38*(4), 806-814. <https://doi.org/10.1093/pubmed/fdv184>

Lim, Y.-H., Hong, Y.-C., & Kim, H. (2012). Effects of diurnal temperature range on cardiovascular and respiratory hospital admissions in Korea. *The Science of the Total Environment, 417-418*, 55-60. <https://doi.org/10.1016/j.scitotenv.2011.12.048>

Lim, Y.-H., So, R., Lee, C., Hong, Y.-C., Park, M., Kim, L., & Yoon, H.-J. (2018). Ambient temperature and hospital admissions for acute kidney injury : A time-series analysis. *The Science of the Total Environment, 616,* 1134-1138.

Lin, S., Lawrence, W. R., Lin, Z., DiRienzo, S., Lipton, K., Dong, G.-H., Leung, R., Lauper, U., Nasca, P., & Stuart, N. (2018). Are the current thresholds, indicators, and time window for cold warning effective enough to protect cardiovascular health? *The Science of the Total Environment, 639,* 860-867.

Linos, E., Keiser, E., Kanzler, M., Sainani, K. L., Lee, W., Vittinghoff, E., Chren, M.-M., & Tang, J. Y. (2012). Sun protective behaviors and vitamin D levels in the US population : NHANES 2003–2006. *Cancer Causes & Control, 23*(1), 133-140. <https://doi.org/10.1007/s10552-011-9862-0>

Liotta, G., Inzerilli, M. C., Palombi, L., Madaro, O., Orlando, S., Scarcella, P., Betti, D., & Marazzi, M. C. (2018). Social interventions to prevent heat-related mortality in the older adult in Rome, Italy : A quasi-experimental study. *International Journal of Environmental Research and Public Health, 15*(4), 715. <https://doi.org/10.3390/ijerph15040715>

Liu, D., Fernandez, B. O., Hamilton, A., Lang, N. N., Gallagher, J. M. C., Newby, D. E., Feelisch, M., & Weller, R. B. (2014). UVA irradiation of human skin vasodilates arterial vasculature and lowers blood pressure independently of nitric oxide synthase. *Journal of Investigative Dermatology, 134*(7), 1839-1846. <https://doi.org/10.1038/jid.2014.27>

Liu, G. T., Dancause, K. N., Elgbeili, G., Laplante, D. P., & King, S. (2016a). Disaster-related prenatal maternal stress explains increasing amounts of variance in body composition through childhood and adolescence : Project Ice Storm. *Environmental Research, 150*, 1-7. <https://doi.org/10.1016/j.envres.2016.04.039>

Liu, J. C., Mickley, L. J., Sulprizio, M. P., Yue, X., Peng, R. D., Dominici, F., & Bell, M. L. (2016b). Future respiratory hospital admissions from wildfire smoke under climate change in the Western US. *Environmental Research Letters, 11*(12), 124018.

Liu, J. C., Wilson, A., Mickley, L. J., Ebisu, K., Sulprizio, M. P., Wang, Y., Peng, R. D., Yue, X., Dominici, F., & Bell, M. L. (2017). Who among the elderly is most vulnerable to exposure to and health risks of fine particulate matter from wildfire smoke? *American Journal of Epidemiology, 186*(6), 730-735. <https://doi.org/10.1093/aje/kwx141>

Lowe, D., Ebi, K. L., & Forsberg, B. (2013). Factors increasing vulnerability to health effects before, during and after floods. *International Journal of Environmental Research and Public Health, 10*(12), 7015-7067. <https://doi.org/10.3390/ijerph10127015>

Lu, C., Yang, J., Yu, W., Li, D., Xiang, Z., Lin, Y., & Yu, C. (2015). Association between 25(OH)D level, ultraviolet exposure, geographical location, and inflammatory bowel disease activity : A systematic review and meta-analysis. *Plos One, 10*(7), e0132036. <https://doi.org/10.1371/journal.pone.0132036>

Lucas, R. (2010). Solar ultraviolet radiation : Assessing the environmental burden of disease at national and local levels. Organisation mondiale de la Santé.

Lucas, R. M., Byrne, S. N., Correale, J., Ilschner, S., & Hart, P. H. (2015). Ultraviolet radiation, vitamin D and multiple sclerosis. *Neurodegenerative Disease Management, 5*(5), 413-424. <https://doi.org/10.2217/nmt.15.33>

Lundgren Kownacki, K., Gao, C., Kuklane, K., & Wierzbicka, A. (2019). Heat stress in indoor environments of Scandinavian urban areas : A literature review. *International Journal of Environmental Research and Public Health, 16*(4). <https://doi.org/10.3390/ijerph16040560>

Lutsch, E., Dammers, E., Conway, S., & Strong, K. (2016). Long-range transport of NH3, CO, HCN, and C2H6 from the 2014 Canadian wildfires. *Geophysical Research Letters, 43*(15), 8286-8297. <https://doi.org/10.1002/2016GL070114>

Macciotta, R., & Lefsrud, L. (2018). Framework for developing risk to life evaluation criteria associated with landslides in Canada. *Geoenvironmental Disasters, 5*(1), 10.

Maguet, S. (2018). *Interventions liées à la santé publique en présence de fumée de feux de forêt*. British Columbia Centre for Disease Control & National Collaborating Centre for Environmental Health. Retrieved from <https://ccnse.ca/documents/evidence-review/interventions-li%C3%A9es-%C3%A0-la-sant%C3%A9-publique-en-pr%C3%A9sence-de-fum%C3%A9e-de-feux-de>

Mak, P. W., & Singleton, J. (2017). Burning questions : Exploring the impact of natural disasters on community pharmacies. *Research in Social and Administrative Pharmacy, 13*(1), 162-171.

Mäkinen, T. M., Juvonen, R., Jokelainen, J., Harju, T. H., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M., & Hassi, J. (2009). Cold temperature and low humidity are associated with increased occurrence of respiratory tract infections. *Respiratory Medicine, 103*(3), 456-462. <https://doi.org/10.1016/j.rmed.2008.09.011>

Maltais, D. (2006). *Impact of the July 1996 floods on older persons in Quebec's Saguenay region.* Université du Québec à Chicoutimi.

Manning, C., & Clayton, S. (2018). Threats to mental health and wellbeing associated with climate change. In S. Clayton & C. Manning (Eds.), *Psychology and Climate change: Human perceptions, impacts and responses* (pp. 217-44). Amsterdam, Netherlands: Academic Press.

Manuel, P., Rapaport, E., Keefe, J., & Krawchenko, T. (2015). Coastal climate change and aging communities in Atlantic Canada : A methodological overview of community asset and social vulnerability mapping. *The Canadian Geographer = Le Géographe Canadien, 59*(4), 433-446. <https://doi.org/10.1111/cag.12203>

Mares, D. (2013). Climate change and levels of violence in socially disadvantaged neighborhood groups. *Journal of Urban Health, 90*(4), 768-783. <https://doi.org/10.1007/s11524-013-9791-1>

Marmot Review Team. (2011). *The health impacts of cold homes and fuel poverty*. Friends of the Earth & Marmot Review Team. Retrieved from <https://www.instituteofhealthequity.org/resources-reports/the-health-impacts-of-cold-homes-and-fuel-poverty/the-health-impacts-of-cold-homes-and-fuel-poverty.pdf>

Martel, B., Ouarda, T. B., Vanasse, A., Chebana, F., Orzanco, M. G., Charron, C., Courteau, J., Asghari, S., & Gosselin, P. (2010). Modélisation des fractures de la hanche en fonction de variables météorologiques à l'aide du modèle GAM dans deux régions métropolitaines du Québec, Canada. INRS, Centre Eau, Terre et Environnement.

Martin, S. L., Cakmak, S., Hebbern, C. A., Avramescu, M.-L., & Tremblay, N. (2012). Climate change and future temperature-related mortality in 15 Canadian cities. *International Journal of Biometeorology, 56*(4), 605-619. <https://doi.org/10.1007/s00484-011-0449-y>

Martinez Garcia, D., & Sheehan, M. C. (2016). Extreme weather-driven disasters and children's health. *International Journal of Health Services, 46*(1), 79-105. <https://doi.org/10.1177/0020731415625254>

Matz, C. J., Egyed, M., Xi, G., Racine, J., Pavlovic, R., Rittmaster, R., Henderson, S. B., & Stieb, D. M. (2020). Health impact analysis of $PM_{2.5}$ from wildfire smoke in Canada (2013-2015, 2017-2018). *The Science of the Total Environment*, *725*, 138506. <https://doi.org/10.1016/j.scitotenv.2020.138506>

Mavrogianni, A., Wilkinson, P., Davies, M., Biddulph, P., & Oikonomou, E. (2012). Building characteristics as determinants of propensity to high indoor summer temperatures in London dwellings. *Building and Environment, 55,* 117-130.

Mayer-Jouanjean, I., & Bleau, N. (2018). *Historique des sinistres d'inondations et d'étiages et des conditions météorologiques associées.* Ouranos.

McClelland, E., Amlôt, R., Rogers, M. B., Rubin, G. J., Tesh, J., & Pearce, J. M. (2017). Psychological and physical impacts of extreme events on older adults : Implications for communications. *Disaster Medicine and Public Health Preparedness, 11*(1), 127-134.

McIntyre, K. M., Setzkorn, C., Hepworth, P. J., Morand, S., Morse, A. P., & Baylis, M. (2017). Systematic assessment of the climate sensitivity of important human and domestic animals pathogens in Europe. *Scientific reports, 7*(1), 7134.

McKinley, A., Janda, M., Auster, J., & Kimlin, M. (2011). In vitro model of vitamin D synthesis by UV radiation in an Australian urban environment. *Photochemistry and Photobiology, 87*(2), 447-451. <https://doi.org/10.1111/j.1751-1097.2010.00865.x>

McLean, K., Yao, J., & Henderson, S. (2015). An evaluation of the British Columbia Asthma Monitoring System (BCAMS) and PM2.5 exposure metrics during the 2014 forest fire season. *International Journal of Environmental Research and Public Health, 12*(6), 6710-6724. <https://doi.org/10.3390/ijerph120606710>

McMartin, D. W., Merino, B. H. H., Bonsal, B., Hurlbert, M., Villalba, R., Ocampo, O. L., Upegui, J. J. V., Poveda, G., & Sauchyn, D. J. (2018). Limitations of water resources infrastructure for reducing community vulnerabilities to extremes and uncertainty of flood and drought. *Environmental Management, 62,* 1038-1047.

McMichael, A. J. (2015). Extreme weather events and infectious disease outbreaks. *Virulence, 6*(6), 543-547. <https://doi.org/10.4161/21505594.2014.975022>

Medina, A., Akbar, A., Baazeem, A., Rodriguez, A. & Magan, N. (2017). Climate change, food security and mycotoxins: do we know enough? *Fungal Biology Reviews*, *31*(3), 143154. doi:10.1016/j.fbr.2017.04.002

Mehiriz, K., & Gosselin, P. (2016). Municipalities' Preparedness for Weather Hazards and Response to Weather Warnings. *PLOS ONE, 11*(9), e0163390. <https://doi.org/10.1371/journal.pone.0163390>

Mehiriz, K., & Gosselin, P. (2017). Évaluation du projet pilote d'alertes téléphoniques automatisées pour les personnes vulnérables à la chaleur et au smog. Institut national de la recherche scientifique, Centre Eau Terre Environnement. Retrieved from <http://espace.inrs.ca/6285/>

Mehiriz, K., Gosselin, P., Tardif, I., Lemieux, M.-A., Mehiriz, K., Gosselin, P., Tardif, I., & Lemieux, M.-A. (2018). The effect of an automated phone warning and health advisory system on adaptation to high heat episodes and health services use in vulnerable groups—Evidence from a randomized controlled study. *International Journal of Environmental Research and Public Health, 15*(8), 1581. <https://doi.org/10.3390/ijerph15081581>

Mental Health Commission of Canada. (2014). *Overview of Mental Health Data in Canada: Background, Needs, and Gaps.* Calgary, AB. Retrieved from <https://www.mentalhealthcommission.ca/sites/default/files/2017-05/Overview_on_Mental_Health_Data_in_Canada.pdf>

Ministère des Forêts, de la Faune et des Parcs (MFFP). (2019). *Carte de susceptibilité aux affaissements de sol associés au dégel du pergélisol.* Cartographie écologique du Nord québécois. Retrieved from <https://mffp.gouv.qc.ca/les-forets/inventaire-ecoforestier/nord-quebecois/cartographie-ecologique/>

Mitchell, D. (2011). The relationship between Vitamin D and cancer. *Clinical Journal of Oncology Nursing,* 15(5), 557-560. <https://doi.org/10.1188/11.CJON.557-560>

Modarres, R., Ouarda, T. B., Vanasse, A., Orzanco, M. G., & Gosselin, P. (2014). Modeling climate effects on hip fracture rate by the multivariate GARCH model in Montreal region, Canada. *International Journal of Biometeorology, 58*(5), 921-930.

Modenese, A., Korpinen, L., & Gobba, F. (2018). Solar radiation exposure and outdoor work : An underestimated occupational risk. *International Journal of Environmental Research and Public Health, 15*(10), 2063. <https://doi.org/10.3390/ijerph15102063>

Moffatt, H., & Struck, S. (2011). *Water-borne disease outbreaks in Canadian small drinking water systems.* National Collaboration Centre for Environmental Health. Retrieved from <https://ncceh.ca/content/water-borne-disease-outbreaks-canadian-small-drinking-water-systems>

Moghadamnia, M. T., Ardalan, A., Mesdaghinia, A., Keshtkar, A., Naddafi, K., & Yekaninejad, M. S. (2017). Ambient temperature and cardiovascular mortality : A systematic review and meta-analysis. *Peerj, 5,* e3574. <https://doi.org/10.7717/peerj.3574>

Monteiro, A. F., Rato, M., & Martins, C. (2016). Drug-induced photosensitivity : Photoallergic and phototoxic reactions. *Clinics in Dermatology, 34*(5), 571-581. <https://doi.org/10.1016/j.clindermatol.2016.05.006>

Moquin, P. A., & Wrona, F. J. (2015). Effects of permafrost degradation on water and sediment quality and heterotrophic bacterial production of Arctic tundra lakes : An experimental approach. *Limnology and Oceanography, 60*(5), 1484-1497. <https://doi.org/10.1002/lno.10110>

Morency, P., Voyer, C., Burrows, S., & Goudreau, S. (2012). Outdoor falls in an urban context: winter weather impacts and geographical variations. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *103*(3), 218–222. <https://doi.org/10.1007/BF03403816>

Morin, M. (2008). *Concepts de base en sécurité civile.* Québec, QC: Ministère de la Sécurité publique. Retrieved from <https://www.securitepublique.gouv.qc.ca/fileadmin/Documents/securite_civile/publications/concepts_base/concepts_base.pdf>

Moritz, M. A., Batllori, E., Bradstock, R. A., Gill, A. M., Handmer, J., Hessburg, P. F., Leonard, J., McCaffrey, S., Odion, D. C., Schoennagel, T., & Syphard, A. D. (2014). Learning to coexist with wildfire. *Nature, 515*(7525), 58-66. <https://doi.org/10.1038/nature13946>

Moudrak, N., Feltmate, B., Venema, H., & Osman, H. (2018). *Combatting Canada's rising flood costs : Natural infrastructure is an underutilized option.* Insurance Bureau of Canada, University of Waterloo, Intact Centre on Climate Adaptation, and International Institute for Sustainable Development. Retrieved from <http://www.ibc.ca/ab/resources/studies/natural-infrastructure-is-an-underutilized-option>

Mulchandani, R., Smith, M., Armstrong, B., English National Study of Flooding and Health Study Group, Beck, C. R., & Oliver, I. (2019). Effect of insurance-related factors on the association between flooding and mental health outcomes. *International Journal of Environmental Research and Public Health, 16*(7), 1174. <https://doi.org/10.3390/ijerph16071174>

Munro, A., Kovats, R. S., Rubin, G. J., Waite, T. D., Bone, A., & Armstrong, B. (2017). Effect of evacuation and displacement on the association between flooding and mental health outcomes : A cross-sectional analysis of UK survey data. *The Lancet. Planetary Health,* 1(4), e134-e141. <https://doi.org/10.1016/S2542-5196(17)30047-5>

Murphy, H. M., Thomas, M. K., Schmidt, P. J., Medeiros, D. T., McFadyen, S., & Pintar, K. D. (2016). Estimating the burden of acute gastrointestinal illness due to Giardia, Cryptosporidium, Campylobacter, E. coli O157 and norovirus associated with private wells and small water systems in Canada. *Epidemiology and infection*, 144(7), 1355–1370. <https://doi.org/10.1017/S0950268815002071>

Na, H. R., Heisler, G. M., Nowak, D. J., & Grant, R. H. (2014). Modeling of urban trees' effects on reducing human exposure to UV radiation in Seoul, Korea. *Urban Forestry & Urban Greening, 13*(4), 785-792. <https://doi.org/10.1016/j.ufug.2014.05.009>

Navarro, K. M., Schweizer, D., Balmes, J. R., & Cisneros, R. (2018). A review of community smoke exposure from wildfire compared to prescribed fire in the United States. *Atmosphere, 9*(5), 185.

Neale, R. E., Barnes, P. W., Robson, T. M., Neale, P. J., Williamson, C. E., Zepp, R. G., ... & Zhu, M. (2021). Environmental effects of stratospheric ozone depletion, UV radiation, and interactions with climate change: UNEP Environmental Effects Assessment Panel, Update 2020. *Photochemical & Photobiological Sciences*, 20(1), 1-67. <https://doi.org/10.1007/s43630-020-00001-x>

Neegan Burnside Ltd. (2011). *National Assessment of First Nations Water and Wastewater Systems*. Retrieved from <https://www.sac-isc.gc.ca/eng/1313426883501/1533821951118>

Ng, F., Wilson, L., & Veitch, C. (2015). Climate adversity and resilience : The voice of rural Australia. *Rural and Remote Health, 15*(4), 1-12.

Ngom, R., Gosselin, P., & Blais, C. (2016). Reduction of disparities in access to green spaces : Their geographic insertion and recreational functions matter. *Applied Geography, 66*, 35-51. <https://doi.org/10.1016/j.apgeog.2015.11.008>

Nordio, F., Zanobetti, A., Colicino, E., Kloog, I., & Schwartz, J. (2015). Changing patterns of the temperature-mortality association by time and location in the US, and implications for climate change. *Environment International, 81*, 80-86. <https://doi.org/10.1016/j.envint.2015.04.009>

Nowak, D. J., Hirabayashi, S., Bodine, A., & Hoehn, R. (2013). Modeled PM2.5 removal by trees in ten U.S. cities and associated health effects. *Environmental Pollution, 178,* 395-402. <https://doi.org/10.1016/j.envpol.2013.03.050>

OBrien, L., Berry, H., Coleman, C., & Hanigan, I. (2014). Drought as a mental health exposure. *Environmental Research, 131,* 181-187.

Office of the Auditor General of Canada. (2018). *Perspectives on Climate Change Action in Canada—A Collaborative Report from Auditors General.* Commissioner of the Environment and Sustainable Development from the Office of the Auditor General of Canada, and auditors general of provinces and territories. Retrieved from <https://www.oag-bvg.gc.ca/internet/English/parl_otp_201803_e_42883.html>

Ordon, M., Welk, B., Li, Q., Wang, J., Lavigne, E., Yagouti, A., Copes, R., Cakmak, S., & Chen, H. (2016). Ambient temperature and the risk of renal colic : A population-based study of the impact of demographics and comorbidity. *Journal of Endourology, 30*(10), 1138-1143. <https://doi.org/10.1089/end.2016.0374>

Ottawa Riverkeeper. (2020). *Combined Sewer Overflows*. Retrieved from <https://www.ottawariverkeeper.ca/what-we-do-2/initiatives/watershed-health-assessment-and-monitoring/combined-sewer-overflows/>

Ouranos. (2015). *Vers l'adaptation: Synthèse des connaissances sur les changements climatiques au Québec – Édition 2015*. Retrieved from <https://www.ouranos.ca/wp-content/uploads/SyntheseRapportfinal.pdf>

Page, C. E., Atkins, D., Shockley, L. W., & Yaron, M. (1999). Avalanche deaths in the United States: a 45-year analysis. *Wilderness & Environmental Medicine*, *10*(3), 146-151.

Page, L. A., Hajat, S., Kovats, R. S., & Howard, L. M. (2012). Temperature-relkated deaths in people with psychosis, dementia and substance misuse. *The British Journal of Psychiatry, 200*(6), 485-490. <https://doi.org/10.1192/bjp.bp.111.100404>

Parks Canada. (2018). *Avalanche Control Program in Glacier National Park*. Glacier National Park. Retrieved from <https://www.pc.gc.ca/en/pn-np/bc/glacier/nature/AvCon2>

Parsons, K. (2014). *Human thermal environments : The effects of hot, moderate, and cold environments on human health, comfort, and performance*. CRC press.

Parsons, N., Odumenya, M., Edwards, A., Lecky, F., & Pattison, G. (2011). Modelling the effects of the weather on admissions to UK trauma units : A cross-sectional study. *Emergency Medicine Journal, 28*(10), 851-855.

Patrick, C. (2014). *Aboriginal homelessness in Canada : A literature review*. Canadian Homelessness Research Network. Retrieved from <https://www.homelesshub.ca/sites/default/files/AboriginalLiteratureReview.pdf>

Patrick, R. J. (2018). Adapting to climate change through source water protection : Case studies from Alberta and Saskatchewan, Canada. *The International Indigenous Policy Journal, 9*(3), 1.

Pendrey, C. G. A., Carey, M., & Stanley, J. (2014). Impacts of extreme weather on the health and well-being of people who are homeless. *Australian Journal of Primary Health, 20*(1), 2-3. <https://doi.org/10.1071/PY13136>

Peters, C. E., Nicol, A. M., & Demers, P. A. (2012). Prevalence of exposure to solar ultraviolet radiation (UVR) on the job in Canada. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *103*(3), 223–226. <https://doi.org/10.1007/BF03403817>

Phung, D., Thai, P. K., Guo, Y., Morawska, L., Rutherford, S., & Chu, C. (2016). Ambient temperature and risk of cardiovascular hospitalization : An updated systematic review and meta-analysis. *The Science of the Total Environment, 550,* 1084-1102. <https://doi.org/10.1016/j.scitotenv.2016.01.154>

Pierce, J. R., Morley, S. K., West, T. A., Pentecost, P., Upton, L. A., & Banks, L. (2017). Improving long-term care facility disaster preparedness and response : A literature review. *Disaster Medicine and Public Health Preparedness, 11*(1), 140-149.

Pinault, L., & Fioletov, V. (2017). *Exposition au soleil, protection solaire et coup de soleil chez les adultes canadiens*. Statistique Canada. <http://www.statcan.gc.ca/pub/82-003-x/2017005/article/14792-fra.pdf>

Pinault, L., Bushnik, T., Fioletov, V., Peters, C. E., King, W. D., & Tjepkema, M. (2017). The risk of melanoma associated with ambient summer ultraviolet radiation. *Health reports*, *28*(5), 3–11.

Pludowski, P., Holick, M. F., Pilz, S., Wagner, C. L., Hollis, B. W., Grant, W. B., Shoenfeld, Y., Lerchbaum, E., Llewellyn, D. J., Kienreich, K., & Soni, M. (2013). Vitamin D effects on musculoskeletal health, immunity, autoimmunity, cardiovascular disease, cancer, fertility, pregnancy, dementia and mortality—A review of recent evidence. *Autoimmunity Reviews, 12*(10), 976-989. <https://doi.org/10.1016/j.autrev.2013.02.004>

Porcherie, M., Lejeune, M., Gaudel, M., Pommier, J., Faure, E., Heritage, Z., Rican, S., Simos, J., Cantoreggi, N. L., Roué Le Gall, A., Cambon, L., & Regnaux, J.-P. (2018). Urban green spaces and cancer : A protocol for a scoping review. *BMJ Open, 8*(2). <https://doi.org/10.1136/bmjopen-2017-018851>

Porritt, S. M., Cropper, P. C., Shao, L., & Goodier, C. I. (2012). Ranking of interventions to reduce dwelling overheating during heat waves. *Energy and Buildings, 55,* 16-27. <https://doi.org/10.1016/j.enbuild.2012.01.043>

Porter, M. J., & Morgenstern, N. R. (2013). *Landslide risk evaluation—Canadian technical guidelines and best practices related to landslides : A national initiative for loss reduction*. Natural Resources Canada.

Poursafa, P., Keikha, M., & Kelishadi, R. (2015). Systematic review on adverse birth outcomes of climate change. *Journal of Research in Medical Sciences: The Official Journal of Isfahan University of Medical Sciences, 20*(4), 397.

Poussin, J. K., Botzen, W. J. W., & Aerts, J. C. J. H. (2014). Factors of influence on flood damage mitigation behaviour by households. *Environmental Science & Policy, 40,* 69-77. <https://doi.org/10.1016/j.envsci.2014.01.013>

Poussin, J. K., Wouter Botzen, W. J., & Aerts, J. C. J. H. (2015). Effectiveness of flood damage mitigation measures : Empirical evidence from French flood disasters. *Global Environmental Change, 31,* 74-84. <https://doi.org/10.1016/j.gloenvcha.2014.12.007>

Powers, J. R., Dobson, A. J., Berry, H. L., Graves, A. M., Hanigan, I. C., & Loxton, D. (2015). Lack of association between drought and mental health in a cohort of 45–61 year old rural Australian women. *Australian and New Zealand journal of public health, 39*(6), 518-523.

Prairie Climate Centre. (2019). *The Climate Atlas of Canada (version 2, July 10, 2019)*. Retrieved from <https://climateatlas.ca>

Preval, N., Keall, M., Telfar-Barnard, L., Grimes, A., & Howden-Chapman, P. (2017). Impact of improved insulation and heating on mortality risk of older cohort members with prior cardiovascular or respiratory hospitalisations. *BMJ Open, 7*(11), e018079. <https://doi.org/10.1136/bmjopen-2017-018079>

Psarros, C., Theleritis, C., Economou, M., Tzavara, C., Kioulos, K. T., Mantonakis, L., Soldatos, C. R., & Bergiannaki, J.-D. (2017). Insomnia and PTSD one month after wildfires : Evidence for an independent role of the "fear of imminent death". *International Journal of Psychiatry in Clinical Practice, 21*(2), 137-141. <https://doi.org/10.1080/13651501.2016.1276192>

Psarros, C., Theleritis, C., Kokras, N., Lyrakos, D., Koborozos, A., Kakabakou, O., Tzanoulinos, G., Katsiki, P., & Bergiannaki, J. D. (2018). Personality characteristics and individual factors associated with PTSD in firefighters one month after extended wildfires. *Nordic Journal of Psychiatry, 72*(1), 17-23. <https://doi.org/10.1080/08039488.2017.1368703>

Public Health Agency of Canada (PHAC). (2019). *Public Health Infobase*. Retrieved from <https://health-infobase.canada.ca/>

Public Health Agency of Canada (PHAC). (2020a). *People who are at risk of more severe disease or outcomes from COVID-19*. Retrieved from <https://www.canada.ca/en/public-health/services/publications/diseases-conditions/people-high-risk-for-severe-illness-covid-19.html>

Public Health Agency of Canada (PHAC). (2020b). *Canada COVID-19 weekly epidemiology report (2* August to 8 August 2020). Retrieved from <https://www.canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19/epidemiological-economic-research-data.html>

Public Health England. (2020). *Heatwave plan for England*. Retrieved from <https://www.gov.uk/government/publications/heatwave-plan-for-england>

Public Safety Canada. (2019). *National Disaster Mitigation Program (NDMP)*. Retrieved from <https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/index-en.aspx>

Radio-Canada. (2018). Érosion des berges : Sainte-Flavie aidera au déménagement d'une cinquantaine de résidences. Retrieved from <https://ici.radio-canada.ca/nouvelle/1122112/erosion-berges-cotiere-sainte-flavie-relocalisation-residences>

Rajaram, N., Hohenadel, K., Gattoni, L., Khan, Y., Birk-Urovitz, E., Li, L., & Schwartz, B. (2016). Assessing health impacts of the December 2013 ice storm in Ontario, Canada. *BMC Public Health, 16*(1), 544.

Raji, B., Tenpierik, M. J., & van den Dobbelsteen, A. (2015). The impact of greening systems on building energy performance : A literature review. *Renewable and Sustainable Energy Reviews, 45*, 610-623.

Ramin, B., & Svoboda, T. (2009). Health of the homeless and climate change. *Journal of Urban Health-Bulletin of the New York Academy of Medicine, 86*(4), 654-664. <https://doi.org/10.1007/s11524-009-9354-7>

Ranson, M. (2014). Crime, weather, and climate change. *Journal of Environmental Economics and Management, 67*(3), 274-302. <https://doi.org/10.1016/j.jeem.2013.11.008>

Rapaport, E., Manuel, P., Krawchenko, T., & Keefe, J. (2015). How can aging communities adapt to coastal climate change ? Planning for both social and place vulnerability. *Canadian Public Policy, 41*(2), 166-177.

Rappold, A. G., Cascio, W. E., Kilaru, V. J., Stone, S. L., Neas, L. M., Devlin, R. B., & Diaz-Sanchez, D. (2012). Cardio-respiratory outcomes associated with exposure to wildfire smoke are modified by measures of community health. *Environmental Health, 11*(1), 71.

Rappold, A. G., Fann, N. L., Crooks, J., Huang, J., Cascio, W. E., Devlin, R. B., & Diaz-Sanchez, D. (2014). Forecast-based interventions can reduce the health and economic burden of wildfires. *Environmental Science & Technology, 48*(18), 10571-10579. <https://doi.org/10.1021/es5012725>

Rappold, A. G., Reyes, J., Pouliot, G., Cascio, W. E., & Diaz-Sanchez, D. (2017). Community vulnerability to health impacts of wildland fire smoke exposure. *Environmental Science & Technology, 51*(12), 6674-6682. <https://doi.org/10.1021/acs.est.6b06200>

Ravanelli, N. M., Hodder, S. G., Havenith, G., & Jay, O. (2015). Heart rate and body temperature responses to extreme heat and humidity with and without electric fans. *JAMA, 313*(7), 724-725. <https://doi.org/10.1001/jama.2015.153>

Regroupement des organismes de bassins versants du Québec. (2019). *Gestion intégrée de l'eau par bassin versant. La gestion intégrée de l'eau par bassin versant - GIEBV.* Retrieved from <https://robvq.qc.ca/la-giebv/>

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., & Elliott, C. T. (2016). Critical review of health impacts of wildfire smoke exposure. *Environmental Health Perspectives, 124*(9), 1334.

Remmers, T., Thijs, C., Timperio, A., Salmon, J., Veitch, J., Kremers, S. P. J., & Ridgers, N. D. (2017). Daily weather and children's physical activity patterns. *Medicine & Science in Sports & Exercise, 49*(5), 922-929. <https://doi.org/10.1249/MSS.0000000000001181>

Rezaei, M. (2017). *Power to the people : Thinking (and rethinking) energy poverty in British Columbia, Canada* [Doctorate Thesis, University of British Columbia]. The University of British Columbia. Retrieved from <https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0351974>

Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J. (2014). Projected increase in lightning strikes in the United States due to global warming. *Science, 346*(6211), 851-854. <https://doi.org/10.1126/science.1259100>

Ross, A. C., Manson, J. E., Abrams, S. A., Aloia, J. F., Brannon, P. M., Clinton, S. K., Durazo-Arvizu, R. A., Gallagher, J. C., Gallo, R. L., Jones, G., Kovacs, C. S., Mayne, S. T., Rosen, C. J., & Shapses, S. A. (2011). The 2011 report on dietary reference intakes for calcium and vitamin D from the institute of medicine : What clinicians need to know. *The Journal of Clinical Endocrinology & Metabolism, 96*(1), 53-58. <https://doi.org/10.1210/jc.2010-2704>

Rouquette, A., Mandereau-Bruno, L., Baffert, E., Laaidi, K., Josseran, L., & Isnard, H. (2011). Surveillance hivernale des effets du froid sur la santé des populations sans-domicile en région Île-de-France : Utilisation des données du réseau d'Organisation de la surveillance coordonnée des urgences (Oscour®). *Revue d'épidémiologie et de santé publique, 59*(6), 359-368. <https://doi.org/10.1016/j.respe.2011.05.006>

Rucker, D., Allan, J. A., Fick, G. H. & Hanley, D. A. (2002). Vitamin D insufficiency in a population of healthy western Canadians. *CMAJ*, *166*(12), 1517-1524.

Ryan, B. J., Franklin, R. C., Burkle, F. M., Watt, K., Aitken, P., Smith, E. C., & Leggat, P. (2016). Defining, describing, and categorizing public health infrastructure priorities for tropical cyclone, flood, storm, tornado, and tsunami-related disasters. *Disaster Medicine and Public Health Preparedness, 10*(4), 598-610.

Ryti, N. R. I., Guo, Y., & Jaakkola, J. J. K. (2016). Global association of cold spells and adverse health effects : A systematic review and meta-analysis. *Environmental Health Perspectives, 124*(1), 12-22. <https://doi.org/10.1289/ehp.1408104>

Sahni, V., Scott, A. N., Beliveau, M., Varughese, M., Dover, D. C., & Talbot, J. (2016). Public health surveillance response following the southern Alberta floods, 2013. *Canadian Journal of Public Health, 107*(2), e142-e148. https://doi.org/10.17269/cjph.107.5188

Sakamoto, R. (2015). Legionnaire's disease, weather and climate. *Bulletin of the World Health Organization, 93*(6), 435-436. <https://doi.org/10.2471/BLT.14.142299>

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M. & Wang, M. (2014). Anthropogenic heating of the urban environment due to air conditioning. *Journal of Geophysical Research: Atmospheres*, *119*(10), 5949-5965. <https://doi.org/10.1002/2013JD021225>

Sanborn, M., & Takaro, T. (2013). Recreational water–related illness: Office management and prevention. *Canadian Family Physician, 59*(5), 491-495.

Sandhu, P. K., Elder, R., Patel, M., Saraiya, M., Holman, D. M., Perna, F., Smith, R. A., Buller, D., Sinclair, C., Reeder, A., Makin, J., McNoe, B., & Glanz, K. (2016). Community-based interventions to prevent skin cancer : Two community guide systematic reviews. *American journal of preventive medicine, 51*(4), 531-539. <https://doi.org/10.1016/j.amepre.2016.03.020>

Santamouris, M. (2014). Cooling the cities–a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy, 103,* 682-703.

Sartini, C., Barry, S. J. E., Wannamethee, S. G., Whincup, P. H., Lennon, L., Ford, I., & Morris, R. W. (2016). Effect of cold spells and their modifiers on cardiovascular disease events : Evidence from two prospective studies. *International Journal of Cardiology, 218,* 275-283. <https://doi.org/10.1016/j.ijcard.2016.05.012>

Saulnier, D. D., Ribacke, K. B., & von Schreeb, J. (2017). No calm after the storm : A systematic review of human health following flood and storm disasters. *Prehospital and Disaster Medicine, 32*(5), 568-579.

Schmeltz, M. T., Sembajwe, G., Marcotullio, P. J., Grassman, J. A., Himmelstein, D. U., & Woolhandler, S. (2015). Identifying individual risk factors and documenting the pattern of heat-related illness through analyses of hospitalization and patterns of household cooling. *PLOS ONE, 10*(3), e0118958. <https://doi.org/10.1371/journal.pone.0118958>

Schmitt, J., Seidler, A., Diepgen, T. l., & Bauer, A. (2011). Occupational ultraviolet light exposure increases the risk for the development of cutaneous squamous cell carcinoma : A systematic review and meta-analysis. *British Journal of Dermatology, 164*(2), 291-307. <https://doi.org/10.1111/j.1365-2133.2010.10118.x>

Schuster, P. F., Schaefer, K. M., Aiken, G. R., Antweiler, R. C., Dewild, J. F., Gryziec, J. D., Gusmeroli, A., Hugelius, G., Jafarov, E., Krabbenhoft, D. P., Liu, L., Herman-Mercer, N., Mu, C., Roth, D. A., Schaefer, T., Striegl, R. G., Wickland, K. P., & Zhang, T. (2018). Permafrost stores a globally significant amount of mercury. *Geophysical Research Letters, 45*(3), 1463-1471. <https://doi.org/10.1002/2017GL075571>

Shore-Lorenti, C., Brennan, S. L., Sanders, K. M., Neale, R. E., Lucas, R. M., & Ebeling, P. R. (2014). Shining the light on sunshine : A systematic review of the influence of sun exposure on type 2 diabetes mellitus-related outcomes. *Clinical Endocrinology, 81*(6), 799-811.<https://doi.org/10.1111/cen.12567>

Sillmann, J., Kharin, V., Zwiers, F., Zhang, X., & Bronaugh, D. (2013). Climate extremes indices in the CMIP5 multimodel ensemble : Part 2. Future climate projections. *Journal of Geophysical Research: Atmospheres, 118*(6), 2473-2493.

Silver, A., & Grek-Martin, J. (2015). "Now we understand what community really means" : Reconceptualizing the role of sense of place in the disaster recovery process. *Journal of Environmental Psychology, 42,* 32-41. <https://doi.org/10.1016/j.jenvp.2015.01.004>

Simpson, S., van der Mei, I., Lucas, R. M., Ponsonby, A.-L., Broadley, S., Blizzard, L., & Taylor, B. (2018). Sun exposure across the life course significantly modulates early multiple sclerosis clinical course. *Frontiers in Neurology, 9,* 16. <https://doi.org/10.3389/fneur.2018.00016>

Sinickas, A., Jamieson, B., & Maes, M. A. (2016). Snow avalanches in western Canada : Investigating change in occurrence rates and implications for risk assessment and mitigation. *Structure and Infrastructure Engineering, 12*(4), 490-498. <https://doi.org/10.1080/15732479.2015.1020495>

Sloka, J., Pryse-Phillips, W., & Stefanelli, M. (2008). The relation of ultraviolet radiation and multiple sclerosis in Newfoundland. *Canadian Journal of Neurological Sciences, 35*(1), 69-74.

Smargiassi, A., Goldberg, M. S., Plante, C., Fournier, M., Baudouin, Y., & Kosatsky, T. (2009). Variation of daily warm season mortality as a function of micro-urban heat islands. *Journal of Epidemiology and Community Health*, *63*(8), 659–664. <https://doi.org/10.1136/jech.2008.078147>

Smith, B. A., & Fazil, A. (2019). Increased risk of microbial foodborne diseases with climate change. *Canada Communicable Disease Report*, *45*(4), 108–113. <https://doi.org/10.14745/ccdr.v45i04a05>

Smith, H. G., Sheridan, G. J., Lane, P. N., Nyman, P., & Haydon, S. (2011). Wildfire effects on water quality in forest catchments : A review with implications for water supply. *Journal of Hydrology, 396*(1-2), 170-192.

Song, X., Wang, S., Hu, Y., Yue, M., Zhang, T., Liu, Y., Tian, J., & Shang, K. (2017). Impact of ambient temperature on morbidity and mortality : An overview of reviews. *The Science of the Total Environment, 586,* 241-254. <https://doi.org/10.1016/j.scitotenv.2017.01.212>

Stanke, C., Kerac, M., Prudhomme, C., Medlock, J., & Murray, V. (2013). Health effects of drought: a systematic review of the evidence. *PLoS Currents*, *5*, ecurrents.dis.7a2cee9e980f91ad7697b570bcc4b004. <https://doi.org/10.1371/currents.dis.7a2cee9e980f91ad7697b570bcc4b004>

Stares, J. (2014). *Evidence review : Use of evacuation to protect public health during wildfire smoke event*s (C. Elliott & K. Rideout, Eds.). British Columbia Center for Disease Control. Retrieved from <http://www.bccdc.ca/resource-gallery/Documents/Guidelines%20and%20Forms/Guidelines%20and%20Manuals/Health-Environment/WFSG_EvidenceReview_Evacuation_FINAL_V3_edstrs.pdf>

Statistics Canada. (2020). *Chart 3 Dwelling conditions for First Nations, Métis and Inuit, Canada, 2016.* Retrieved from <https://www150.statcan.gc.ca/n1/daily-quotidien/200417/cg-b003-eng.htm>

Stephani, E., Fortier, D., Shur, Y., Fortier, R., & Doré, G. (2014). A geosystems approach to permafrost investigations for engineering applications, an example from a road stabilization experiment, Beaver Creek, Yukon, Canada. *Cold Regions Science and Technology, 100*, 20-35. <https://doi.org/10.1016/j.coldregions.2013.12.006>

Sterk, A., Schijven, J., de Nijs, T., & de Roda Husman, A. M. (2013). Direct and indirect effects of climate change on the risk of infection by water-transmitted pathogens. *Environmental science & technology*, *47*(22), 12648–12660. <https://doi.org/10.1021/es403549s>

St-Hilaire, A., Steiger, H., Liu, A., Laplante, D. P., Thaler, L., Magill, T., & King, S. (2015). A prospective study of effects of prenatal maternal stress on later eating-disorder manifestations in affected offspring : Preliminary indications based on the project ice storm cohort. *International Journal of Eating Disorders, 48*(5), 512-516.

Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events : Are sprawling cities more vulnerable to climate change than compact cities? *Environmental Health Perspectives, 118*(10), 1425-1428. <https://doi.org/10.1289/ehp.0901879>

Stone, B., Vargo, J., Liu, P., Habeeb, D., DeLucia, A., Trail, M., Hu, Y., & Russell, A. (2014). Avoided heat-related mortality through climate adaptation strategies in three US cities. *Plos One, 9*(6), e100852. <https://doi.org/10.1371/journal.pone.0100852>

Strand, L. B., Barnett, A. G., & Tong, S. (2011). The influence of season and ambient temperature on birth outcomes : A review of the epidemiological literature. *Environmental Research, 111*(3), 451-462. <https://doi.org/10.1016/j.envres.2011.01.023>

Sun, Z., Chen, C., Xu, D., & Li, T. (2018). Effects of ambient temperature on myocardial infarction : A systematic review and meta-analysis. *Environmental Pollution, 241*, 1106-1114. <https://doi.org/10.1016/j.envpol.2018.06.045>

Sutherland, L.-A., & Glendinning, T. (2008). Farm family coping with stress : The impact of the 1998 ice storm. *Journal of Comparative Family Studies, 39*(4), 527-543.

Tallis, M., Taylor, G., Sinnett, D., & Freer-Smith, P. (2011). Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments. *Landscape and Urban Planning, 103*(2), 129-138. <https://doi.org/10.1016/j.landurbplan.2011.07.003>

Tan, J., Zheng, Y., Tang, X., Guo, C., Li, L., Song, G., Zhen, X., Yuan, D., Kalkstein, A. J., & Li, F. (2010). The urban heat island and its impact on heat waves and human health in Shanghai. *International Journal of Biometeorology, 54*(1), 75-84.

Tapsell, S. M., & Tunstall, S. M. (2008). "I wish I'd never heard of Banbury" : The relationship between 'place' and the health impacts from flooding. *Health & Place, 14*(2), 133-154. <https://doi.org/10.1016/j.healthplace.2007.05.006>

Tempark, T., Lueangarun, S., Chatproedprai, S., & Wananukul, S. (2013). Flood-related skin diseases : A literature review. *International Journal of Dermatology, 52*(10), 1168-1176. <https://doi.org/10.1111/ijd.12064>

Tereszchuk, K. A., Rochon, Y. J., McLinden, C. A., & Vaillancourt, P. A. (2018). Optimizing UV Index determination from broadband irradiances. *Geoscientific Model Development, 11*(3), 1093-1113. <https://doi.org/10.5194/gmd-11-1093-2018>

The Ontario Sun Safety Working Group. (2010). *Sun Exposure and Protective Behaviours in Ontario: An Ontario Report Based on the 2006 Second National Sun Survey*. Toronto, ON: Canadian Cancer Society, Ontario Division. Retrieved from <https://www.cancercareontario.ca/sites/ccocancercare/files/assets/CCOSunExposure.pdf>

Thistlethwaite, J., Henstra, D., Peddle, S., & Daniel, S. (2017). *Canadian voices on changing flood risk—Findings from a National Survey.* University of Waterloo. Retrieved from <https://uwaterloo.ca/climate-centre/news/canadian-voices-changing-flood-risk-findings-national-survey>

Thistlethwaite, J., Minano, A., Henstra, D., Scott, D. (2020). *Indigenous Reserve Lands in Canada Face High Flood Risk. Centre for International Governance Innovation.* Policy Brief No. 159. Retrieved from <https://www.cigionline.org/sites/default/files/documents/PB%20no.159.pdf>

Thompson, R., Garfin, D. R., & Silver, R. C. (2017). Evacuation from natural disasters : A systematic review of the literature. *Risk Analysis, 37*(4), 812-839.

Thompson, R., Hornigold, R., Page, L., & Waite, T. (2018). Associations between high ambient temperatures and heat waves with mental health outcomes : A systematic review. *Public Health, 161*, 171-191. <https://doi.org/10.1016/j.puhe.2018.06.008>

Thomson, H., Snell, C., & Bouzarovski, S. (2017). Health, well-being and energy poverty in Europe : A comparative study of 32 European countries. *International Journal of Environmental Research and Public Health, 14*(6). <https://doi.org/10.3390/ijerph14060584>

Thordardottir, E. B., Valdimarsdottir, U. A., Hansdottir, I., Resnick, H., Shipherd, J. C., & Gudmundsdottir, B. (2015). Posttraumatic stress and other health consequences of catastrophic avalanches : A 16-year follow-up of survivors. *Journal of Anxiety Disorders, 32*, 103-111. <https://doi.org/10.1016/j.janxdis.2015.03.005>

Toloo, G., FitzGerald, G., Aitken, P., Verrall, K., & Tong, S. (2013). Evaluating the effectiveness of heat warning systems : Systematic review of epidemiological evidence. *International Journal of Public Health, 58*(5), 667-681. <https://doi.org/10.1007/s00038-013-0465-2>

Touchaei, A. G., & Akbari, H. (2015). Evaluation of the seasonal effect of increasing albedo on urban climate and energy consumption of buildings in Montreal. *Urban Climate, 14*, 278-289. <https://doi.org/10.1016/j.uclim.2015.09.007>

Toutant, S., Gosselin, P., Bélanger, D., Bustinza, R., & Rivest, S. (2011). An open source web application for the surveillance and prevention of the impacts on public health of extreme meteorological events: the SUPREME system. *International Journal of Health Geographics*, *10*, 39. <https://doi.org/10.1186/1476-072X-10-39>

Townshend, I., Awosoga, O., Kulig, J., Botey, A. P., Shepard, B., & McFarlane, B. (2015). Impacts of wildfires on school children : A case study of Slave Lake, Alberta, Canada. *International Journal of Mass Emergencies & Disasters, 33*(2), 148-187.

Traffic Injury Research Foundation (TIRF). (2012). *Winter tires: A review of research on effectiveness and use.* Retrieved from <https://tirf.ca/wp-content/uploads/2017/01/2012_Winter_Tire_Report_7.pdf>

Tunstall, S., Tapsell, S., Green, C., Floyd, P., & George, C. (2006). The health effects of flooding : Social research results from England and Wales. *Journal of Water and Health, 4*(3), 365-380. <https://doi.org/10.2166/wh.2006.031>

Turcotte-Tremblay, A. M., Lim, R., Laplante, D. P., Kobzik, L., Brunet, A., & King, S. (2014). Prenatal maternal stress predicts childhood asthma in girls: project ice storm. *BioMed Research International*, *2014*, 201717. <https://doi.org/10.1155/2014/201717>

Turner, L., Alderman, K., & Tong, S. (2012a). The 2011 Brisbane floods affected residents' health. *Medical Journal of Australia, 197*(4), 214-216.

Turner, L. R., Barnett, A. G., Connell, D., & Tong, S. (2012b). Ambient temperature and cardiorespiratory morbidity : A systematic review and meta-analysis. *Epidemiology, 23*(4), 594-606. <https://doi.org/10.1097/EDE.0b013e3182572795>

Uscher-Pines, L. (2009). Health effects of relocation following disaster : A systematic review of the literature. *Disasters, 33*(1), 1-22. <https://doi.org/10.1111/j.1467-7717.2008.01059.x>

U.S. Climate Resilience Toolkit. (2017). Iñupiat Work to Preserve Food and Traditions on Alaska›s North Slope. Case study. Retrieved from <https://toolkit.climate.gov/case-studies/i%C3%B1upiat-work-preserve-food-and-traditions-alaskas-north-slope>

Vahmani, P., Jones, A. D., & Patricola, C. M. (2019). Interacting implications of climate change, population dynamics, and urban heat mitigation for future exposure to heat extremes. *Environmental Research Letters*, *14*(8), 084051. <https://doi.org/10.1088/1748-9326/ab28b0>

Valois, P., Bouchard, D., Talbot, D., Caron, M., Renaud, J. S., Gosselin, P. & Jacob, J. (2020a). Adoption of flood-related preventive behaviours by people having different risks and histories of flooding. *Natural Hazards*, *102*(3), 1155-1173. <https://doi.org/10.1007/s11069-020-03950-9>

Valois, P., Caron, M., Gousse-Lessard, A. S., Talbot, D., & Renaud, J. S. (2019). Development and validation of five behavioral indices of flood adaptation. *BMC public health*, *19*(1), 1-17. <https://doi.org/10.1186/s12889-019-6564-0>

Valois, P., Jacob, J., Mehiriz, K., Talbot, D., Renaud, J.-S. & Caron, M. (2017a). *Portrait de l'adaptation aux changements climatiques dans les organisations du secteur de la santé au Québec*. Université Laval. <http://www.monclimatmasante.qc.ca/Data/Sites/1/publications/oqacc_rapport_sante_21_nov_final.pdf>

Valois, P., Talbot, D., Caron, M., Carrier, M.-P., Morin, A. J. S., Renaud, J.-S., Jacob, J. & Gosselin, P. (2017b). Development and Validation of a Behavioural Index for Adaptation to High Summer Temperatures among Urban Dwellers. International *Journal of Environmental Research and Public Health*, *14*(7), 820. <https://doi.org/10.3390/ijerph14070820>

Valois, P., Talbot, D., Bouchard, D., Renaud, J. S., Caron, M., Canuel, M. & Arrambourg, N. (2020b). Using the theory of planned behavior to identify key beliefs underlying heat adaptation behaviors in elderly populations. *Population and Environment, 41*, 480-506. <https://doi.org/10.1007/s11111-020-00347-5>

Vanasse, A., Cohen, A., Courteau, J., Bergeron, P., Chebana, F., Gosselin, P., Rochette, L., Blais, C., & Ouarda, T. B. M. J. (2015). *Impact des inondations importantes sur la santé cardiovasculaire au Québec : Les cas de Saguenay (1996) et de St-Jean-sur-Richelieu (2011) : Rapport final.* INRS, Centre Eau Terre Environnement. Retrieved from <http://espace.inrs.ca/2814/>

Vanasse, A., Cohen, A., Courteau, J., Bergeron, P., Dault, R., Gosselin, P., Blais, C., Bélanger, D., Rochette, L., Chebana, F. (2016a). Association between floods and acute cardiovascular diseases : A population-based cohort study using a geographic information system approach. *International Journal of Environmental Research and Public Health, 13*(2), 168. <https://doi.org/10.3390/ijerph13020168>

Vanasse, A., Talbot, D., Chebana, F., Bélanger, D., Gosselin, P., Blais, C., Gamache, P., Giroux, J.-X., & Dault, R. (2016b). *Impact des conditions météorologiques sur le délai de survenue des événements d'insuffisance cardiaque chez les personnes âgées de 65 ans et plus diagnostiquées avec cette condition médicale au Québec, de 2001 à 2011 : Rapport final.* INRS, Centre Eau Terre Environnement. Retrieved from <http://espace.inrs.ca/5789/>

van der Kamp, D. (2016). *Drought, wildfire, and climate change in Metro Vancouver's water supply area.* Metro Vancouver. Retrieved from <https://sustain.ubc.ca/about/resources/drought-wildfire-and-climate-change-metro-vancouver%E2%80%99s-water-supply-area>

van der Leun, J. C., Piacentini, R. D., & Gruijl, F. R. de. (2008). Climate change and human skin cancer. *Photochemical & Photobiological Sciences, 7*(6), 730-733. <https://doi.org/10.1039/B719302E>

Vanos, J. K. (2015). Children's health and vulnerability in outdoor microclimates : A comprehensive review. *Environment International, 76*, 1-15.

VanStone, N., van Dijk, A., Chisamore, T., Mosley, B., Hall, G., Belanger, P., & Moore, K. M. (2017). Characterizing the effects of extreme cold using real-time syndromic surveillance, Ontario, Canada, 2010-2016. *Public Health Reports, 132,* 48S-52S. <https://doi.org/10.1177/0033354917708354>

Van Wagner, C. (2015). Forest Fire in Canada. *The Canadian Encyclopedia.* Retrieved from <https://thecanadianencyclopedia.ca/en/article/forest-fire>

Varghese, B. M., Hansen, A., Bi, P., & Pisaniello, D. (2018). Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. *Safety Science, 110,* 380-392. <https://doi.org/10.1016/j.ssci.2018.04.027>

Veru, F., Dancause, K., Laplante, D. P., King, S., & Luheshi, G. (2015). Prenatal maternal stress predicts reductions in CD4+lymphocytes, increases in innate-derived cytokines, and a Th2 shift in adolescents : Project Ice Storm. *Physiology & Behavior, 144,* 137-145. <https://doi.org/10.1016/j.physbeh.2015.03.016>

Vida, S., Durocher, M., Ouarda, T. B. M. J., & Gosselin, P. (2012). Relationship between ambient temperature and humidity and visits to mental health emergency departments in Québec. *Psychiatric Services, 63*(11), 1150-1153. <https://doi.org/10.1176/appi.ps.201100485>

Vieth, R., Cole, D. E., Hawker, G. A., Trang, H. M., & Rubin, L. A. (2001). Wintertime vitamin D insufficiency is common in young Canadian women, and their vitamin D intake does not prevent it. *European Journal of Clinical Nutrition, 55*(12), 1091-1097. <https://doi.org/10.1038/sj.ejcn.1601275>

Vins, H., Bell, J., Saha, S., & Hess, J. J. (2015). The mental health outcomes of drought : A systematic review and causal process diagram. *International Journal of Environmental Research and Public health, 12*(10), 13251-13275.

Vodden, K., & Cunsolo, A. (2021). Rural and Remote Communities. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report.* Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/national-issues/>

Vonk, J. E., Tank, S. E., Bowden, W. B., Laurion, I., Vincent, W. F., Alekseychik, P., Amyot, M., Billet, M., Canario, J., & Cory, R. M. (2015). Reviews and syntheses : Effects of permafrost thaw on Arctic aquatic ecosystems. *Biogeosciences, 12*(23), 7129-7167.

Vutcovici, M., Goldberg, M. S., & Valois, M.-F. (2014). Effects of diurnal variations in temperature on non-accidental mortality among the elderly population of Montreal, Quebec, 1984–2007. *International Journal of Biometeorology, 58*(5), 843-852.

Wachinger, G., Renn, O., Begg, C., & Kuhlicke, C. (2013). The risk perception paradox—Implications for governance and communication of natural hazards. *Risk analysis, 33*(6), 1049-1065.

Wai, K.-M., Yu, P. K. N., & Lam, K.-S. (2015). Reduction of solar UV radiation due to urban high-rise buildings – a coupled modelling study. *PLoS ONE, 10*(8), e0135562. <https://doi.org/10.1371/journal.pone.0135562>

Waite, T., Murray, V., & Baker, D. (2014). Carbon monoxide poisoning and flooding : Changes in risk before, during and after flooding require appropriate public health interventions. *PLoS Currents, 6*. <https://doi.org/10.1371/currents.dis.2b2eb9e15f9b982784938803584487f1>

Walder, D. J., Laplante, D. R., Sousa-Pires, A., Veru, F., Brunet, A., & King, S. (2014). Prenatal maternal stress predicts autism traits in 61/2 year-old children : Project Ice Storm. *Psychiatry Research, 219*(2), 353-360. <https://doi.org/10.1016/j.psychres.2014.04.034>

Wang, L., Liu, T., Hu, M., Zeng, W., Zhang, Y., Rutherford, S., Lin, H., Xiao, J., Yin, P., Liu, J., Chu, C., Tong, S., Ma, W., & Zhou, M. (2016a). The impact of cold spells on mortality and effect modification by cold spell characteristics. *Scientific Reports, 6*, 38380. <https://doi.org/10.1038/srep38380>

Wang, X., Lavigne, E., Ouellette-Kuntz, H., & Chen, B. E. (2014). Acute impacts of extreme temperature exposure on emergency room admissions related to mental and behavior disorders in Toronto, Canada. *Journal of Affective Disorders, 155*, 154-161.

Wang, Yan., Bobb, J. F., Papi, B., Wang, Y., Kosheleva, A., Di, Q., Schwartz, J. D., & Dominici, F. (2016b). Heat stroke admissions during heat waves in 1,916 US counties for the period from 1999 to 2010 and their effect modifiers. *Environmental Health, 15*(1), 83. <https://doi.org/10.1186/s12940-016-0167-3>

Wang, Yupeng., Berardi, U., & Akbari, H. (2015). Comparing the effects of urban heat island mitigation strategies for Toronto, Canada. *Energy and Buildings, 114*, 2-19.

Wang, Yuxuan., Xie, Y., Dong, W., Ming, Y., Wang, J., & Shen, L. (2017). Adverse effects of increasing drought on air quality via natural processes. *Atmospheric Chemistry and Physics, 17*(20), 12827-12843. <https://doi.org/10.5194/acp-17-12827-2017>

Warren, F. & Lulham, N. (Eds.). (2021). *Canada in a Changing Climate: National Issues Report*. Ottawa, ON: Government of Canada. Retrieved from <www.ChangingClimate.ca/National-Issues>

Warsini, S., West, C., Ed, G. D., Res Meth, G. C., Mills, J., & Usher, K. (2014). The psychosocial impact of natural disasters among adult survivors : An integrative review. *Issues in Mental Health Nursing, 35*(6), 420-436.

Watson, M., Holman, D. M., & Maguire-Eisen, M. (2016). Ultraviolet radiation exposure and its impact on skin cancer risk. *Seminars in Oncology Nursing, 32*(3), 241-254. <https://doi.org/10.1016/j.soncn.2016.05.005>

Weinstein, J. M., Yarnold, P. R., & Hornung, R. L. (2001). Parental knowledge and practice of primary skin cancer prevention : Gaps and solutions. *Pediatric Dermatology, 18*(6), 473-477. <https://doi.org/10.1046/j.1525-1470.2001.1861996.x>

Weller, R. B. (2017). The health benefits of UV radiation exposure through vitamin D production or non-vitamin D pathways. Blood pressure and cardiovascular disease. *Photochemical & Photobiological Sciences, 16*(3), 374-380.

Wheaton, E., Kulshreshtha, S., Wittrock, V., & Koshida, G. (2008). Dry times : Hard lessons from the Canadian drought of 2001 and 2002. *The Canadian Geographer = Le Géographe Canadien, 52*(2), 241-262. doi:10.1111/j.1541-0064.2008.00211.x

Williams, S., Hanson-Easey, S., Robinson, G., Pisaniello, D., Newbury, J., Saniotis, A., & Bi, P. (2017). Heat adaptation and place : Experiences in South Australian rural communities. *Regional environmental change, 17*(1), 273-283.

Willoughby, M., Kipsaina, C., Ferrah, N., Blau, S., Bugeja, L., Ranson, D., & Ibrahim, J. E. (2017). Mortality in nursing homes following emergency evacuation : A systematic review. *Journal of the American Medical Directors Association, 18*(8), 664-670.

Wintermeyer, E., Ihle, C., Ehnert, S., Stöckle, U., Ochs, G., de Zwart, P., Flesch, I., Bahrs, C., & Nussler, A. K. (2016). Crucial Role of Vitamin D in the Musculoskeletal System. *Nutrients, 8*(6), 319. <https://doi.org/10.3390/nu8060319>

Witham, M. D., Donnan, P. T., Vadiveloo, T., Sniehotta, F. F., Crombie, I. K., Feng, Z., & McMurdo, M. E. T. (2014). Association of day length and weather conditions with physical activity levels in older community dwelling people. *PLOS ONE, 9*(1), e85331. <https://doi.org/10.1371/journal.pone.0085331>

World Health Organization. (2013a). *Review of evidence on health aspects of air pollution–REVIHAAP Project*. Retrieved from <http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report-final-version.pdf?ua=1>

World Health Organization. (2013b). *Review of the 2012-2013 winter influenza season, northern hemisphere. Weekly Epidemiological Record*, *88*(22), 225 - 232. <https://apps.who.int/iris/handle/10665/242074>

Wotton, B. M., Flannigan, M. D., & Marshall, G. A. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. *Environmental Research Letters, 12*(9), 095003. <https://doi.org/10.1088/1748-9326/aa7e6e>

Wouters, H., De Ridder, K., Poelmans, L., Willems, P., Brouwers, J., Hosseinzadehtalaei, P., Tabari, H., Vanden Broucke, S., van Lipzig, N. P. M., & Demuzere, M. (2017). Heat stress increase under climate change twice as large in cities as in rural areas : A study for a densely populated midlatitude maritime region. *Geophysical Research Letters, 44*(17), 8997-9007. <https://doi.org/10.1002/2017GL074889>

Wright, C. J., Sargeant, J. M., Edge, V. L., Ford, J. D., Farahbakhsh, K., RICG, Shiwak, I., Flowers, C., IHACC Research Team, & Harper, S. L. (2018). Water quality and health in northern Canada: stored drinking water and acute gastrointestinal illness in Labrador Inuit. *Environmental Science and Pollution Research International*, *25*(33), 32975–32987. <https://doi.org/10.1007/s11356-017-9695-9>

Xiang, J., Bi, P., Pisaniello, D., & Hansen, A. (2014). Health impacts of workplace heat exposure : An epidemiological review. *Industrial Health, 52*(2), 91-101. <https://doi.org/10.2486/indhealth.2012-0145>

Xu, Z., Etzel, R. A., Su, H., Huang, C., Guo, Y., & Tong, S. (2012). Impact of ambient temperature on children's health : A systematic review. *Environmental Research, 117*, 120-131. <https://doi.org/10.1016/j.envres.2012.07.002>

Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B., & Tong, S. (2016). Impact of heatwave on mortality under different heatwave definitions : A systematic review and meta-analysis. *Environment International, 89,* 193-203.

Xu, Z., Liu, Y., Ma, Z., Li, S., Hu, W., & Tong, S. (2014a). Impact of temperature on childhood pneumonia estimated from satellite remote sensing. *Environmental Research, 132,* 334-341. <https://doi.org/10.1016/j.envres.2014.04.021>

Xu, Z., Sheffield, P. E., Su, H., Wang, X., Bi, Y., & Tong, S. (2014b). The impact of heat waves on children's health : A systematic review. *International Journal of Biometeorology, 58*(2), 239-247. <https://doi.org/10.1007/s00484-013-0655-x>

Yam, J. C. S., & Kwok, A. K. H. (2014). Ultraviolet light and ocular diseases. *International Ophthalmology, 34*(2), 383-400. <https://doi.org/10.1007/s10792-013-9791-x>

Yan, B., Chebana, F., Masselot, P., Campagna, C., Gosselin, P., Ouarda, T. B., & Lavigne, E. (2020). A cold-health watch and warning system, applied to the province of Quebec (Canada). *Science of The Total Environment*, *741*, 140188. <10.1016/j.scitotenv.2020.140188>

Yao, J., Brauer, M., & Henderson, S. B. (2013). Evaluation of a wildfire smoke forecasting system as a tool for public health protection. *Environmental health perspectives, 121*(10), 1142.

Yao, J., Stieb, D. M., Taylor, E., & Henderson, S. B. (2020). Assessment of the Air Quality Health Index (AQHI) and four alternate AQHI-Plus amendments for wildfire seasons in British Columbia. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *111*(1), 96–106. <https://doi.org/10.17269/s41997-019-00237-w>

Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., & Tong, S. (2012). Ambient temperature and morbidity : A review of epidemiological evidence. *Environmental Health Perspectives, 120*(1), 19-28. <https://doi.org/10.1289/ehp.1003198>

Youl, P. H., Janda, M., & Kimlin, M. (2009). Vitamin D and sun protection : The impact of mixed public health messages in Australia. *International Journal of Cancer, 124*(8), 1963-1970. <https://doi.org/10.1002/ijc.24154>

Young, I., Smith, B. A., & Fazil, A. (2015). A systematic review and meta-analysis of the effects of extreme weather events and other weather-related variables on Cryptosporidium and Giardia in fresh surface waters. *Journal of Water and Health, 13*(1), 1-17.

Youssouf, H., Liousse, C., Roblou, L., Assamoi, E.-M., Salonen, R. O., Maesano, C., Banerjee, S., & Annesi-Maesano, I. (2014). Non-accidental health impacts of wildfire smoke. *International Journal of Environmental Research and Public Health, 11*(11), 11772-11804.

Yu, W., Mengersen, K., Wang, X., Ye, X., Guo, Y., Pan, X., & Tong, S. (2012). Daily average temperature and mortality among the elderly : A meta-analysis and systematic review of epidemiological evidence. *International Journal of Biometeorology, 56*(4), 569-581. <https://doi.org/10.1007/s00484-011-0497-3>

Yusa, A., Berry, P., J. Cheng, J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health, 12*(7), 8359-8412. <https://doi.org/10.3390/ijerph120708359>

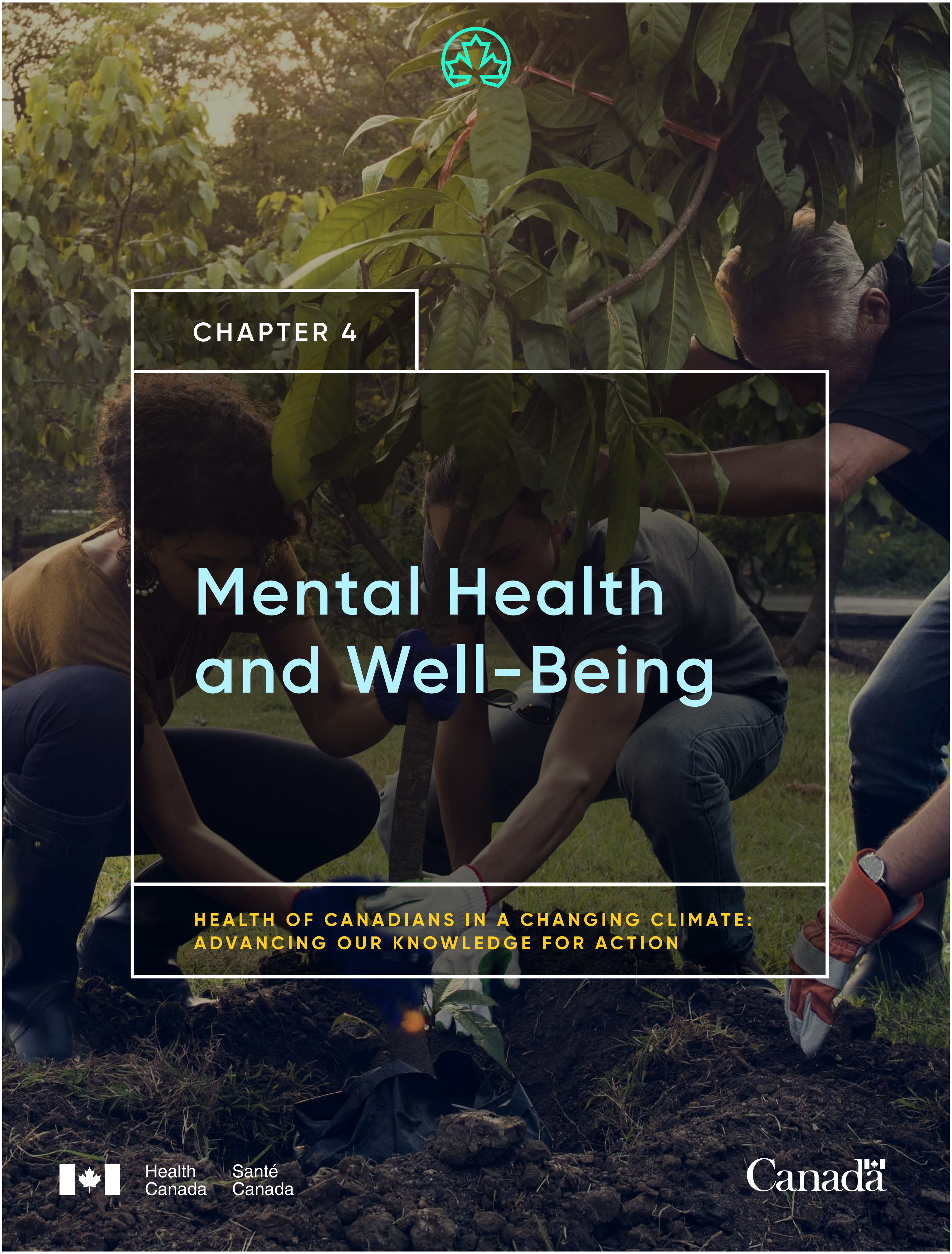
Zeng, J., Zhang, X., Yang, J., Bao, J., Xiang, H., Dear, K., Liu, Q., Lin, S., Lawrence, W. R., & Lin, A. (2017). Humidity may modify the relationship between temperature and cardiovascular mortality in Zhejiang Province, China. *International Journal of Environmental Research and Public Health, 14*(11), 1383.

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., & Kharin, V. V. (2019). Changes in temperature and precipitation across Canada. In E. Bush & D.S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019>

Zimmermann, E., Bracalenti, L., Piacentini, R., & Inostroza, L. (2016). Urban flood risk reduction by increasing green areas for adaptation to climate change. *Procedia Engineering, 161,* 2241-2246. <https://doi.org/10.1016/j.proeng.2016.08.822>

Zivin, J. G., & Neidell, M. (2014). Temperature and the allocation of time : Implications for climate change. *Journal of Labor Economics, 32*(1), 1-26. <https://doi.org/10.1086/671766>

Zscheischler, J., Westra, S., Van Den Hurk, B. J., Seneviratne, S. I., Ward, P. J., Pitman, A., AghaKouchak, A., Bresch, D.N., Leonard, M., Wahl, T., & Zhang, X. (2018). Future climate risk from compound events. *Nature Climate Change, 8*(6), 469-477. <https://doi.org/10.1038/s41558-018-0156-3>



CHAPTER 4

Mental Health and Well-Being

HEALTH OF CANADIANS IN A CHANGING CLIMATE:
ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Author

Katie Hayes, Health Canada

Contributing Authors

Ashlee Cunsolo, Memorial University

Jura Augustinavicius, McGill University

Rebecca Stranberg, Health Canada

Susan Clayton, College of Wooster

Maria Malik, Canadian Food Inspection Agency

Shawn Donaldson, Health Canada and Carleton University

Gabrielle Richards, University of Ottawa

Amber Bedard, University of Calgary

Lewis Archer, Save the Children

Tyrone Munro, Four Arrows Regional Health Authority

Carla Hilario, University of Alberta

Suggested Citation

Hayes, K., Cunsolo, A., Augustinavicius, J., Stranberg, R., Clayton, S., Malik, M., Donaldson, S., Richards, G., Bedard, A., Archer, L., Munro, T., & Hilario, C. (2022). Mental Health and Well-Being. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

Summary

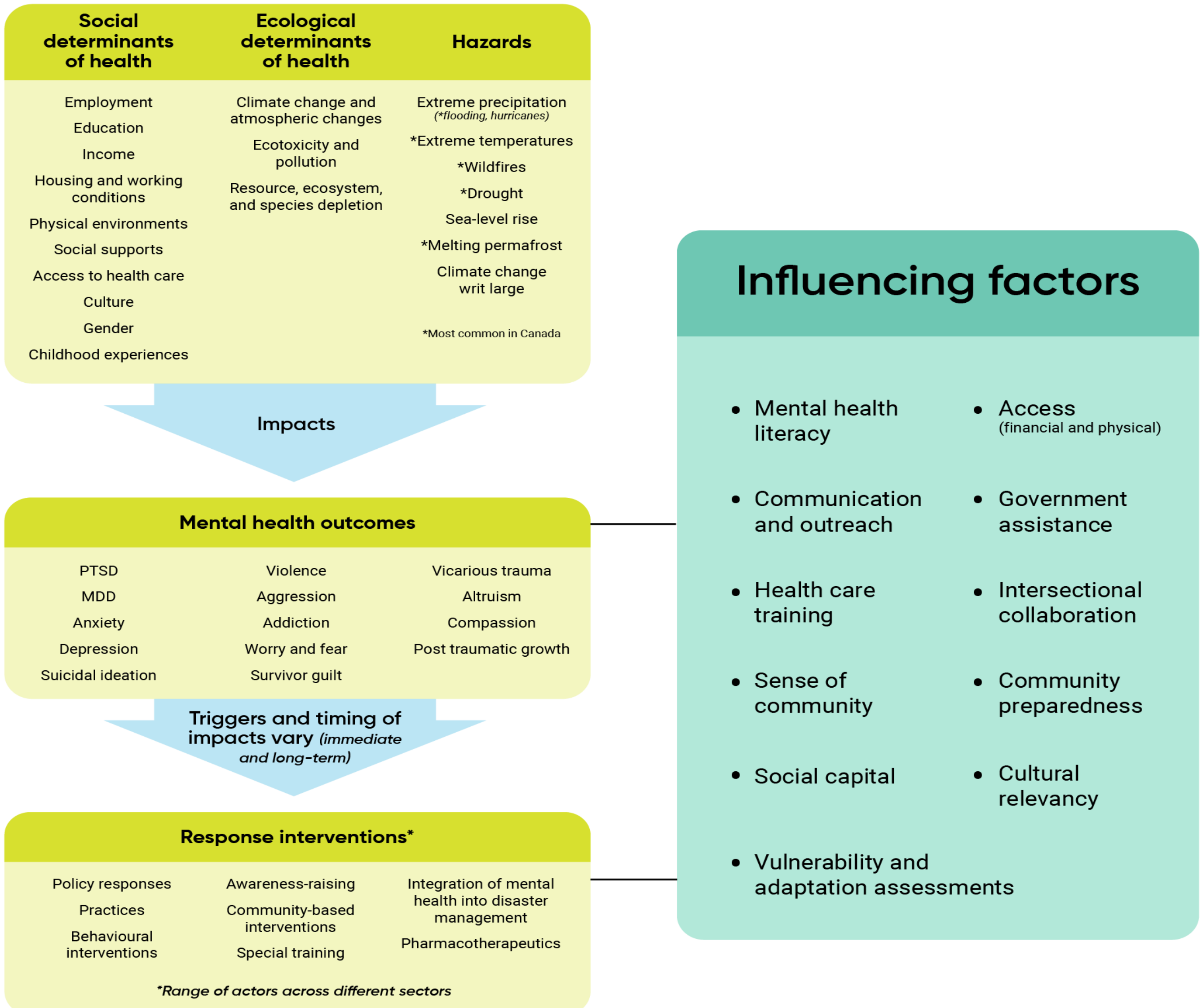
Climate change increases risks to the mental health and well-being of many people in Canada. Specific populations that can be disproportionally and inequitably affected include those experiencing health inequities based on race, culture, gender, age, socio-economic status, ability, and geographic location. These factors are encompassed within the social, biological, environmental, and cultural determinants of health that are amplified by climate change. Mental health can be impacted by hazards that occur over the shorter and longer term, such as floods, extreme heat events, wildfires, and hurricanes as well as drought, sea-level rise, and melting permafrost. Knowledge and awareness of climate change threats can also affect mental health and well-being, resulting in emotional and behavioural responses, such as worry, grief, anxiety, anger, hopelessness, and fear.

Mental health impacts of climate change may include exacerbation of existing mental illness such as psychosis; new-onset mental illness such as post-traumatic stress disorder; mental health stressors such as grief, worry, anxiety, and vicarious trauma; and a lost sense of place, which refers to the perceived or actual detachment from community, environment, or homeland. Impacts can also include disruptions to psychosocial well-being and resilience, disruptions to a sense of meaning in a person's life, and lack of community cohesion, all of which can result in distress, higher rates of hospital admissions, increased suicide ideation or suicide, and increased negative behaviours such as substance misuse, violence, and aggression. Adaptation efforts that can reduce the mental health impacts of climate change include expanded communication and outreach activities and community preparedness, greater access to health care for those requiring assistance, and improved mental health literacy and training.

Key Messages

- The current burden of mental ill health in Canada is likely to rise as a result of climate change. Given the very large number of Canadians who experience mental health problems, the potential increase of mental ill health outcomes from future climate change is large.
- Climate change hazards that can affect the mental health of people in Canada include acute hazards such as floods, extreme heat events, wildfires, and hurricanes, as well as slow-onset hazards such as drought, sea-level rise, and melting permafrost. Secondary impacts of climate hazards (such as economic insecurity, displacement, food and water insecurity) can lead to ongoing stress, anxiety, and depression.

- Mental health impacts of climate change may include exacerbation of existing mental illness such as psychosis; new-onset mental illness such as post-traumatic stress disorder; mental health stressors such as grief, worry, anxiety, and vicarious trauma; and a lost sense of place, which refers to the perceived or actual detachment from community, environment, or homeland. Impacts can also include disruptions to psychosocial well-being and resilience, disruptions to a sense of meaning in a person's life, and lack of community cohesion, all of which can result in distress, higher rates of hospital admissions, increased suicide ideation or suicide, and increased negative behaviours such as substance misuse, violence, and aggression.
- Climate change and related environmental change can cause complex emotional and behavioural reactions in individuals, that are not necessarily pathological. These environmental distress reactions, called psychoterratic syndromes, include ecoanxiety, solastalgia, and ecoparalysis.
- Climate change disproportionately affects the mental health of specific populations, including Indigenous Peoples; women; children; youth; older adults; people living in low socio-economic conditions (including the homeless); people living with pre-existing physical and mental health conditions; and certain occupational groups, such as land-based workers and first responders. For example, Indigenous Peoples are at greater risk of being displaced by climate-related hazards and this can result in a loss of community connections and loss of livelihoods that affect individual and collective well-being.
- Given the current high costs of mental illness to society, and the breadth of mental health impacts that are related to climate change, future costs borne by Canadians and health systems are expected to be large as the climate continues to warm.
- Access to mental health practitioners, mental health and health care facilities, social services, and culturally relevant mental health care information can prevent adverse mental health outcomes, improve outcomes, and enhance well-being in a changing climate. Rural, remote, and urban settings that currently face challenges providing mental health care will face increased demands for services from climate change impacts.
- Greater communication and outreach about the mental health impacts of climate change, enhanced community preparedness for possible impacts, broad access to culturally relevant health care to assist people in need, intersectoral and transdisciplinary collaboration on adaptation initiatives, and improved mental health literacy and training support efforts to prepare for climate change impacts on Canadians.
- Well-designed actions to mitigate greenhouse gas emissions and adapt to climate change — for example, active transportation, environmental stewardship, green infrastructure, and enhanced social networks and community supports — can also benefit mental health.



Factors that influence the psychosocial health impacts of climate change. Source: Hayes et al., 2019.

Overview of Climate Change Impacts on Mental Health

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Mental health	• Increased frequency and severity of precipitation (such as hurricanes, flooding, ice storms) • Droughts • Wildfires • Extreme temperatures • Decreased food and water security • Melting permafrost • Sea-level rise • Gradual warming	• Post-traumatic stress disorder (PTSD) • Anxiety • Worry and fear • Depression • Stress • Vicarious trauma • Recovery fatigue • Suicide ideation • Weakened social ties • Addictions (such as drug and alcohol usage) • Aggression including domestic violence • Ecoanxiety/climate anxiety • Ecogrief/climate grief • Solastalgia • Post-traumatic growth • Impacts on health and social services

4.1 Introduction

Climate change poses significant risks to the mental health of Canadians. The past decade has seen rapid growth in research, discussion, and media reporting on climate change and its associated mental health implications. In a 2019 national survey of 2,000 residents of Canada (aged 18 and older), 49% of respondents indicated they were increasingly worried about the effects of climate change, and 25% indicated that they often think about climate change and are "really anxious about it" (Abacus Data, 2019). There is growing concern among public health officials in Canada about these impacts and how to support psychosocial[1] adaptation and resilience (BC Ministry of Environment and Climate Change Strategy, n.d.; Toronto Public Health, 2015; Yaffe, 2016; Howard et al., 2017). Supporting psychosocial adaptation means developing or enhancing existing coping behaviours, practices, tools, or interventions to protect mental health and social well-being in a changing climate (Séguin, 2008; Brown & Westaway, 2011). This chapter provides information on the mental health impacts of climate change in Canada to support public health officials, practitioners, and decision makers in their efforts to prepare Canadians and their health systems.

The mental health impacts from climate change are associated with both acute and slow-onset hazards. Acute hazards — such as floods, extreme heat events, wildfires, and hurricanes — can result in mental health impacts, such as mood and behavioural disorders (Berry et al., 2010a; Clayton et al., 2014; Dodgen et al., 2016; Clayton et al., 2017). Acute hazards may also result in secondary impacts on mental health from physical harm and displacement, which can result in loss of livelihood, trauma, a lost sense of place, fear of impending impacts, and ongoing mood and behavioural disorders such as post-traumatic stress disorder (PTSD), depression, and anxiety (Berry et al., 2011; Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Clayton et al., 2014; Dodgen et al., 2016; Clayton et al., 2017; Cunsolo & Ellis, 2018; Clayton, 2020; Clayton & Karazsia, 2020). Acute hazards can also result in affirmative outcomes, such as a sense of community cohesion, altruism, and a sense of meaning in a person's life as communities come together to support one another in the aftermath of acute events (Weissbecker, 2011; Hayes & Poland, 2018; Hayes et al., 2020). Slow-onset hazards, such as drought, sea-level rise, and melting permafrost, can affect an individual's sense of place, ecosystem health, culture and identity, and can lead to emotional responses of anxiety, grief, anger, helplessness, and depression (Cunsolo Willox et al., 2012; Clayton et al., 2017; Adlard et al., 2018; Cunsolo & Ellis, 2018; Middleton et al., 2020b). Both acute and slow-onset hazards can have secondary impacts on mental health (e.g., income insecurity, food and water insecurity). Knowledge and awareness of climate change threats, often identified as "vicarious," "mediated," or "anticipatory" experiences, can also affect mental health and well-being, resulting in emotional and behavioural responses, such as worry, grief, anxiety, anger, hopelessness, and fear (Clayton et al., 2017; Cunsolo & Ellis, 2018; Clayton, 2020; Clayton & Karazsia, 2020; Pihkala, 2020).

Addressing the impacts of climate change on the mental health of people living in Canada requires both greater understanding of risks and of adaptation efforts, as risks are increasing with climate warming. Temperatures in Canada have increased at a rate that is twice the global average, with Northern communities

1 Mental health is one aspect of the broader definition of psychosocial health. As defined in Section 4.2 Key Terms, psychosocial health is the interplay between social well-being, which arises from relationships with others and one's context and culture, and psychological well-being, including thoughts, feelings, and behaviours (Berry et al., 2014).

warming even faster, particularly throughout Inuit Nunangat[2] (Inuit homelands) (Bush & Lemmen, 2019). Future occurrences of many of the acute and slow-onset climate-related hazards that affect mental health are projected to increase (see Chapter 3: Natural Hazards, and Chapter 5: Air Quality). In addition, mental illness is already a leading cause of disability in the country, even before considering the projected increase in climate change hazards (CAMH, 2012). According to the Mental Health Commission of Canada (MHCC), approximately 7.5 million Canadians experience mental health problems each year (MHCC, 2017). Mental illness can affect anyone of any age, background, education level, income, or culture (MHCC, 2017). By the time they reach the age of 40, approximately 50% of people living in Canada will have, or have had, some form of mental illness (MHCC, 2017). Also, while the burden of mental health problems is high, many people in Canada lack access to mental health services, which affects opportunities for adaptation to reduce risks (Cunsolo Willox et al., 2013b; Petrasek MacDonald et al., 2015; Moroz et al., 2020). For example, in Northern, rural, and remote places in Canada, many communities do not have access to regular mental health care providers or related resources (including a family physician), and transportation within and to remote communities can be impeded by changing weather patterns and disruptions to land, water, ice, and air travel routes (CMHA, 2009; Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Standing Committee on Indigenous and Northern Affairs, 2017; MHCC, 2020). Barriers to accessing mental health care throughout Canada are numerous, and can include, for example, financial and/or physical constraints; mental health stigma; a lack of mental health literacy; and limited culturally relevant mental health resources (Rodriguez & Kohn, 2008; Osofsky et al., 2010; MHCC, 2016; Hayes et al., 2019).

The total burden of mental illness related to climate change in Canada is currently unknown; however, a number of empirical studies have documented the effects of a warming climate on mental health, largely in Northern and Indigenous[3] communities (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Donaldson et al., 2013; Durkalec et al., 2015; Dodd et al., 2018; Hayes et al., 2020; Middleton et. al., 2020a). Compared with the number of studies on climate change impacts on physical health, far fewer have examined mental health. Reasons for this difference include challenges related to:

- attributing environmental hazards to climate change and then attributing mental health outcomes to these hazards;
- isolating the mental health outcomes related to climate change from other compounding life stressors;
- measuring some types of mental health impacts and compounding stressors (e.g., the difficulty of measuring compounding stressors of those experiencing colonialism, intergenerational trauma, and connections to the land, such as many Indigenous Peoples);
- studying and reporting on mental health indicators when mental health can be understood differently among diverse populations; and,

2 Inuit Nunangat includes Inuvialuit (part of the Northwest Territories and Yukon), Nunavut, Nunavik (Northern Quebec), and Nunatsiavut (Labrador).

3 The term Indigenous is used in this chapter to refer collectively to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples, as defined under Section 35 of the *Constitution Act, 1982*. Wherever possible, clear distinctions are made between these three distinct, constitutionally recognized groups. Indigenous Peoples outside of Canada are also referenced in some instances particularly with respect to international climate policy, processes, and rights and are identified as such.

- under- or over-reporting of mental health outcomes related to climate change; under-reporting may occur because of the stigma surrounding mental illness, and over-reporting may occur because research is conducted too soon after a climate hazard, and, thus, normal reactions to abnormal events may be inappropriately pathologized (Hayes et al., 2018a).

4.2 Key Terms

The World Health Organization (WHO) defines **mental health** as: "A state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community" (WHO, 2018, n.p.). Mental health can be demonstrated by the range of thoughts, feelings, and behaviours that people experience in their lifetimes. This conceptualization of mental health goes beyond diagnostic categories to encompass broader definitions of mental health across cultures and contexts. Mental health, like physical health, exists on a spectrum and includes states of mental wellness, mental challenges, and mental illness, each of which can influence functioning across life domains (MHCC, 2018). Throughout this chapter, the term mental health refers to specific mental health–related outcomes, such as PTSD, anxiety, depression, and post-traumatic growth (PTG).

Mental wellness refers to affirmative mental health outcomes, such as psychosocial resilience, which is the ability to adapt, thrive, develop, and transform despite experiencing stressors (Kumar, 2016).

Mental challenges include problems related to thoughts, feelings, or behaviours, such as overwhelming emotions, including fear, panic, and worry (American Psychiatric Association, n.d.).

Mental illness includes moderate to severe diagnosable mental disorders, such as major depressive disorder, psychosis, and PTSD (Coppock & Dunn, 2009; American Psychiatric Association, 2013).

Emotional distress refers to experiencing symptoms of poor mental health outcomes (e.g., anxiety, depression, loss of motivation). The term **mental ill health** encompasses the definitions of mental challenges, formally diagnosable mental illnesses, and emotional distress.

Mental health is one aspect of the broader definition of psychosocial health. **Psychosocial health** is defined as the interplay between social well-being, which arises from relationships with others and one's context and culture, and psychological well-being, including thoughts, feelings, and behaviours (Berry et al., 2014). Psychosocial health depends on social factors in a person's life domain (home, work, school, and community) that are related to mental health and that allow people to live in optimal social conditions. **Psychosocial impacts** refer to outcomes that affect social relationships and context; for example, a lost sense of place related to experiencing climate change hazards.

A holistic understanding of mental health also includes an understanding of important social, cultural, and environmental determinants, which may include spiritual well-being, connectedness to nature and one's environment, and sense of place (MHCC, 2016; Hayes et al., 2018a). There are many approaches to understanding, supporting, and treating mental health from multiple cultural perspectives, which are valued and shared by people in Canada. For example, First Nations, Inuit, and Métis communities often have their own definitions of mental wellness, which include connections to land; an interplay among physical, mental, emotional, and spiritual wellness; and the importance of community and culture (Kirmayer et al., 2003; Health Canada, 2015; ITK, 2016; Sawatzky et al., 2019).

Specific qualities of environment-related trauma can foster complex emotional and behavioural reactions. For example, Glenn Albrecht noted the increase in environmental distress following climate-related hazards, such as drought and wildfires in Northern Australia, Hurricane Katrina, and the changing ice conditions in Northern Canada (Albrecht, 2011; Albrecht, 2012; Albrecht, 2017). He and his colleagues coined these environmental distress reactions "psychoterratic syndromes" and they include ecoanxiety, ecoparalysis, and solastalgia (Albrecht, 2011). These terms describe complex emotional and behavioural reactions of experiencing climate change that are not necessarily pathological. These reactions might actually be quite justified in response to climate change impacts and may serve as normal expressions of grief and/or loss in response to environmental degradation from climate change (Albrecht, 2011; Albrecht, 2019). Table 4.1 provides definitions for some common environment-related distress.

Table 4.1 Definitions of environment-related distress

TERM	DEFINITION
Ecoanxiety	Ecoanxiety (or climate anxiety) refers to the anxiety people experience that is triggered by awareness of ecological threats facing the planet due to climate change (Albrecht, 2011; Albrecht, 2012).
Ecoparalysis	Ecoparalysis refers to the complex feelings of not being able to do anything grand enough to mitigate or stop climate change (Koger et al., 2011).
Solastalgia	Solastalgia refers to the distress of bearing witness to ecological changes in one's home environment due to climate change; conceptualized as feeling homesick when a person is still in their home environment (Albrecht, 2011; Albrecht, 2012).
Ecological grief	Ecological grief (or ecogrief) refers to distress related to ecological loss or anticipated losses related to climate change. These losses may relate to land, species, culture, or lost sense of place and/or of cultural identity and ways of knowing. Ecogrief can include loss and trauma related to specific hazards such as climate-related flooding or wildfires, or slow-onset climate change impacts such as rising global temperatures, drought, melting permafrost, and sea-level rise (Cunsolo & Ellis, 2018).

4.3 Methods and Approach

As the literature in Canada on climate change and mental health is limited, this chapter also draws on the global literature and applies lessons learned to a Canadian context,where appropriate, to substantiate existing studies and fill knowledge gaps. A scoping review was conducted of English- and French-language peer reviewed and grey literature on climate change and mental health. Peer reviewed literature was identified by searching the PubMed, Scopus, PsycINFO (Proquest), Cochrane Review, and Google Scholar databases, using the search terms "climate change" or "changing climate" and "mental health" or "psychosocial" or "well-being/well-being," as well as synonyms and related words, such as "mental ill health," and "mental wellness." In an effort to capture literature that addressed psychosocial adaptation, the terms "resilience," "response," and "adaptation" were used in combination with the primary search terms. Grey literature sources included government reports, workshop reports, unpublished project reports, conference presentations, and communication with practitioners, and knowledge leaders.

The initial scoping review took place in July 2017, and English-language literature on climate change and mental health from the year 2000 onward was captured. An updated review took place in May 2019 and, at that time, French-language literature from 2000 to 2019 was included. After removing duplicates and irrelevant articles, a total of 207 articles were reviewed in depth for relevance and incorporated into this literature review.

Studies of climate change and psychosocial health tend to apply either survey or interview methods to learn about the lived experiences of psychosocial distress associated with a changing climate (e.g., Cunsolo Willox et al., 2012; Alderman et al., 2013; Ampuero et al., 2015; Durkalec et al., 2015; Eisenman et al., 2015; Harper et al., 2015; Albrecht, 2017; Dodd et al., 2018; Hayes et al., 2020; Middleton et al., 2020a). Most surveys and interviews are self-reported accounts from people who have experienced extreme temperatures or extreme weather events. Many of the findings presented in this chapter are from self-reported surveys and interviews, which mostly used a variety of validated survey tools and scales to assess how extreme temperatures or extreme events affect people's psychosocial health.

4.4 Mental Health Impacts of Climate Change

4.4.1 Causal Pathways

The casual pathways linking climate change hazards to mental health are multifaceted. Figure 4.1 describes how climate change negatively affects mental, physical, and community health. In the centre of this figure are the geophysical impacts of climate change, which amplify pre-existing social, individual, and physical health inequities. The interactions among climate hazards and pre-existing health inequities can lead to a host of mental, physical, and community health outcomes.

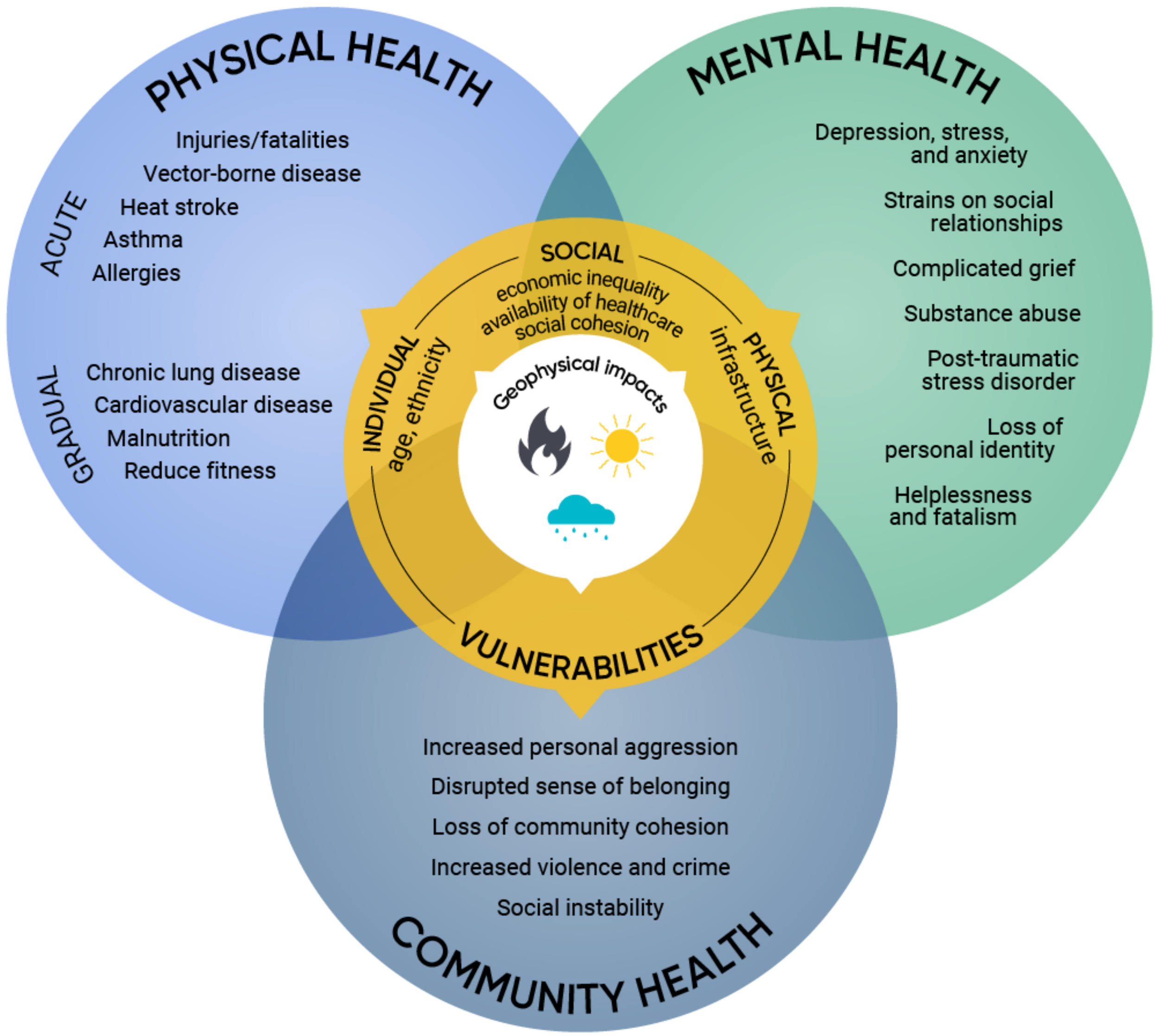


Figure 4.1 Linkages among climate change and physical, mental, and community health. Source: Clayton et al., 2017.

Exposure to climate hazards may trigger direct mental health impacts, such as depression, grief, or PTSD (Clayton et al., 2014; Dodge et al., 2016; Clayton et al., 2017; Hayes & Poland, 2018; Middleton et al., 2020b). Psychological reactions may also occur as a result of experiencing physical health impacts, such as heat stress, vector-borne disease, or injury (Berry et al., 2010a; Clayton et al., 2017) or impacts on community well-being, such as economic disruptions, displacement, and a loss of social cohesion (Berry et al., 2010a; Agnew, 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Sahni et al., 2016; Clayton et al., 2017; Miles-Novelo & Anderson, 2019). Disruption of social cohesion and resource scarcity can significantly affect health and related services for those who already have mental health problems and/or substance use disorder (Dodgen et al., 2016; Clayton et al., 2017). After experiencing climate stressors, some people may experience a combination of both affirmative mental health outcomes and mental problems or illness (Weissbecker, 2011; Hayes & Poland, 2018; Hayes et al., 2020). Affirmative outcomes can include a sense of optimism for the future, compassion, and altruism for others who have been affected by climate hazards, and a sense of meaning or purpose in one's life. Post-traumatic growth (PTG) can result from an increase in social cohesion after a climate disaster (Edwards & Wiseman, 2011; Ramsay & Manderson, 2011).

4.4.2 Timing of Impacts

In the literature, three timeframes related to the onset of psychosocial responses from acute hazards have been identified. They include immediate effects (hours, days, weeks), mid-range effects (six months to a year), and long-term effects (2.5 years and beyond) (Tunstall et al., 2006; Fritze et al., 2008; Anderson et al., 2017; Clayton et al., 2017). Immediate effects of acute, extreme weather events can include acute trauma, a normal response to a disaster (e.g., "normal reactions to abnormal situations") in which the traumatic reaction tends to subside once security and safety are established (Fritze et al., 2008). However, this is not always the case, as higher rates of more severe mental health concerns, such as suicide, have been reported in relation to acute climate change hazards such as extreme heat events (Carleton, 2017; Burke et al., 2018). Some mental health impacts can also extend over the medium- and long-term; those most commonly identified in the literature include anxiety, depression, PTSD, and drug and alcohol misuse, which can occur any time during ongoing climatic stressors or well after a climate-related extreme event has ended. They may also be related to the awareness of the threats posed by a changing climate (Fritze et al., 2008; Dodgen et al., 2016; Clayton et al., 2017). Notably, there are no key timeframes specified in the literature related to slow-onset hazards. People exposed to these hazards may experience an ongoing lost sense of place and/or distress from displacement, economic insecurity, food insecurity, and water insecurity.

4.4.3 Mental Health Impacts of Acute Hazards

The majority of studies in the climate change and mental health literature examine the mental health outcomes of acute hazards, such as flooding, extreme heat events, wildfires, and hurricanes. Exposure to acute disasters can trigger a host of mental health outcomes, including PTSD, major depressive disorder, anxiety, complicated grief, survivor guilt, recovery fatigue, and suicidal ideation or attempts (Berry et al., 2010a; Berry et al., 2011; Doherty & Clayton, 2011; Reser & Swim, 2011; Weissbecker, 2011; Cunsolo Willox et al., 2012; Stanke et al., 2012; Cunsolo Willox et al., 2013b; Bourque & Cunsolo Willox et al., 2014; O'Brien et al., 2014; Harper et al., 2015; Durkalec et al., 2016; Gifford & Gifford, 2016; Clayton et al., 2017; Mantoura et al., 2017; Dodd et al., 2018; Hayes et al., 2018a; Clayton, 2020; Clayton & Karazsia, 2020; Middleton et al., 2020a; Middleton et al., 2020b). In many cases, people exposed to acute disasters experience relatively little distress or only brief experiences with mental illness or mental health challenges, and instead demonstrate significant resilience (Bonanno, 2004). There is also evidence that suggests that people who are not exposed to acute hazards can experience mental health outcomes, such as vicarious trauma, secondary stress, and/or compassion fatigue for those whose lives have been disrupted by extreme events (Lambert & Lawson, 2013; Naturale, 2015). These forms of indirect distress are often due to close connection with people exposed to extreme events, media coverage of survivor experiences, or caring for survivors in a professional capacity

(Naturale, 2015). The following sections provide information on specific hazards and mental health outcomes, with a focus on literature that is specific to Canada and/or relevant to the Canadian context.

4.4.3.1 Flooding

Flooding has become the most frequent type of disaster globally, and risks of flooding are projected to increase as a result of the impacts of climate change in Canada (Alderman et al., 2012; Stanke et al., 2012; IPCC, 2014; Fernandez et al., 2015; UNISDR, 2015; Zhang et al., 2019). Evidence suggests that flooding can significantly affect mental health, and its effects can include increased levels of PTSD, general distress, depression, and anxiety among flood survivors (Alderman et al., 2012; Berry et al., 2014; Fernandez et al., 2015; Sahni et al., 2016; Waite et al., 2017). People exposed to flooding events may also experience an enhanced sense of community, compassion, and altruism, as community members come together to support one another in the wake of a disaster (Weissbecker, 2011; Hetherington et al., 2018; Hayes et al., 2020). These affirmative mental health outcomes may co-occur with poor mental health outcomes, such as anxiety or general distress (Weissbecker, 2011; Hayes et al., 2020). People do not need to be directly exposed to a flood to experience poor mental health outcomes. For example, a study based in England by Waite et al. (2017) surveyed 2126 people to understand the effects of flooding on mental health. Respondents included individuals whose homes had been flooded and those who were disrupted by the flood (e.g., could not travel to work), but whose homes were not directly flooded (Waite et al., 2017). Psychological morbidity was highest among respondents directly affected by flooding (622), with PTSD being the most commonly reported impact (36.2%), followed by anxiety (28.3%), and depression (20.1%) (Waite et al., 2017). Interestingly, those who were disrupted by the flood, but who had not directly experienced flooding (1099), also experienced PTSD (15.2%), anxiety (10.7%), and depression (9.6%) related to the flood event (Waite et al., 2017).

Flooding can exacerbate pre-existing mental health conditions and contribute to new ones (Stanke et al., 2012). The impacts of floods can include increased substance misuse, increased family violence after the flood exposure, and effects on sleep, which can lead to poor mental health outcomes (Burton et al., 2016; Sahni et al., 2016). Broader psychosocial health outcomes associated with flooding are often related to job insecurity and economic insecurity from flood damage to homes and businesses that strain individuals' and families' sense of place and livelihoods.

There is also evidence to suggest long-term mental health and psychosocial effects of experiencing flooding, including anxiety when it rains many years after experiencing a flooding event; reduced sense of security, including fears and anxiety about experiencing another extreme event; stress of living in floodplains; financial stress and family breakdown related to housing insecurity and/or economic insecurity from rebuilding; and lost sense of place due to displacement from flooding (Burton et al., 2016; Decent & Feltmate, 2018; Hayes et al., 2020).

4.4.3.2 Extreme Heat Events

There is a growing body of literature documenting the mental health impacts from exposure to extreme heat events. These impacts include increased mood and behavioural distress; exacerbated mental illness;

and increased risk of aggression, violence, and suicide (Anderson & Jané-Llopis, 2011; Agnew, 2012; Vida et al., 2012; Bélanger et al., 2014; Dixon et al., 2014; Wang et al., 2014; Ding et al., 2016; Dodgen et al., 2016; Obradovich et al., 2018; Thompson et al., 2018; Kaiser et al., 2019; Miles-Novelo & Anderson, 2019). People who tend to be at greater risk of poor mental health outcomes from exposure to extreme heat include the elderly, people with chronic physiological conditions, and people with pre-existing mental health conditions, including those taking psychotropic medications that affect thermoregulation (Price et al., 2013; Bélanger et al., 2014; Wang et al., 2014; Trang et al., 2016; Anderson et al., 2017). Some mental illnesses may be associated with inefficient physiological reactions to extreme heat, which make it harder for the body to cool down (Trang et al., 2016). Also, some medications may predispose people to heat illnesses (Health Canada, 2011), as they can inhibit important physiological reactions and/or cause cognitive impairment that may affect judgment and limit the uptake of protective measures. In addition, people with mental illness may face greater challenges in adapting because of cognitive impairment (e.g., not seeking shade) and/or socio-economic barriers, which disproportionately affect people with mental illness (Cusack et al., 2011; Page et al., 2012; Price et al., 2013; Bélanger et al., 2014; Wang et al., 2014; Dodgen et al., 2016; Trang et al., 2016; Anderson et al. 2017).

Higher temperatures may also be linked with violence (including suicide) and aggression (Stephen et al., 1999; Anderson & Jané-Llopis, 2011; Agnew, 2012; Dixon et al., 2014; Dodgen et al., 2016; Thompson et al., 2018; Kim et al., 2019; Miles-Novelo & Anderson, 2019). A 2019 study analyzed the association between the daily mean temperature and incidence of suicide for 341 locations in 12 countries and found that the pooled excess relative risk (1.46, 95% confidence interval [CI] 1.25 to 1.70) for suicide for 26 Canadian locations (1986 to 1999) was highest at a daily mean temperature of 24.2°C (Kim et al., 2019). It is important to note that this temperature is at the 99th percentile; however, as climate change progresses, reaching this threshold more often is likely. This may result in an increased number of suicides, depending on the levels of acclimatization and adaptation. Some Canadian locations have higher increases in the relative risk than the pooled value at different temperatures, including Oshawa, with a relative risk of 3.80 (95% CI 1.06 to 13.59) at 24.9°C; Ottawa, with a relative risk of 2.44 (95% CI 1.18 to 5.02) at 25.9°C; and Toronto, with a relative risk of 1.75 (95% CI 1.18 to 2.59) at 26.5°C (Kim et al., 2019).

Extreme heat also poses strain on systems that support mental health and well-being. Increased ambulance calls, emergency department visits, calls to telehealth and other helplines, and/or increases in people seeking outpatient care for mental health–related reasons during periods of extreme heat have been observed (Basu et al., 2018). In addition, drug storage in extreme temperatures may affect the efficacy of medications (De Winter et al., 2013; Armenian et al., 2017).

4.4.3.3 Wildfires

The research on the mental health impacts of wildfires has grown in recent years, likely due to the increase in wildfire disasters (particularly in communities in Western Canada). Similar to the research on flooding, the main mental health impacts of wildfires include increased risk of PTSD, anxiety (including generalized anxiety disorder), worry, and depression (Hutton, 2005; Eisenman et al., 2015; Yusa et al., 2015; Klinkenberg, 2017; Agyapong et al., 2018; Dodd et al., 2018). Wildfires can also lead to population displacement, damage to infrastructure, loss of property, threats to food security, and respiratory conditions, which can result in exacerbated or the onset of psychological distress (including anxiety, stress, and PTSD) (Hutton, 2005; Yusa et al., 2015; Dodd et al., 2018). Recent findings from a study on the 2016 wildfire in Fort McMurray, Alberta, revealed significant increases in PTSD. Findings revealed 60% of respondents self-reported symptoms of PTSD, while 29% were formally diagnosed with PTSD (Klinkenberg, 2017). Another 26% of respondents highlighted experiences of depression and 36% noted experiences of insomnia (Klinkenberg, 2017). Researchers comparing youth exposed to the Fort McMurray wildfires to controls in Red Deer, Alberta, found that depression scores, suicidal thinking, and increased tobacco use were significantly higher in the youth from Fort McMurray (Brown et al., 2019).

A study published in 2018 of the health impacts of wildfires in the Northwest Territories between June and August of 2014 revealed that displacement and evacuation related to the wildfires resulted in increased stress, fear, and long-term mental and emotional trauma (Dodd et al., 2018). Indigenous Peoples' mental health and well-being was at particular risk because the fires disrupted land-based activities and cultural practices that are essential to the livelihoods in many of these communities (Dodd et al., 2018).

4.4.3.4 Hurricanes

There is limited literature documenting the mental health outcomes related to hurricanes in Canada, as hurricane exposure is relatively low compared to that in the U.S., for example. The primary mental health impacts from hurricanes that have been documented in studies outside of Canada include increased risk of PTSD and anxiety and mood disorders (Galea et al., 2007; Kessler et al., 2008; Whaley, 2009; Zwiebach et al., 2010; Ferré et al., 2019; Orengo-Aguayo et al., 2019). The literature also highlights long-term effects, including affirmative outcomes such as a sense of resilience. Negative outcomes include, for example, lingering depression and PTSD (Rhodes & Chan, 2010; Pitts, 2015; Ferré et al., 2019).

Much of the literature documenting the mental health impacts of hurricanes is focused on the experiences of Hurricane Katrina and Hurricane Maria survivors. Hurricane Katrina was a Category 5 hurricane that struck the Gulf Coast of the U.S. in 2005, devastating the city of New Orleans (Whaley, 2009). It has been estimated that 20% to 35% of survivors experienced some form of mental health impact following Hurricane Katrina (Whaley, 2009). Nearly half (47.7%) of marginalized community members of New Orleans (mainly low-income, African-American women) showed probable signs of PTSD (Rhodes & Chan, 2010). This rate is significantly higher than the representative sample obtained by Kessler et al. (2008), which showed the prevalence of PTSD among the population at large who were affected by the hurricane to be between 14% and 20% (Kessler et al., 2008). Moreover, a 31.2% prevalence of anxiety and mood disorders among Hurricane Katrina survivors was observed (Kessler et al., 2008).

Similar to the findings on the mental health impacts of Hurricane Katrina, researchers exploring the impacts of Hurricane Maria, which struck Puerto Rico in 2017, found clinically significant increases in depression, anxiety, and PTSD among two-thirds of the 74 households surveyed six months after the event (Ferré et al., 2019). When looking at the mental health impacts of Hurricane Maria survivors who relocated to Florida, researchers found that adaptation and adjustment to a new environment added psychological burdens (Scaramutti et al., 2019). Therefore, adaptation efforts that lead to displacement do not always correlate with affirmative mental health outcomes (see section 4.4.5.1 Migration and Displacement).

In Canada, Hurricane Igor, which struck the Eastern coast of Newfoundland in 2010, was one of the most devastating hurricanes in Canadian history, reaching a Category 4 status (Gosse, 2010; Insurance Board of Canada, 2010; Pitts, 2015). While there are no known empirical investigations of the mental health impacts of this hurricane, there were reports documenting the psychosocial toll of loss and destruction (Gosse, 2010; Insurance Board of Canada, 2010). There was also one media report, five years after the hurricane, that documented psychosocial outcomes among community members in Clarenville and the Bonavista Peninsula in Newfoundland. These outcomes included an increased sense of community and resilience in the wake of the hurricane and in the months and years that followed the rebuilding efforts (Pitts, 2015).

4.4.4 Mental Health Impacts of Slow-Onset Hazards

Climate change impacts on mental health may also occur as result of slow-onset hazards, such as drought, melting sea ice, and sea-level rise.

4.4.4.1 Drought

Climate change is expected to continue to increase the risk of drought in Canada (Bush & Lemmen, 2019). Drought can affect livelihoods, socio-economic status, drinking water resources, food availability, and respiratory function (Vins et al., 2015; Watts et. al., 2017). As a consequence of these impacts, drought can also affect mental health (Yusa et al., 2015; Bard, 2017). The literature documenting the mental health impacts of drought highlights the secondary impacts from drought-related income, water, and food insecurity. These mental health impacts include increased risk of suicide, lost sense of place, and general despair (Nicholls et al., 2006; Polin et al., 2011; Rigby et al., 2011; Hanigan et al., 2012; Bryant & Granham, 2015).

Those at greatest risk of experiencing poor mental health outcomes from drought include land-based workers (in the current research literature, land-based workers tended to be male and farmers), rural dwellers, and Indigenous Peoples (Rigby et al., 2011; O'Brien et al., 2014; Bryant & Granham, 2015; Powers et al., 2015; Flecther & Knuttila, 2016; Ellis & Albrecht, 2017). People involved in the agricultural industry are among the most commonly affected by the mental health impacts of drought because their economic livelihoods depend on environmental conditions (Vins et al., 2015; Ellis & Albrecht, 2017). For example, Ellis and Albrecht (2017) found that climate change contributed to increased worry and place-based distress, and also increased the perceived risk of depression and suicide among farmers in Australia. These outcomes emerged as a result of a lost sense of identity, deep emotional links to family farms, feelings of failure due to the inability to protect the land, and an understanding of ecological destruction occurring in their community (Ellis & Albrecht, 2017).

Emotional responses to drought can be complex, involving both negative and positive effects. For example, in a study of drought impacts among First Peoples of Australia in New South Wales, Rigby et al. (2011) found impacts on culture and place, in particular, the inability to conduct cultural practices and displacement from traditional lands, which led to feelings of despair (Rigby et al., 2011). Noting the complexity of psychosocial responses to drought, authors also found that "the drought prompted increased love of and concern for land and a renewed enthusiasm for expressing connectedness to land through all forms of art" (Rigby et al., 2011, p. 249).

Droughts place significant psychosocial burdens on people because they tend to last longer than other extreme weather events, they tend to be more geographically expansive, and, thus, they have wide-ranging economic impacts. Furthermore, ecological recovery tends to be slow (Yusa et al., 2015; Fletcher & Knuttila, 2016).

4.4.4.2 Melting Sea Ice and Sea-Level Rise

The mental health impacts of melting sea ice and sea-level rise are a growing field of study, and much of the Canadian literature is focused on sea-ice decline in Northern communities. This is the region of Canada where the most rapid warming is being experienced, particularly in remote Inuit and First Nations communities (Bush & Lemmen, 2019). The mental health impacts from melting sea ice and sea-level rise include psychosocial distress related to food insecurity, a lost sense of place and identity, increased stress and anxiety from unsafe travel conditions, and increased substance use (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Asugeni et al., 2015; Durkalec et al., 2015; Harper et al., 2015). For example, it has been documented that warming temperatures and melting sea ice caused a variety of strong emotional reactions, including fear, anxiety, sadness, anger, frustration, stress, and distress among Nunatsiavut Inuit (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Durkalec et al., 2015; Harper et al., 2015). Changing weather patterns and sea ice thickness and extent affected community members' abilities to travel and to participate in traditional food-gathering methods, thus affecting food security. These impacts affected the sense of place and identity, as cultural practices were disrupted by the lack of access to stable and safe ice (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Harper et al., 2015). Mental health problems, suicidal ideation, family stress, and increased drug and alcohol use were often associated with this disrupted sense of place and identity (Cunsolo Willox et al., 2012).

4.4.5 Overarching Issues Related to Mental Health and a Changing Climate

4.4.5.1 Migration and Displacement

People exposed to climate hazards may be subject to job losses (particularly land-based workers), food and water insecurity, and forced migration, all of which can impact psychosocial health (Fritze et al., 2008; Agnew, 2012; Vins et al., 2015). Global displacement due to climate change is projected to vary from 25 million to 1 billion by 2050; however, 200 million is the most frequently cited estimate (IEHS, 2015). In addition to the effects of being displaced, migrants often face psychosocial impacts related to racism and discrimination experienced by many people in their new host countries or when people are displaced within a country (Gleick, 2014).

Box 4.1 Mental health and cultural safety in Indigenous communities affected by evacuations caused by extreme weather events

Understanding the history of relocation of First Nations, Inuit, and Métis populations in Canada is integral for informing effective and culturally safe evacuations during climate change impacts. Relocations have historically been implemented to establish the reserve system in Canada. Historical displacement among First Nations communities, for example, has meant moving communities to reserve lands through forcible means, often to unknown territory and land (Bussidor & Bilgen-Reinart, 1997; Christmas, 2013). Indigenous Peoples today inhabit less than 1% of their traditional lands and territories in Canada (Usher, 2003). Climate change and the increased impacts on Indigenous Peoples, paired with this history of relocation, have significant impacts on community members, which may exacerbate pre-existing trauma as a result of colonial legacy.

In 2018, the Climate Change and Health Adaptation Program at Indigenous Services Canada launched a three-year project entitled Addressing Mental Health Impacts in Indigenous Communities Due to Evacuations Caused by Extreme Weather Events. Participants included people from First Nations communities across Canada. This research was piloted in collaboration with First Nations community members and other key stakeholders to identify tangible solutions to inform policy and programs during evacuations, responses and recovery efforts, and to ensure that Indigenous voices are included in emergency planning and management.

Various conversations with participants suggested that climate change intensifies existing inequities experienced by communities by affecting subsistence lifestyles and connections to land and territory. First Nations communities were disproportionately evacuated due to climate change events, at 28.7 times the rates of their off-reserve Canadian counterparts, between 2009 and 2016 (Durocher, 2018). During times of evacuations, mental health and cultural safety are often not adequately considered in emergency response. Mental health challenges of experiencing an evacuation are often compounded and exacerbated through:

- the breakdown of communications systems between multiple jurisdictions;
- the intergenerational trauma of residential school systems;
- limited cultural wellness supports; and
- the often limited cultural spaces to provide country food and other spaces of healing.

Recommendations to reduce the mental health challenges of these events included integrating First Nations communities and knowledge systems into all stages of evacuation planning and process, and promoting and strengthening resilience before, during, and after evacuations. Importantly, concepts of resilience differ among clans, families, Nations, and communities. However, more broadly, resilience work for many Indigenous communities means understanding what capacity looks like from a space of cultural and traditional knowledge — including incorporating the role of oral history, maintaining or re-establishing access to subsistence practices, and involving social and familial structures in emergency management and preparedness.

Acute and slow-onset hazards due to climate change interact with existing socio-economic and political conditions to drive increases in voluntary and forced migration (Schwerdtle et al., 2017). In response to hazards related to climate change, not all populations migrate voluntarily, and some populations are not able to do so at all (Black et al., 2011). Some populations experiencing climate-related impacts may choose not to migrate, but rather to adopt other adaptation strategies (Black et al., 2011). Others may choose temporary migration with planned return or circular mobility between home and new host areas. "Trapped populations" represent those who are unable or less able to migrate because of social, political, or economic conditions, despite high vulnerability to climate change hazards (Bogic et al., 2015). These populations often live in low-resource settings (within or outside of Canada) and already experience various health inequities. Populations exposed to climate hazards who are unable to relocate remain at heightened or increased risk of mental health impacts of climate change (Foresight: Migration and Global Environmental Change, 2011). Climate-related migration can involve adverse health impacts but may also include positive impacts on health and well-being. For example, a review by Schwerdtle et al. (2017) on climate change and migration, which included case studies from various countries, described how voluntary, planned relocation can be an effective adaptation if it is based on the consent of migrating communities, if it improves the standards of living, and if used as a last resort.

In Canada, displacement related to climate change is an important issue, particularly for Indigenous communities. For example, the 2011 Manitoba flood displaced residents of Lake St. Martin First Nation in Manitoba for over six years (Macyshon, 2017). Approximately 7% of the evacuees never returned home, and some of these cases were due to suicide and homelessness (Macyshon, 2017). Substance misuse may also be related to displacement. The health director of the Montreal Lake Cree Nation in Saskatchewan suggested that increased use of crystal methamphetamine by 600 community members is related to a 2015 wildfire evacuation that displaced the entire community of 1200 people (Zakreski, 2019). The psychosocial effects of displacement related to climate change can therefore include increased rates of suicide, homelessness, and substance misuse among Indigenous communities that are impacted by evacuations caused by extreme weather events in Canada (Box 4.1). However, more research is needed to better understand these impacts.

4.4.5.2 Impacts on Health Systems and Facilities

Climate change also has implications for mental health services, treatment, and facilities. For example, mental health care facilities may be inaccessible due to infrastructure damage to buildings or roads following acute climate hazard events (Hasket et al., 2008; Osofsky et al., 2010; Clayton et al., 2017). Further, mental health professionals may be unable to reach health care facilities to provide services because of damage to their own property, personal injuries, or damage to infrastructure between their dwellings and health facilities. For the same reasons, people may be unable to access prescription medication to treat pre-existing mental health disorders (Balbus et al., 2013).

Many communities in Canada may not have access to mental health care facilities or practitioners on site even before a climate-related hazard, particularly in rural and remote areas (Cunsolo Willox et al., 2013b; Petrasek MacDonald et al., 2015; Moroz et al., 2020). In such cases, mental health care is often introduced in a community after the event for a short period of time and long-term mental health care needs are often not met (Hayes et al., 2020).

Box 4.2 Strengthening mental health care in High River, Alberta

The town of High River, Alberta, has experienced three major flooding events since 2005, most notably the 2013 flash flood that was declared a state of emergency, with four reported deaths and 13,000 people displaced from their homes (Canadian Disaster Database, 2016). Soon after the 2013 flood, the provincial government responded to the current and future mental health needs of Albertans by investing $50 million in mental health care and creating the first Chief Mental Health Officer in the province (Government of Alberta, 2013). This investment resulted in:

- the deployment of 15 mental health experts to High River;
- 28 additional mental health experts from British Columbia brought in to support evacuees;
- clinical staff visits to hotels where evacuees were housed;
- the hiring of six additional child and youth mental health specialists;
- training for first responders and flood victims in suicide prevention and psychological First Aid;
- 85,000 mental health promotion resources related to mental health care delivered digitally; and,
- mental health care translation services for the mental health promotion resources and services (Government of Alberta, 2013).

Further, staff from the Calgary Counselling Centre were brought into the community to provide free mental health care for residents affected by the flood. According to the Calgary Counselling Centre website, over 2750 people received counselling related to their experiences with the flooding event and 93% reported improved well-being after treatment (Foothills Community Counselling, 2020).

Due to funding shortages, however, the Calgary Counselling Centre in High River closed in 2016. Clients were notified that they could travel to the Calgary offices an hour away to seek support (Foothills Community Counselling, 2020). However, this was not feasible for people of low socio-economic status or with mobility issues, who were unable to travel to Calgary. Further, many of the mental health care responders who were sent into High River following the flood began to leave in 2016, despite persistent mental health care needs in the community (Hayes et al., 2020).

Noting the long-term effects of the flood and the overarching mental health care needs of the community, the municipality of High River and a private donor stepped in to establish the Foothills Community Counselling Service (Foothills Community Counselling, 2020; Hayes et al., 2020). This service is offered in the community with costs on a sliding-scale, so that High River residents, irrespective of income, can receive long-term care.

The municipality has also created the Safe Spot Initiative to build citizen capacity to support the mental health of High River residents (McCracken, 2017). This initiative trains businesses and agencies in psychological First Aid. After receiving training, businesses and agencies post a large orange dot in their window to let community members know that their establishment is a “safe spot” to talk about their mental health with a trained staff member. The aim of this program is to increase access to community-based mental health care (Hayes et al., 2018b).

Clayton et al. (2017) noted that, where cities have set plans in place to enhance or build resilient infrastructure to support climate change and health needs, they often overlook mental health infrastructure (including mental health care facilities and wellness services). Enhancing access to and expanding mental health services can support psychosocial resilience to climate change (Box 4.2).

4.4.5.3 Loss and Damage

The United Nations Framework Convention on Climate Change (UNFCCC) highlights the community-wide negative impacts of loss and damage related to climate change (Tschakert et al., 2017; UNFCCC, 2020). Loss and damage refer to physical losses and damage to environmental resources, biodiversity, properties, businesses, and infrastructure from slow-onset and acute climate hazards. There is a growing body of literature that highlights how climate-related loss and damage affects psychosocial well-being (Barnett et al., 2016; Tschakert et al., 2017; Cunsolo & Ellis, 2018; Tschakert et al., 2019). As noted earlier, a lost sense of place, particularly among Indigenous Peoples in Canada and globally, is tied to a loss of culture, identity, and connectedness to the land and land-based activities; thus, the psychosocial effects of loss are myriad and complex (Rigby et al., 2011; Cunsolo Willox et al., 2012; Tam et al., 2013; Cunsolo & Ellis, 2018; Middleton et al., 2020a; Middleton et al., 2020b). For example, Tam et al. (2013) assessed how climate change affected well-being in a First Nation community in the Western region of James Bay, and found that both slow-onset hazards (e.g., increased temperatures, changes in the timing of seasons, etc.) and acute hazards (e.g., flooding events) led to the loss of traditional harvesting practices, damaged the winter road, and disrupted the behaviour of animals. Similarly, in Nunatsiavut, Labrador, it was found that disruptions from increasing temperatures, melting sea ice, and shifting plant and wildlife patterns, as well as subsequent impacts on food and cultural security, resulted in decreased sense of place, diminished cultural continuity, and concerns about loss of place-based connections moving forward (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Middleton et al., 2020a). These experiences of loss, damage, and disruption subsequently led to socio-economic challenges and food insecurity that affected the communities' psychosocial well-being (Tam et al., 2013).

In a systematic analysis, entitled *One thousand ways to experience loss*, Tschakert et al. (2019) documented the many ways people and communities experience climate-related loss and damage through a comparative review of over 100 case studies. An array of negative emotional outcomes, including sadness, worry, trauma, depression, and suicidal ideation, a lost sense of place, a lost sense of safety, feeling homesick in one's home environment (solastalgia), grief, and loss of identity were identified (Tschakert et al., 2019). Further, a systematic literature review of climate-sensitive mental health outcomes for Indigenous Peoples globally found that changing place attachments and food systems can lead to diverse, interconnected, and overlapping emotional and psychological outcomes (Middleton et al., 2020b). The authors of this study highlight that there is no one single or simple relationship between climate stressors and intangible loss and damage and that climate-related harm is "mediated by personal circumstance, culture, and socio-economic context" (Tschakert et al., 2019, p. 69). An overview of how health inequities — based on biological, cultural, social, and environmental determinants of health — influence climate-related exposures, risks, and impacts is provided in the following section.

4.5 Populations at Higher Risk

While all people are at risk of experiencing the health impacts of climate change, some populations and communities are disproportionately affected. This section highlights populations throughout Canada who are at higher risk of the mental health impacts of a changing climate, including Indigenous Peoples; children, youth, and older adults; low socio-economic groups and the homeless; people with pre-existing health conditions; and certain occupational groups. This section emphasizes the need for appropriate attention, promotion, prevention, and care for specific subsets of the population.

In many cases, individuals who experience existing health inequities are at increased risk of mental health outcomes related to climate change. Health inequities refer to avoidable differences in health status and occur as a result of unfair or unjust systems, policies, and factors that influence health status (Government of Canada, 2018; see also Chapter 9: Climate Change and Health Equity). In order to address these systemic health inequities, it is important to better understand who is most at risk and the systemic factors that increase risk.

Individuals may fit into several population groups of higher concern and experience multiple health inequities, which can compound risks of the mental health impacts of climate change. The way multiple risk factors and health inequities can compound risk is not well understood. For example, there are many populations who may be at increased risk of the mental health impacts of climate change and who also experience discrimination. This can include racialized groups, those discriminated against because of sexual orientation, and those discriminated against as a result of mental health conditions. There is limited information about how discrimination can exacerbate the mental health impacts of climate change in specific populations.

Importantly, many populations who are at increased risk of mental health outcomes related to climate change have and continue to demonstrate adaptive and/or resilient behaviours, despite the challenges and inequities they face. While there is a nascent base of literature that explores the strengths and adaptation actions among populations considered at higher risk to mental health outcomes related to climate change (Ford et al., 2016; Hayes et al., 2019), such information can elucidate important learnings about those experiencing the most severe climate change impacts to better understand adaptation and resilience (Hayes, 2019).

4.5.1 Indigenous Peoples

There is a large body of literature documenting climate change impacts on the mental health of Indigenous Peoples in Canada and globally, with a specific focus on Indigenous Peoples in remote Australia (Shipley & Berry, 2010; Bardsley & Wiseman, 2012; Green & Minchin, 2014; O'Brien et al., 2014; Bowles, 2015) and Inuit Nunangat in Canada (Cameron, 2012; Cunsolo Willox et al., 2012; Ford, 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Durkalec et al., 2015; Harper et al., 2015; Ford et al., 2016). Indigenous Peoples in these distinct geographic locations are on the front lines of a changing climate and are bearing witness to the loss or degradation of land, which can take a toll on individual and collective well-being (Cunsolo Willox et al., 2012; Tam et al., 2013; Cunsolo Willox et al., 2014; Middleton et al., 2020b).

Compounding the impacts of a rapidly changing climate are the ongoing legacies and traumas stemming from colonization, land dispossession, residential schools, forced relocation, racism, social exclusion, and the continued marginalization of First Nations, Inuit, and Métis peoples in Canada (Kirmayer et al., 2009; Cameron, 2012; Ford, 2012). There is also a lack of culturally relevant health services for many First Nations, Inuit, and Métis peoples in Canada, leading to systematic and cultural barriers to service access and uptake (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). It is also well understood that Indigenous Peoples have a greater burden of chronic physical illness as a result of experiencing systemic health inequities that can exacerbate climate-related mental ill health outcomes (Earle, 2013; ITK, 2016).

4.5.2 Sex and Gender

Evidence suggests that women[4] tend to be more prone to anxiety, worry, and PTSD related to a changing climate (Tunstall et al., 2006; Lowe et al., 2013; Dodgen et al., 2016; Clayton et al., 2017). The literature also suggests that women tend to be at greater risk from climate changes as a result of gender-based marginalization (Fletcher & Knuttila, 2016; Williams et al., 2018). In particular, women tend to be in caregiving roles, which are typically undervalued and underpaid, and, in these roles, women are at greater risk of experiencing compassion fatigue, particularly during periods of exposure (or vicarious exposure) to climate hazards (Hayes, 2019). Pacheco (2020) also highlights that pregnant people are at greater risk of heat-induced illnesses and nutritional deficiencies, which are exacerbated by climate-related heat events and food insecurity.

Studies indicate that men also experience mental health impacts of climate change. For example, Cunsolo Willox et al.'s (2012) work in Northern Inuit communities in Nunatsiavut found that middle-aged men often suffered the most from changing environmental conditions because they were unable to provide food for family and community, with resulting negative effects on sense of place and identity (Durkalec et al., 2015). Further, as discussed previously, there is an increased risk of suicide among male farmers during times of drought (Hanigan et al., 2012). It is important to consider the role of gender-based socialization related to seeking mental health care (Tunstall et al., 2006). The literature suggests that the issue may be less about who is affected and more about who is socialized to engage in help-seeking behaviours and who has access to mental health services (Tunstall et al., 2006; Alston & Kent, 2008; Berry et al., 2011; Polain et al., 2011; Granham, 2015).

4.5.3 Children, Youth, and Older Adults

Children, youth, and older adults tend to be at greater risk from the psychosocial impacts of a changing climate because they are more dependent on others to maintain their health and well-being (Lowe et al., 2013; Clayton et al., 2014). Limited evidence suggests that pregnant people exposed to climate change stressors may have children with increased risks of intrauterine growth retardation, low birth weight, and prematurity (Pacheco, 2020). Among other types of long-term adverse effects, climate change may lead to

4 In Western science, sex is typically considered binary (male and female), which overlooks intersex individuals. Gender refers to the socially constructed roles assigned to men and women. In Western science, gender is commonly conflated with sex, and presented as binary (man and woman), overlooking non-binary individuals.

psychosocial impacts, such as attention deficit hyperactivity disorder, autism spectrum disorder, and other neurodevelopmental disorders; cognitive deficits; mood disorders; and schizophrenia (Pacheco, 2020).

Experiences of anxiety and feelings of impending doom related to climate change can also affect children (Tucci et al., 2007; Fritze et al., 2008; Ojala, 2012). A survey of Australian children by Tucci et al. (2007) noted that one in four children were so concerned about the global threat of climate change that they believed the world would end before they reached adulthood. Children may also be at increased risk of long-term trauma and anxiety from extreme weather events (Simpson et al., 2011: Brown et al., 2019; Roberts et al., 2019). The concerns of children and youth over climate change may be more prevalent because they think more about their future, they have less agency and control in their lives and behaviours, and they have more time to focus on the issue (Ojala, 2012; Clayton, 2020).

4.5.4 Low Socio-Economic Populations and the Homeless

People living with low socio-economic status are at higher risk of the health impacts of climate change (see Chapter 9: Climate Change and Health Equity), including effects on mental health. For example, homeless people tend to live in urban and suburban areas where there is greater exposure to extreme temperatures, which can disproportionately affect people with pre-existing mental health conditions who have difficulty with thermoregulation (Dodgen et al., 2016). People who are homeless are at greater risk of vector-borne diseases because they spend large portions of time outdoors in precarious weather and in areas where host vectors may be more prevalent (Dodgen et al., 2016). Vector-borne diseases, such as West Nile virus and Lyme disease, may compound mental health issues for people with pre-existing mental health illness by contributing to cognitive, neurological, and mental health problems (Dodgen et al., 2016). While the current base of research on the mental health implications of climate change among the homeless and those living with low socio-economic status in Canada is limited, socio-economic status is recognized as a predictor of poor mental health outcomes (Hudson, 2005).

4.5.5 People with Pre-Existing Health Conditions

People with pre-existing health conditions, including mental health issues, are at greater risk for the mental health impacts of a changing climate (Cusack et al., 2011; Dodgen et al., 2016). For example, in the U.S., veterans with mental illness were 6.8 times more likely to suffer from exacerbated mental illness after Hurricane Katrina compared to veterans with no pre-existing mental health conditions (Dodgen et al., 2016). Further, people with severe mental illness are extremely vulnerable during climate hazards, and their needs can often be overlooked in emergencies (Jones et al., 2009). Individuals with pre-existing mental health issues are at increased risk for other morbidities and mortality. Mental health care and social resources to support well-being (such as support groups) are required during and after climate hazard exposures among this target population.

4.5.6 Occupational Groups

People whose occupations are primarily outdoors, or whose economic livelihoods depend on the health of the land and environment, are at greater risk for psychosocial impacts of climate change (Fritze et al., 2008; Costello et al., 2009; Berry et al., 2010a; Clayton et al., 2014; IPCC, 2014). Outdoor labourers who tend to be most at risk include fishers, herders, hunters, and trappers, and people in the tourism industry (Fritze et al., 2008; Costello et al., 2009; Berry et al., 2010a; Clayton et al., 2014; IPCC, 2014).

As climate change affects traditional, resource-based industries and workers who rely on these industries for their livelihoods, these workers may experience emotional distress related to job insecurity. There is anecdotal evidence to suggest that people working in resource-based industries in Alberta, for example, are presenting with severe emotional distress as they contemplate the collapse of the traditional sectors in which they have worked (Mouallen, 2015). Limited evidence also suggests that ecoanxiety can affect people working in the fields of climate science, environmental science, and public health (Clayton, 2018; Pihkala, 2020).

Another occupational group that tends to disproportionately experience the psychosocial impacts of a changing climate are first responders who support health response efforts after extreme events (e.g., hurricanes, floods, wildfires) (Carleton et al., 2017). Dodgen et al. (2016) noted that PTSD rates among first responders range from 13% to 18% four years after responding to an extreme weather event.

4.6 Projected Mental Health Risks and Economic Costs

4.6.1 Projected Mental Health Risks from Climate Change

There are no known studies in Canada that project the mental health impacts of climate change. However, one study projected the mental health outcomes of climate change under future climate scenarios, focusing on suicide rates related to warming tempearatures in the U.S. and Mexico. Burke et al. (2018) estimated that increased warming by 2050 (under the RCP8.5 scenario) could result in a combined 9000 to 40,000 additional suicides in the U.S and Mexico. For a 1°C increase in monthly average temperatures, mortality by suicide increased by 21% in Mexico and 0.7% in the U.S. (Burke et al., 2018).

In the absence of greater adaptation efforts, the current burden of mental ill health in Canada is likely to rise because many climate-related hazards associated with mental health outcomes are expected to increase in severity and frequency (Bush & Lemmen, 2019; Hayes et al., 2019). As previously noted, the Mental Health Commission of Canada reports that 7.5 million people in Canada experience mental health problems every year (MHCC, 2017). Given the very large number of Canadians who experience mental health problems, the potential increase of illness from future climate change is large.

4.6.2 Projected Economic Costs of Health Impacts

There are no known studies documenting the projected economic costs of the mental health impacts related to climate change in Canada. It is estimated that 500,000 people in Canada miss work every week due to mental health issues, which costs the Canadian economy approximately $51 billion annually. Psychiatric conditions are the second most expensive health care expenditure in Canada, following closely behind expenditures for cardiovascular disease (CAMH, 2012; PHAC, 2014). Given the high costs of psychiatric conditions to the health system and society, and given the breadth of mental health impacts that can be related to climate change, future costs borne by Canadians are expected to be large as the climate continues to warm.

4.7 Adaptation to Reduce Risks

Adaptation measures can be effective in reducing the mental health impacts of climate change (Dodgen et al., 2016). This section provides an overview of the roles and responsibilities of officials, within and outside the health sector, for enhancing mental health in a changing climate. It discusses current policies and programs to reduce mental health risks, including new and innovative approaches for the monitoring and surveillance of the mental health impacts of climate change, efforts to support youth, and interventions that encourage interactions with nature. Barriers and opportunities for adaptation action are also presented, as well as the co-benefits of addressing climate change that can benefit mental health.

4.7.1 Roles and Responsibilities for Adaptation to Reduce Risks

Adapting to reduce the mental health impacts of climate change requires intersectoral and transdisciplinary actions rooted in integrated and coordinated support and care (Stanke et al., 2012; Hayes et al., 2019). The disciplines that should be involved include a range of health professionals, such as:

- physicians, nurses, mental health specialists (e.g., psychiatrists, psychologists, psychotherapists);
- allied health professionals (e.g., public health workers, pharmacists, social workers, community mental health workers); and
- emergency preparedness professionals (e.g., first responders).

The most effective support for mental health may be through mental health care professionals and formal services such as therapies, counselling, and/or psychotropic medications (Hayes et al., 2018a). For many, mental illness or emotional distress is still highly stigmatized, and people may prefer to support their well-being through informal family or community supports and networks entirely unrelated to formal mental health care (Rodriguez & Kohn, 2008). As a consequence, people may rely on services and supports offered informally, such as exercise, arts-based activities, or groups that provide an enhanced sense of community (Hayes et al., 2018a). There are also a variety of cultural approaches to mental health care that people may rely on — for example, land-based healing practised by many Indigenous Peoples, which brings people out on the land to create, craft, cook, share stories, and connect with the land and with culture (Radu, 2018).

4.7.2 Policies and Programs that Reduce Risks

There are a range of interventions to address the psychosocial impacts of climate change, including policy-level responses, programs, and practices, community-based approaches, and other strategies for providing mental health services and supports (Table 4.2). Psychosocial health refers more broadly to the social and psychological components that shape well-being, and mental health is one aspect of the broader definition of psychosocial health. The following sections highlight the broader range of adaptation interventions supporting psychosocial health (Clayton et al., 2017; Hayes & Poland, 2018; Hayes et al., 2018a).

Table 4.2 Examples of policy and program responses as well as medical interventions and practices to address the psychosocial impacts of climate change

POLICY AND PROGRAM RESPONSES
• Improved access to, or funding for, mental health care • Economic assistance to reduce economic strain, which is a key stressor for people experiencing climate hazards • Climate change resilience plans that address psychosocial well-being • Climate change and health vulnerability and adaptation assessments that include examination of mental health vulnerabilities and adaptation options
MEDICAL INTERVENTIONS AND PRACTICES
• Specific therapies or medications provided by mental health care professionals • Specific behavioural interventions such as cognitive behavioural therapies, mindfulness-based practices, or ecological grief programs • Specialized training for community members in psychological First Aid or mental health First Aid • Mobile mental health interventions • Walk-in mental health care interventions • Resource guides for professionals and the public on addressing the mental health outcomes related to climate change

4.7.2.1 Monitoring and Surveillance of Mental Health Impacts

The *Toolkit for Post-Disaster Surveillance of Impacts on Mental Health* developed by the National Institute of Public Health of Quebec provides guidance to public health officials on monitoring the mental health impacts of major disasters during the recovery phase, which can last months to years after an extreme event (Canuel et al., 2019). This toolkit includes specific data collection instruments to evaluate the mental health impacts of exposures to climate-related hazards. In addition, novel approaches have been, and are being, developed in Indigenous communities to gain a better understanding of the psychosocial impacts of climate change (Box 4.3).

Box 4.3 eNuk environment and health monitoring program

It's... making sure that we have, we still have things in the future that we have now and we can still use them the same way. Understanding the fact that things are gonna change, ice is gonna change, weather's gonna warm up, but make sure that we are [protecting our environment], what we can protect now we should continue to protect.

Resident of Rigolet, Nunatsiavut, Labrador

Climatic and environmental changes present major challenges for human health in Inuit Nunangat (Inuit homelands) and Northern Canada (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). In particular, because of their close connection to and reliance on the land for sustenance, culture, livelihoods, and well-being, Inuit throughout the North have identified negative impacts on physical and mental health in their communities. While research has uncovered many connections among environment and health outcomes, detecting these outcomes and responding to them is a serious challenge. Community-led, comprehensive, and sustainable surveillance and monitoring systems to assist with climate-health adaptation that can yield timely and usable data, and provide decision-making strategies for communities and governments, are needed.

The Rigolet Inuit Community Government, the Nunatsiavut Department of Health and Social Development, and a team of Inuit and non-Inuit researchers have been working with the community of Rigolet, Nunatsiavut, Labrador, Canada to develop and implement the eNuk program, an Inuit-designed and -developed participatory environment and health surveillance system (The eNuk Program, 2018). Premised on Inuit values, knowledge systems, sciences, and priorities, the eNuk app is designed to track, analyze, and respond to the health impacts of climate change, including impacts on mental health (Sawatsky et al., 2018; Sawatsky et al., 2020).

Inuit can use this app to take pictures and videos, insert text, and document the safety of ice routes and culturally important places for hunting, fishing, and berry picking. App users can also insert health-related information, including mental health indicators related to shifting environmental patterns; impacts on sense of place, cultural continuity, food security, and challenges to identity; emotional responses, such as ecological grief and anxiety; and acute and chronic mental health outcomes. Information from the app will provide information about climate change impacts on mental and physical health, and allow health professionals and decision makers to respond to local needs. The eNuk app is in a preliminary pilot phase (Sawatsky et al., 2018; The eNuk Program, 2018; Sawatsky et al., 2020).

4.7.2.2 Supporting Youth

Youth can be particularly vulnerable to experiences of anxiety, grief, and stress related to climate change, including ecoanxiety and ecogrief. Ray (2020) refers to youth born between the 1990s and the 2000s as "the climate generation," because of their exposure to the climate crisis over their lives. The *Field Guide to Climate Anxiety: How to Keep Your Cool on a Warming Planet* (Ray, 2020) is aimed at youth and provides a number of resources for dealing with climate change, including:

- tools to address burnout related to climate activism and the climate crisis;
- techniques to make sense of the climate crisis and to find purpose and meaning in addressing it;
- strategies to enhance collective and individual resilience;
- tools to address potentially negative impacts of climate change media coverage; and
- tips on how to infuse climate justice work with joy, humour, and optimism.

The field guide places individual and collective well-being, along with social and environmental justice, at the centre of these actions. Supporting the well-being of children and youth in their efforts to cope with the impacts of climate change has also been the focus of some Indigenous communities and organizations. Box 4.4 highlights how two organizations from three Island Lake First Nations exposed to a wildfire came together to support the well-being of children.

Box 4.4 Ka Pimthatek Pakthehnamoowin, a journey of hope in Island Lake, Manitoba

In August 2017, approximately 3700 people from three Island Lake First Nations were forced from their homes by a 77,000 hectare wildfire. The entire community of Wasagamack First Nation, as well as residents of St. Theresa Point and Garden Hill First Nations, were evacuated by boat and plane to Brandon and Winnipeg, Manitoba, to stay in hotels. While in evacuation centres in the south, children were subject to discrimination, predatory drug dealers, and separation from parents.

Following this experience, Four Arrows Regional Health Authority, a regional organization focused on improving health outcomes for the Island Lake membership, collaborated with Save the Children, a child-rights organization, to support child-focused mental health in response to the fires, and to prepare for future climate extremes and disasters. Through this partnership, the two organizations:

- trained over 100 frontline workers on addressing the unique needs of children in emergencies, helping children in crisis, and implementing psychological First Aid;
- trained over 100 frontline workers on the importance of self-care through "care for caregivers" workshops; and
- distributed emergency backpacks full of supplies to 2000 children to keep them safe during emergencies.

Through this process, it was observed that children were struggling with the wide-reaching implications of climate change and the emotional impacts of the 2017 evacuation. Children were exhibiting increased externalizing behaviours and were also living in challenging contexts of the opioid crisis, theft, domestic violence, and a lack of safe housing.

To support the emotional resilience of children in response to these challenges, the two organizations worked to create an evidence-based psycho-educational program that builds resilience and coping skills in safe small-group settings. The program sought to enhance the resilience of children, adolescents, and their caregivers in St. Theresa Point First Nation in response to, and in preparation for, climate extremes and disasters.

4.7.2.3 Interactions with the Natural Environment

Much of the current literature exploring new and innovative approaches to addressing the psychosocial impacts of climate change highlights the importance of interactions with the natural environment. Interactions that include practices that preserve the natural environment provide people with a sense of stewardship and personal investment that may help overcome feelings of hopelessness, anxiety, and ecoparalysis. One environmental clinic treated "impatients," people who were emotionally and physically tired of waiting for legislative interventions on climate change, with "prescriptions" for environmental action (Koger et al., 2011). The clinic provided students with problem-focused coping strategies that increase well-being through environmental activism (Koger et al., 2011).

Spending time in nature has also been linked with enhanced physical and psychosocial health (Ulrich, 1979). A common practice in Japan to reduce stress and anxiety is shinrin-yoku ("forest bathing") — a way of connecting deeply with nature. In a study by Lee et al. (2011), authors found that forest bathing resulted in decreased cortisol levels and pulse rates and significantly increased positive feelings.

Indigenous communities have traditionally found psychosocial enhancement through land-based healing practices (Cunsolo Willox et al., 2012; Cunsolo Willox et al., 2013a; Cunsolo Willox et al., 2013b; Petrasek MacDonald et al., 2015; Cunsolo & Ellis, 2018; Middleton et al., 2020a). Land-based healing provides space and opportunity for community members to come together, to learn and impart knowledge about land-based culture and knowledge, and to enhance a sense of community, all of which increase psychosocial well-being (Kirmayer & Valaskakis, 2009; Radu et al., 2014).

Other proposed approaches to build the human–nature relationship that supports psychosocial well-being include ecopsychology, the branch of environmentalism that integrates psychology to support psychosocial well-being and planetary health, and deep ecology practices, which provide people with opportunities to integrate meditative practices in nature to calm the mind and body while building a relationship with nature (Bragg & Reser, 2012). Many new therapies still need to be evaluated for their effectiveness in reducing the psychosocial impacts of climate change.

4.7.3 Co-Benefits of Addressing Climate Change that Improve Mental Health Outcomes

Greenhouse gas mitigation and adaptation actions to address climate change can produce significant health co-benefits (see Chapter 10: Adaptation and Health System Resilience), including benefits to mental health (City of Toronto, 2019). For example, increasing opportunities in a community for active transportation (e.g., walking, jogging, and biking) have been shown to reduce depression and improve moods (Koger et al., 2011; Whitfield et al., 2017). In addition, community-based environmental stewardship projects that support adaptation and/or efforts to mitigate greenhouse gases can enhance a sense of social cohesion and thus support psychosocial well-being (Koger et al., 2011). Increasing green infrastructure is also an important strategy to mitigate greenhouse gases and adapt to climate change that has been demonstrated to reduce urban heat islands, improve physical health, and support mental well-being (Zupancic et al., 2013; Huang et al., 2017; Health Canada, 2020).

4.7.4 Barriers and Opportunities for Adaptation Actions

Psychosocial adaptation to the effects of climate change is influenced by a number of factors that may be protective of psychosocial health when they are in place and may hinder psychosocial health when they are absent. These include (Hayes et al., 2019):

- social capital;
- sense of community;

- communication and outreach;
- intersectoral and transdisciplinary collaboration;
- community preparedness;
- government interventions;
- access to resources (financial and physical);
- mental health literacy;
- culturally relevant resources and responses;
- health care training; and
- vulnerability and adaptation assessments.

Figure 4.2 presents factors that influence the psychosocial health impacts of climate change, illustrating how these impacts are mediated by the social and ecological determinants of health, response interventions, and the factors previously identified that influence psychosocial adaptation. While specific Indigenous determinants of health such as food insecurity, colonialism, racism and social exclusion, self-determination, and environmental stewardship are not included in this figure, it is recognized that they are integral to understanding the factors that influence the psychosocial health of Indigenous Peoples experiencing the effects of climate change.

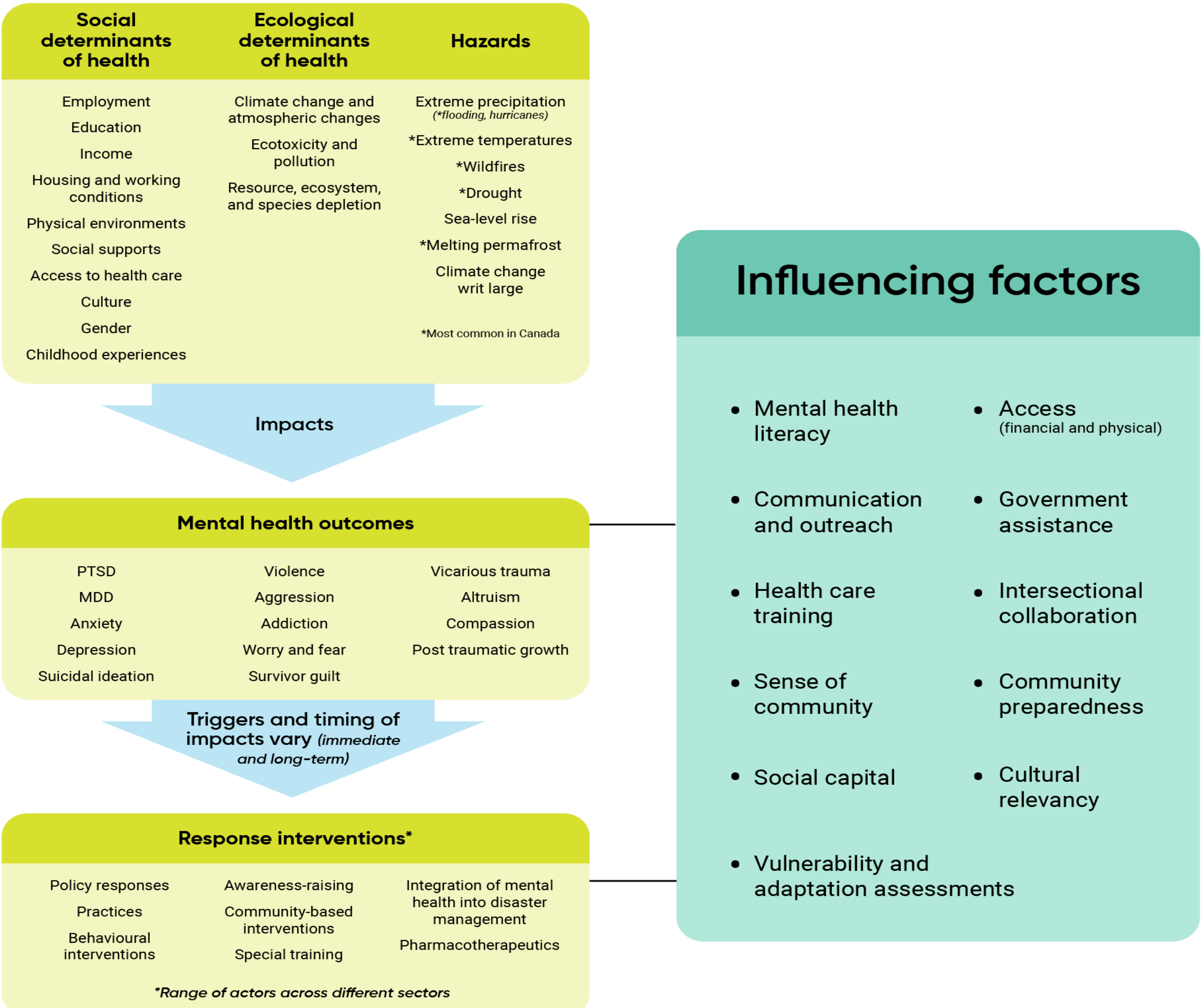


Figure 4.2 Factors that influence the psychosocial health impacts of climate change. Source: Hayes et al., 2019.

4.7.4.1 Social Capital

Social capital refers to the "networks and resources available to people throughout their connections to others" (Aldrich, 2012, p. 172). Two important dimensions of social capital include the structural dimension, in which people engage and interact in activities, and the cognitive dimension, which encompasses perceptions about trust, social cohesion, and reciprocity (e.g., a sense of community) (Berry et al., 2010b; Aldrich, 2012). Essentially, social capital is both the networks and relationships people form to support one another, as well as perceptions about these networks and relationships. Social capital is of paramount importance in post-disaster recovery, even when compared with economic or other types of assistance (Aldrich, 2012).

Social capital may serve as a protective factor for farmers affected by wildfires and drought. The "Hay West" movement, for example, demonstrated how social capital is not bound by a single geographic location but can benefit farm workers across the country. In 2002, drought-affected Prairie farmers received 64,000 hay bales from farmers in Eastern Canada, who understood the plight of those affected by the drought and sought to support one another (Yusa et al., 2015). Social capital was also identified as an important protective factor in decreasing the risk of suicide among adult female farmers during periods of prolonged or worsening drought in Australia (Hanigan et al., 2012).

4.7.4.2 Sense of Community

A sense of community refers to feelings of belonging and is often referred to as the opposite of feeling isolated (Bajayo, 2012). A sense of community is particularly important when addressing the mental health impacts of climate change, because it can provide space to explore and discuss challenging emotions such as ecological grief and ecoparalysis. Resources that enhance a sense of community have been developed to support people experiencing emotions such as ecoanxiety. For example, the "Ecoanxious" website was created to make people feel less alone in their fears about the climate crisis (Malena-Chan & Gatley, 2020). This forum offers people the opportunity to share their stories of ecoanxiety, learn from others' experiences, and practise guided meditation (Malena-Chan & Gatley, 2020). The website "Is This How You Feel?" provides an online platform for people to explore how climate change makes them feel ("Is This How You Feel?", 2020). Additionally, the Good Grief Network, which is a 10-step program to support individuals and communities as they explore and address ecogrief, connects people to build "personal resilience while strengthening community ties" (Schmidt & Lewis-Reau, 2020). The network provides specific tools that can help address the negative impacts of ecogrief, including denial, hopelessness, helplessness, activism fatigue, and burnout (Schmidt & Lewis-Reau, 2020) "Climate and Mind" is a U.S.-based online repository of research and resources for addressing climate-related distress, including a listing of mental health professionals who can support people (Bryant, 2020). This site offers guidance on how to host climate cafés or climate circles, which are informal community gatherings that offer people the opportunity to share and explore feelings of ecoanxiety, ecological grief, and climate-related distress while building a community of support (Bryant, 2020). All of these resources emphasize the importance of fostering a sense of community to support psychosocial resilience.

4.7.4.3 Communication and Outreach

It is important that messages about the mental health impacts of climate change include actions to support psychosocial well-being (Clayton & Manning, 2018; King et al., 2018). Messages about impending climate risks alone may invoke more fear and anxiety in people, in particular among those with pre-existing mental health issues, and may contribute to mental health problems (Dodgen et al., 2016). Messages that trigger fear may also increase avoidance behaviours; that is, people may feel so overwhelmed that they disengage and avoid messages about climate change as a way to cope (Stern, 2012). Pairing messages about risks from climate hazards with messages about what, where, and how people can support their well-being may help people to feel more empowered and in control of their wellness (Maibach et al., 2011). Trusted sources for this information include health professionals, meteorologists, climatologists, and governments (Zhao et al., 2014). A good example of a communication product is presented in Figure 4.3. This image highlights that ecological grief and anxiety associated with climate change are increasing and identifies health sector responses that can reduce emotional suffering and build resilience.

Figure 4.3 Ecological grief and anxiety: the start of a healthy response to climate change? Source: Cunsolo et al., 2020; Image credit: Alex Sawatzky.

4.7.4.4 Intersectoral and Transdisciplinary Collaboration

Intersectoral and transdisciplinary collaboration is key to supporting adaptation to the psychosocial impacts of a changing climate (Morrisey & Reser, 2007; Stanke, 2012; Hayes et al., 2019). Mental health care professionals, along with other health and allied health professionals, provide mental health care on the front lines during extreme weather events and disasters. In addition, community groups, faith-based and spiritual institutions, and non-governmental organizations provide a sense of community and support for people experiencing psychosocial outcomes. Emergency preparedness professionals also support adaptation, particularly during these events. The mental health and wellness of these professionals can be seriously affected, as they tend to be more exposed to hazardous events (Carleton et al., 2017). Enhanced collaboration across disciplines and sectors can increase the effectiveness of adaptations to reduce the psychosocial impacts of climate change (Hayes et al., 2020).

4.7.4.5 Government Interventions and Access to Resources

Access to mental health care and social services that support psychosocial health can reduce negative mental health outcomes (MHCC, 2016; Thompson et al., 2018). These resources may include mental health care from medical professionals, or informal support from community-based groups; access to these resources, however, may be affected or disrupted by climate hazards (Hayes et al., 2019).

Government interventions that enhance access (both financial and physical) to psychosocial resources are foundational for enhancing mental health care (Polain et al., 2011; MHCC, 2016; Hayes et al., 2019). Canada's universal, single-payer health system may not cover many mental health care services, and mental health services vary by province, territory, and region (Goldner et al., 2016). Additionally, although many First Nations and Inuit receive a range of mental health services and supports free of charge as part of the Non-Insured Health Benefits Program, many do not have access to them (Government of Canada, 2020).

Provinces and territories provide outpatient physician services (e.g., primary care and psychiatry) and in-patient mental health care at hospitals. Allied professionals (e.g., nurses, social workers, counsellors, psychotherapists) are often provided at no charge during in-patient care; however, these services may include a fee when they are delivered as outpatient services. Many people in Canada, therefore, may need to pay for mental health services directly or through private insurance in order to access such services (Goldner et al., 2016). Some people may not be able to access mental health care due to financial constraints or simply because there are no mental health care facilities to access (Moroz et al., 2020). The unequal access of some populations in Canada to mental health care services increases their vulnerability to climate change impacts. Enhanced and equitable access to mental health care could improve mental health outcomes in a changing climate.

4.7.4.6 Mental Health Literacy and Mental Health Care Training

There is significant stigma surrounding mental ill health and mental health service use in Canada (Tam, 2019). This barrier can reduce the number of people who seek help for their mental health needs related to the effects of climate change. Developing mental health literacy among the general public can help to reduce this stigma and encourage people who are struggling with the mental health impacts of climate change to seek care (Hayes et al., 2019). Mental health literacy refers to the knowledge of mental health outcomes, factors that influence mental health outcomes, and mental health care management and options (Davis, 2013). psychological First Aid and mental health First Aid can enhance mental health literacy, by providing guidance and training on how to support people experiencing mental distress.

Efforts to reduce the mental health impacts of climate change include training public health and emergency management officials. Training should focus on the activities required following a disaster, advocated by Neria and Shultz (2012):

- promoting a sense of safety;
- calming anxiety and decreasing physiological arousal;
- increasing self-efficacy and collective efficacy;
- encouraging social support and bonding with others; and
- instilling hope to promote a sense of a positive future.

The application of these approaches may enhance mental health literacy and reduce long-term psychosocial impacts from climate change, especially among populations who experience disproportionate health burdens (Neira & Schultz, 2012).

4.7.4.7 Culturally Relevant Resources and Responses

Adaptation efforts that support psychosocial health need to use culturally relevant and locally appropriate resources. For example, in Canada, increased availability of mental health care is needed in rural farming communities to help reduce impacts from drought. Such care should also be provided by individuals with knowledge of, and experience in, agriculture and should be designed with attention to gendered dimensions that create different experiences for farm men and women (Fletcher & Knuttila, 2016).

Reducing the mental health impacts of climate change in First Nations, Inuit, and Métis communities also requires culturally relevant resources (MHCC, 2016). For example, responding to the mental health and cultural safety needs of Indigenous Peoples following community evacuations from floods and fires requires integrating the First Nations Mental Wellness Continuum[5] among first responders providing assistance to displaced First Nations populations. It also requires cultural competency training for emergency response personnel, law enforcement, and disaster management specialists at provincial and federal levels (Health Canada, 2015). There is also a need to enhance awareness and support of land-based healing practices relevant to Indigenous communities (Polain et al., 2011; Harper et al., 2015). Noting this, the Yukon's Climate Change Secretariat report on adaptation actions identified strengthening mental health resources and building or enhancing programs that support Indigenous Peoples' reconnection to the land as a top priority (Government of Yukon, 2017).

5 The First Nations Mental Wellness continuum is a culturally relevant framework that supports service coordination and delivery of mental wellness services that are relevant to First Nations Peoples in Canada (Health Canada, 2015).

4.7.4.8 Community Preparedness Utilizing Vulnerability and Adaptation Assessments

Community preparedness to support psychosocial health in the aftermath of climate-related hazards, and to prevent the occurance of impacts in the first place, is highly dependent upon a thorough understanding of the risks and vulnerabilities related to community-level climate hazards and an assessment of adaptation opportunities (Morrissey & Reser, 2007; Hayes et al., 2019). For this reason, many communities throughout Canada have conducted climate change and health vulnerability and adaptation assessments (V&As) (see Chapter 10: Adaptation and Health System Resilience). These assessments, often conducted by local, provincial, and territorial health authorities, or Indigenous communities, increase understanding of current and projected impacts of climate change on health, populations most at risk, and adaptation options.

V&As are useful tools to obtain information needed to address the mental health impacts of climate change; however, few V&As incorporate mental health indicators. Hayes and Poland (2018) provide a set of indicators and measurement tools that can be used to analyze climate change impacts on mental health (Table 4.3).

Table 4.3 Monitoring and measuring climate change impacts on mental health

CLIMATE HAZARD	POPULATIONS AT INCREASED RISK	POTENTIAL MENTAL HEALTH OUTCOMES	INDICATORS AND MEASUREMENT TOOLS
Extreme Heat	• People with pre-existing mental health conditions • People taking psychotropic medications that affect thermoregulation • Older adults (who have poor thermoregulation) • People with substance use disorders • People living in urban heat islands • Urban poor without access to air conditioning • People who are homeless • Workers exposed to heat and people active outdoors	• Exacerbated mood or behavioural disorders • Violence • Aggression • Suicide	• Monitor emergency department visits after extreme heat events for an increase in patients reporting mood or behavioural disorders • Monitor mortality statistics following extreme heat events — look for co-morbidities related to mental health and incidents of suicide • Interviews or questionnaires with people who experienced extreme heat events to ask about their mental health in relation to heat events • Review police records following extreme heat events to monitor elevated incidents of violence or aggression

CLIMATE HAZARD	POPULATIONS AT INCREASED RISK	POTENTIAL MENTAL HEALTH OUTCOMES	INDICATORS AND MEASUREMENT TOOLS
Extreme Weather Event (flood, hurricane, drought, mudslides, etc.)	• Gender (women) • Sex (female, particularly pregnant women) • Age (children, infants, older adults) • Race and ethnicity (non-White) • Immigrants • People with pre-existing health conditions • People with low socio-economic status • People who are under- and non-insured (health care and home insurance) • People who are homeless • Outdoor labourers • First responders • First Nations, Inuit, Métis	• Post-traumatic stress disorder (PTSD) • Depression (including major depressive disorders) • Anxiety • Suicidal ideation • Aggression • Substance abuse and addiction • Violence • Survivor guilt • Vicarious trauma • Altruism • Compassion • Post-traumatic growth	Surveys • Self-report surveys of general health. Consider using: » General Health Questionnaire (GHQ) • Self-report surveys of mental illness and mental problems. Consider using any, or a combination of: » Disaster-PAST » Generalized Anxiety Disorder Scale (GAD-7) » Post-Traumatic Stress Disorder Checklist (PCL) » Center for Epidemiologic Studies Depression Scale (CES-D) » Kessler Psychological Distress Scale (K6; K10) » Brief Trauma Questionnaire • Self-report surveys of affirmative mental health. Consider using: » Stress-Related Growth Scale (SRGS) » Post-Traumatic Growth Index (PTGI) » Benefit Finding Scale (BFS) Review patient records

CLIMATE HAZARD	POPULATIONS AT INCREASED RISK	POTENTIAL MENTAL HEALTH OUTCOMES	INDICATORS AND MEASUREMENT TOOLS
Extreme Weather Event (flood, hurricane, drought, mudslides, etc.) (continued)			Monitor emergency department visits after extreme weather events for an increase in patients reporting mental health problems or illness Review new prescription use for mental health and behavioural disorders after an extreme weather event Interviews • Interviews with primary care physicians and mental health care providers about any surges in patients reporting mental health issues following extreme weather events • Interviews with people who experienced an extreme weather event about their perceptions regarding their mental health related to the event
Vector-Borne Disease (VBD) (e.g., Lyme disease, West Nile virus)	• People who are homeless • People with pre-existing mental health conditions • Outdoor workers • Recreationalists (hunters, fishers, outdoor enthusiasts)	• VBD disease, particularly Lyme disease or West Nile virus, that can compound mental health problems (e.g., cognitive or neurological impairment, behavioural disorders)	• Interviews or questionnaires with patients who have been diagnosed with VBDs to ask about perceptions of their mental health • Interviews with primary care physicians and mental health care providers about any mental health co-morbidities for patients diagnosed with VBDs

CLIMATE HAZARD	POPULATIONS AT INCREASED RISK	POTENTIAL MENTAL HEALTH OUTCOMES	INDICATORS AND MEASUREMENT TOOLS
Sea-Level Rise or Melting Permafrost	• People who work or live near the ocean (sea-level rise) or in the Arctic • Outdoor labourers • First Nations, Inuit, Métis	• Anxiety, worry, or fear of displacement • Anxiety, worry, or fear of job loss • Loss of place (grief, solace	• Interviews or questionnaires with residents who have experienced or are experiencing sea-level rise or prolonged drought in their communities. Interview questions may focus on the mental health implications of: displacement, job loss associated with sea-level rise, infrastructure damage, agricultural or resource loss and resource scarcity, as well as food and water safety and security
Climate Change Overall (i.e., awareness of climate change threats to human and planetary health and survival)	• People at greater risk from and exposure to climate change • Researchers investigating climate change • Environmental and climate change activists • Environmental studies students • Outdoor recreationalists • First Nations, Inuit, Métis	• Anxiety • Worry • Stress • Fear	• Interviews or questionnaires with people who experience concern, anxiety, worry, related to awareness of climate change threats • Generalized Anxiety Disorder Scale (GAD-7)

Source: Adapted from Hayes & Poland, 2018

4.8 Knowledge Gaps

A number of knowledge gaps currently challenge efforts by public health authorities to develop effective adaptation measures to reduce the mental health impacts of climate change. There are limited population-level studies on climate change impacts on mental health within Canada and globally. Greater information from such studies on the key factors that increase risks of impacts on Canadians would help inform future adaptation efforts. Specific knowledge gaps include:

- the mental health impacts of climate change on specific population groups experiencing health inequities, including people of colour and racialized groups, those discriminated against because of sexual orientation or identity, and those discriminated against based on their mental or physical health;
- the mental health complications of vector-borne diseases in Canada;
- affirmative mental health outcomes, such as psychosocial resilience, altruism, and compassion after experiencing climate hazards, which can enhance our understanding of psychosocial adaptation;
- the mental health impacts of cold temperature climate hazards, such as impacts from a polar vortex;
- projections of the impacts of climate change on mental health under different climate scenarios;
- an evaluation of the economic costs of the mental health impacts of climate;
- the effectiveness of psychosocial adaptation opportunities to a changing climate;
- the availability and effectiveness of psychosocial interventions from a health equity perspective; and
- how awareness and communication activities about the climate change problem affect social-emotional responses, such as anxiety, fear, grief, and worry.

Increased surveillance and monitoring of the impacts of climate change on the burden of mental illness in Canada are also needed. This includes monitoring and surveillance of the mental health implications of acute and slow-onset hazards related to climate change at the local, regional, and national levels.

The literature on adaptation also highlights the importance of traditional ecological knowledge, which is foundational in adaptive management strategies and in supporting Indigenous Peoples' abilities to cope within a changing climate (Tam et al., 2013; Williams et al., 2018). Greater research is needed that highlights the importance of Indigenous wisdom in adapting to the psychosocial impacts of climate change.

4.9 Conclusion

Climate change affects the mental health and well-being of many people in Canada. In particular, climate change disproportionately and inequitably affects the mental health and well-being of specific populations, including those experiencing health inequities based on race, culture, gender, age, socio-economic status, ability, and geographic location. Importantly, there are a number of existing programs, interventions, and policies that can support people in Canada as they adapt to a changing climate as well as factors that can influence and enhance psychosocial adaptation. While further work is needed to build on existing research, programs, interventions, and policies to address knowledge and practice gaps related to mental health in a changing climate in Canada, there are existing tools and programs that can enhance and support psychosocial adaptation.

4.10 References

AbacusData. (2019). *Public opinion research: Climate emergency polling (Summer 2019). National Survey of 2,000 Canadians. Retrieved from* <https://abacusdata.ca/wp-content/uploads/2019/08/Climate-Emergency-Polling-July-2019-RELEASE.pdf>

Adlard, B., Donaldson, S. G., Odland, J. O., Weihe, P., Berner, J., Carlsen, A., … Mulvad, G. (2018). Future directions for monitoring and human health research for the Arctic Monitoring and Assessment Programme. *Global Health Action*, *11*(1), 1–4. <https://doi.org/10.1080/16549716.2018.1480084>

Agnew, R. (2012). Dire forecast: A theoretical model of the impact of climate change on crime. *Theoretical Criminology*, *16*(1), 21–42. <https://doi.org/10.1177/1362480611416843>

Agyapong, V. I., Hrabok, M., Juhas, M., Omeje, J., Denga, E., Nwaka, B.,... & Chue, P. (2018). Prevalence rates and predictors of generalized anxiety disorder symptoms in residents of Fort McMurray six months after a wildfire. *Frontiers in psychiatry*, 9, 345. <https://doi. org/10.3389/fpsyt.2018.00345>

Albrecht, G. (2011). Chronic environmental change: Emerging "psychoterratic"syndromes. In I. Weissbecker (Ed.), *Climate Change and Human Well-being*. New York, NY: Springer.

Albrecht, G. (2012). Psychoterratic conditions in a scientific and technological world. In P. Kahn, & P. Hasbach (Eds.), *Ecopsychology: Science, Totems, and the Technological Species* (pp. 241-264). MIT Press.

Albrecht, G. (2017). *Climate change and human responses* (G. Monks, Ed.). Dordrecht, Netherlands: Springer. Retrieved from <https://link.springer.com/book/10.1007%2F978-94-024-1106-5>

Albrecht, G. A. (2019). *Earth Emotions: New Words for a New World*. Ithaca, NY: Cornell University Press.

Alderman, K., Turner, L. R., & Tong, S. (2012). Floods and human health: A systematic review. *Environment International*, *47*, 37–47. <https://doi.org/10.1016/j.envint.2012.06.003>

Alderman, K., Turner, L. R., & Tong, S. (2013). Assessment of the health impacts of the 2011 summer floods in Brisbane. *Disaster Medicine and Public Health Preparedness*, *7*(4), 380–386. <https://doi.org/10.1017/dmp.2013.42>

Aldrich, D. (2012). *Building resilience: Social capital in post-disaster recovery*. University of Chicago Press.

Alston, M., & Kent, J. (2008). The Big Dry: The link between rural masculinities and poor health outcomes for farming men. *Journal of Sociology, 44*(2), 133-147. <https://doi.org/10.1177/1440783308089166>

American Psychiatric Association. (n.d.). *What is mental illness?* Retrieved from <https://www.psychiatry.org/patients-families/what-is-mental-illness>

American Psychiatric Association. (2013). *Diagnostics and statistical manual of mental disorders (DSM-V)* (5th ed).

Ampuero, D., Goldswosthy, S., Delgado, L. E., & Miranda J, C. (2015). Using mental well-being impact assessment to understand factors influencing well-being after a disaster. *Impact Assessment and Project Appraisal*, *33*(3), 184–194. <https://doi.org/10.1080/14615517.2015.1023564>

Anderson, H., Brown, C., Cameron, L. L., Christenson, M., Conlon, K. C., Dorevitch, S., Dumas, J., Eidson, M., Ferguson, A., …Walker, R. (2017). *Climate and health intervention assessment: Evidence on public health interventions to prevent the negative health effects of climate change*. Climate and Health Techninal Report Series. Centers for Disease Control Centers for Disease Control and Prevention. Retrieved from <https://www.cdc.gov/climateandhealth/docs/ClimateAndHealthInterventionAssessment_508.pdf>

Anderson, P., & Jané-Llopis, E. (2011). Mental health and global well-being. *Health Promotion International*, *26*(1 Suppl), 147–155. <https://doi.org/10.1093/heapro/dar060>

Armenian, P., Campagne, D., Stroh, G., Ives Tallman, C., Zeng, W., Lin, T., & Gerona, R. R. (2017). Hot and Cold Drugs: National Park Service Medication Stability at the Extremes of Temperature. *Prehospital Emergency Care : Official Journal of the National Association of EMS Physicians and the National Association of State EMS Directors*, *21*(3), 378–385. <https://doi.org/10.1080/10903127.2016.1258098>

Asugeni, J., MacLaren, D., Massey, P. D., & Speare, R. (2015). Mental health issues from rising sea level in a remote coastal region of the Solomon Islands: current and future. *Australasian Psychiatry*, *23*(6 Suppl), 22–25. <https://doi.org/10.1177/1039856215609767>

Bajayo, R. (2012). Building community resilience to climate change through public health planning. *Health Promotion Journal of Australia*, *23*(1), 30–36. <https://doi.org/10.1080/00222930400014148>

Balbus, J. M., Boxall, A. B. A., Fenske, R. A., McKone, T. E., & Zeise, L. (2013). Implications of global climate change for the assessment and management of human health risks of chemicals in the natural environment. *Environmental Toxicology and Chemistry*, *32*(1), 62–78. <https://doi.org/10.1002/etc.2046>

Bard, D. (2017). Les changements climatiques et leurs consequences sur la sante. *International Journal of Medicine and Surgery*, *4*, 7–11. doi:10.15342/ijms.v4.133

Bardsley, D. K., & Wiseman, N. D. (2012). Climate change vulnerability and social development for remote indigenous communities of South Australia. *Global Environmental Change*, *22*(3), 713–723. <https://doi.org/10.1016/j.gloenvcha.2012.04.003>

Barnett, J., Tschakert, P., Head, L., & Adger, W. N. (2016). A science of loss. *Nature Climate Change*. <https://doi.org/10.1038/nclimate3140>

Basu, R., Gavin, L., Pearson, D., Ebisu, K., & Malig, B. (2018). Examining the association between apparent temperature and mental health-related emergency room visits in California. *American Journal of Epidemiology*, *187*(4), 726–735. <https://doi.org/10.1093/aje/kwx295>

BC Ministry of Environment and Climate Change Strategy. (n.d). *Addressing climate and health risks in BC*. Retrieved from <https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/health/final_climate_and_health_backgrounder_public_health.pdf>

Bélanger, D., Gosselin, P., Valois, P., & Abdous, B. (2014). Perceived adverse health effects of heat and their determinants in deprived neighbourhoods: A cross-sectional survey of nine cities in Canada. *International Journal of Environmental Research and Public Health*, *11*(11), 11028-11053. <https://doi.org/10.3390/ijerph111111028>

Berry, H. L., Bowen, K., & Kjellstrom, T. (2010a). Climate change and mental health: A causal pathways framework. *International Journal of Public Health*, *55*(2), 123–132. <https://doi.org/10.1007/s00038-009-0112-0>

Berry, H. L., Hogan, A., Owen, J., Rickwood, D., & Fragar, L. (2011). Climate change and farmers' mental health: Risks and responses. *Asia-Pacific Journal of Public Health*, *23*(2 Suppl), 119S–32. <https://doi.org/10.1177/1010539510392556>

Berry, H. L., & Welsh, J. A. (2010b). Social capital and health in Australia: An overview from the household, income and labour dynamics in Australia survey. *Social Science and Medicine*, *70*(4). <https://doi.org/10.1016/j.socscimed.2009.10.012>

Berry, P., Clarke, K.-L., Fleury, M. D., & Parker, S. (2014). Human Health. In F. J. Warren, & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 19–22). Ottawa, ON: Natural Resources Canada.

Black, R., Bennett, S. R. G., Thomas, S. M., & Beddington, J. R. (2011). Migration as adaptation. *Nature*. 478, 447-449. <https://doi.org/10.1038/478477a>

Bogic, M., Njoku, A., & Priebe, S. (2015). Long-term mental health of war-refugees: a systematic literature review. *BMC International Health and Human Rights*, *15*, 29. <https://doi.org/10.1186/s12914-015-0064-9>

Bonanno, G. A. (2004). Loss, Trauma, and human resilience: Have we underestimated the human capacity to thrive after extremely aversive events? *American Psychologist*, *59*(1), 20. <https://doi.org/10.1037/0003-066X.59.1.20>

Bourque, F., & Cunsolo Willox, A. (2014). Climate change: The next challenge for public mental health? *International Review of Psychiatry*, *26*(4), 415–422. <https://doi.org/10.3109/09540261.2014.925851>

Bowles, D. C. (2015). Climate change and health adaptation: Consequences for indigenous physical and mental health. *Annals of Global Health*, *81*(3), 427–431. <https://doi.org/10.1016/j.aogh.2015.06.004>

Bragg, E., & Reser, J. (2012). Ecopsychology in the Antipodes: Perspectives from Australia and New Zealand. *Ecopsychology*, *4*(4), 253–265. <https://doi.org/10.1089/eco.2012.0085>

Brown, M. R., Agyapong, V., Greenshaw, A. J., Cribben, I., Brett-MacLean, P., Drolet, J., & Kitching, D. (2019). After the Fort McMurray wildfire there are significant increases in mental health symptoms in grade 7–12 students compared to controls. *BMC Psychiatry*, *19*(1), 18. <https://doi.org/10.1186/s12888-018-2007-1>

Brown, K., & Westaway, E. (2011). Agency, capacity, and resilience to environmental change: Lessons from human development, well-being, and disasters. *Annual Review of Environment and Resources*, *36*, 321–342. <https://doi.org/10.1146/annurev-environ-052610-092905>

Bryant, A. (2020). *Climate & mind*. Retrieved from <https://www.climateandmind.org/about>

Bryant, L., & Garnham, B. (2015). The fallen hero: Masculinity, shame and farmer suicide in Australia. *Gender, Place and Culture*, *22*(1), 67-82. <https://doi.org/10.1080/0966369X.2013.855628>

Burke, M., González, F., Baylis, P., Heft-Neal, S., Baysan, C., Basu, S., & Hsiang, S. (2018). Higher temperatures increase suicide rates in the United States and Mexico. *Nature Climate Change*, *8*(8), 723–729. <https://doi.org/10.1038/s41558-018-0222-x>

Burton, H., Rabito, F., Danielson, L., & Takaro, T. K. (2016). Health effects of flooding in Canada: A 2015 review and description of gaps in research. *Canadian Water Resources Journal*, *41*(1-2), 238-249. <https://doi.org/10.1080/07011784.2015.1128854>

Bush, E., & Lemmen, D. (Eds.). (2019). *Canada's changing climate report*. Ottawa, ON: Environment and Climate Change Canada. Retrieved from <https://changingclimate.ca/CCCR2019>

Bussidor, I., & Bilgen-Reinart, Ü. (1997). *Night spirits: The story of relocation of the Dene*. University of Manitoba Press.

Cameron, E. S. (2012). Securing indigenous politics: A critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian arctic. *Global Environmental Change, 22*(1), 103-114. <https://doi.org/10.1016/j.gloenvcha.2011.11.004>

Canadian Disaster Database. (2016). *The Canadian Disaster Database.* Retrieved from <https://www.publicsafety.gc.ca/cnt/rsrcs/cndn-dsstr-dtbs/index-en.aspx>

Canadian Mental Health Association (CMHA). (2009). *Rural and northern community issues in mental health*. Retrieved from <https://ontario.cmha.ca/documents/rural-and-northern-community-issues-in-mental-health/>

Canuel, M., Gosselin, P., Duhoux, A., Brunet, A., & Lesage, A. (2019). *Boîte à outils pour la surveillance post-sinistre des impacts sur la santé mentale*. Retrieved from <https://www.inspq.qc.ca/publications/2523>

Carleton, R. N., Afifi, T. O., Turner, S., Taillieu, T., Duranceau, S., LeBouthillier, D. M., Sareen, J., Ricciardelli, R., MacPhee, R. S., Groll, D., Hozempa, K., Brunet, A., Weekes, J. R., Griffiths, C. T., Abrams, K. J., Jones, N. A., Beshai, S., Cramm, H. A., Dobson, K. S., Hatcher, S., … Asmundson, G. J. G. (2017). Mental disorder symptoms among public safety personnel in Canada. *Canadian Journal of Psychiatry, 63*(1), 54-64. <https://doi.org/10.1177/0706743717723825>

Carleton, T. A. (2017). Crop-damaging temperatures increase suicide rates in India. *Proceedings of the National Academy of Sciences, 114*(33), 8746-8751. <https://doi.org/10.1073/pnas.1701354114>

Centre for Addiction and Mental Health (CAMH). (2012). *Mental illness and addictions: Facts and statistics*. Retrieved from <https://www.camh.ca/en/driving-change/the-crisis-is-real/mental-health-statistics>

Christmas, R. (2013). Multi-track diplomacy and Canada's Indigenous Peoples. *Peace Research*, *44/45*(2), 5–30. Retrieved from <http://www.jstor.org/stable/24429459>

City of Toronto. (2019). *Benefits of actions to reduce greenhouse gas emissions in Toronto: Health and health equity*. Retrieved from <https://www.toronto.ca/wp-content/uploads/2019/06/8f33-Benefits-of-Actions-to-Reduce-Greenhouse-Gas-Emissions-in-Toronto-Health-and-Health-Equity.pdf>

Clayton, S. (2018). Mental health risk and resilience among climate scientists. *Nature Climate Change*, *8*, 260–261. <https://doi.org/10.1016/j.janxdis.2020.102263>

Clayton, S. (2020). Climate anxiety: Psychological responses to climate change. *Journal of Anxiety Disorders, 74*, 102263. <https://doi.org/10.1016/j.janxdis.2020.102263>

Clayton, S., & Karazsia, B. T. (2020). Development and validation of a measure of climate change anxiety. *Journal of Environmental Psychology, 69*, 101434. <https://doi.org/10.1016/j.jenvp.2020.101434>

Clayton, S., & Manning, C. M. (Eds.). (2018). *Psychology and climate change: Human perceptions, impacts, and responses*. Academic Press. <https://doi.org/10.1016/B978-0-12-813130-5.00012-6>

Clayton, S., Manning, C. M., & Hodge C. (2014). *Beyond storms & droughts: The psychological impacts of climate change.* Washington, DC: American Psychological Association, and ecoAmerica. Retrieved from <https://ecoamerica.org/wp-content/uploads/2014/06/eA_Beyond_Storms_and_Droughts_Psych_Impacts_of_Climate_Change.pdf>

Clayton, S., Manning, C. M., Krygsman, K., & Speiser, M. (2017). *Mental health and our changing climate: Impacts, implications, and guidance*. Washington, DC: American Psychological Association, and ecoAmerica. Retrieved from <https://www.apa.org/news/press/releases/2017/03/mental-health-climate.pdf>

Coppock, V., & Dunn, B. (2009). *Understanding social work practice in mental health*. SAGE Publications Ltd.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., … Patterson, C. (2009). Managing the health effects of climate change. Lancet and University College London Institute for Global Health Commission. *The Lancet*, *373*(9676), 1693–1733. <https://doi.org/10.1016/S0140-6736(09)60935-1>

Cunsolo, A., & Ellis, N. R. (2018). Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change, 8*, 275-281. <https://doi.org/10.1038/s41558-018-0092-2>

Cunsolo, A., Harper, S. L., Minor, K., Hayes, K., Williams, K. G., & Howard, C. (2020). Ecological grief and anxiety: the start of a healthy response to climate change? *The Lancet Planetary Health, 4*(7), e261-e263. <https://www.thelancet.com/pdfs/journals/lanplh/PIIS2542-5196(20)30144-3.pdf>

Cunsolo Willox, A., Harper, S. L., Edge, V. L., Landman, K., Houle, K., & Ford, J. D. (2013a). The land enriches the soul: On climatic and environmental change, affect, and emotional health and well-being in Rigolet, Nunatsiavut, Canada. *Emotion, Space and Society*. <https://doi.org/10.1016/j.emospa.2011.08.005>

Cunsolo Willox, A., Harper, S. L., Ford, J. D., Edge, V. L., Landman, K., Houle, K., … Wolfrey, C. (2013b). Climate change and mental health: An exploratory case study from Rigolet, Nunatsiavut, Canada. *Climatic Change*. <https://doi.org/10.1007/s10584-013-0875-4>

Cunsolo Willox, A., Harper, S. L., Ford, J. D., Landman, K., Houle, K., & Edge, V. L. (2012). "From this place and of this place:" Climate change, sense of place, and health in Nunatsiavut, Canada. *Social Science and Medicine*. <https://doi.org/10.1016/j.socscimed.2012.03.043>

Cunsolo Willox, A., Stephenson, E., Allen, J., Bourque, F., Drossos, A., Elgarøy, S., … Wexler, L. (2014). Examining relationships between climate change and mental health in the Circumpolar North. *Regional Environmental Change*. <https://doi.org/10.1007/s10113-014-0630-z>

Cusack, L., de Crespigny, C., & Athanasos, P. (2011). Heatwaves and their impact on people with alcohol, drug and mental health conditions: a discussion paper on clinical practice considerations. *Journal of Advanced Nursing*, *67*(4), 915–922.

Davis, S. (2013). *Community Mental Health in Canada, revised and expanded edition: Theory, policy, and practice*. UBC Press.

Decent, D., & Feltmate, B. (2018). *After the flood: The impact of climate change on mental health and time lost from work*. Intact Centre on Climate Adpatation, and University of Waterloo. Retrieved from <https://www.intactcentreclimateadaptation.ca/wp-content/uploads/2018/06/After-The-Flood.pdf>

De Winter, S., Vanbrabant, P., Vi, N. T., Deng, X., Spriet, I., Van Schepdael, A., & Gillet, J. B. (2013). Impact of temperature exposure on stability of drugs in a real-world out-of-hospital setting. *Annals of Emergency Medicine*, *62*(4), 380–387.e1. <https://doi.org/10.1016/j.annemergmed.2013.04.018>

Ding, N., Berry, H. L., & Bennett, C. M. (2016). The Importance of Humidity in the Relationship between Heat and Population Mental Health: Evidence from Australia. *PloS One*, *11*(10), e0164190. <https://doi.org/10.1371/journal.pone.0164190>

Dixon, P. G., Sinyor, M., Schaffer, A., Levitt, A., Haney, C. R., Ellis, K. N., & Sheridan, S. C. (2014). Association of weekly suicide rates with temperature anomalies in two different climate types. *International Journal of Environmental Research and Public Health, 11*(11), 11627-11644. <https://doi.org/10.3390/ijerph111111627>

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health, 109*(3), 327-337. Retrieved from <https://link.springer.com/article/10.17269/s41997-018-0070-5>

Dodgen, D., D., Donato, N., Kelly, A., La Greca, J., Morganstein, J., Reser, J., … Ursano, R. (2016). Mental health and well-being. In A. Crimmins, J. Balbus, J. L. Gamble, C. B. Beard, J. E. Bell, D. Dodgen, R. J. Eisen, N. Fann, M. D. Hawkins, S. C. Herring, L. Jantarasami, D. M. Mills, S. Saha, M. C. Sarofim, J. Trtanj, & L. Ziska (Eds.), *The impacts of climate change on human health in the United States: A scientific assessment.* Washington, DC: U.S. Global Change Research Program. Retrieved from <https://health2016.globalchange.gov/mental-health-and-well-being>

Doherty, T. J., & Clayton, S. (2011). The psychological impacts of global climate change. *American Psychologist*, *66*(265–276), 10–1037. Retrieved from <https://www.apa.org/pubs/journals/releases/amp-66-4-265.pdf>

Donaldson, S. G., Curren, M. S., Adlard, B., Provost, J., Leech, T., Tikhonov, C., … Shearer, R. (2013). Future human health research directions for the Canadian Northern Contaminants Program. *International Journal of Circumpolar Health*, *72*(1), 1–2. <https://doi.org/10.3402/ijch.v72i0.23049>

Durkalec, A., Furgal, C., Skinner, M. W., & Sheldon, T. (2015). Climate change influences on environment as a determinant of Indigenous health: Relationships to place, sea ice, and health in anInuit community. *Social Science & Medicine, 136-137*, 17-26. <https://doi.org/10.1016/j.socscimed.2015.04.026>

Durocher, L. (2018). *The Long Road Home: Position Paper*.

Earle, L. (2013). *Understanding chronic disease and the role for traditional approaches in aboriginal communities*. National Collaborating Centre for Aboriginal Health. Retrieved from <https://www.ccnsa-nccah.ca/docs/emerging/FS-UnderstandingChronicDisease-Earle-EN.pdf>

Edwards, T., & Wiseman, J. (2011). Climate change, resilience and transformation: challenges and opportunities for local communities. In I. Weissbecker (Ed.), *Climate Change and Human Well-being*. New York, NY: Springer.

Eisenman, D., McCaffrey, S., Donatello, I., & Marshal, G. (2015). An ecosystems and vulnerable populations perspective on solastalgia and psychological distress after a wildfire. *EcoHealth*, *12*(4), 602–610. <https://doi.org/10.1007/s10393-015-1052-1>

Ellis, N. R., & Albrecht, G. A. (2017). Climate change threats to family farmers' sense of place and mental well-being: A case study from the Western Australian Wheatbelt. *Social Science and Medicine, 175*, 161-168. <https://doi.org/10.1016/j.socscimed.2017.01.009>

Fernandez, A., Black, J., Jones, M., Wilson, L., Salvador-Carulla, L., Astell-Burt, T., & Black, D. (2015). Flooding and mental health: A systematic mapping review. *PLoS ONE*, *10*(4), 1–21. <https://doi.org/10.1371/journal.pone.0119929>

Ferré, I. M., Negrón, S., Shultz, J. M., Schwartz, S. J., Kossin, J. P., & Pantin, H. (2019). Hurricane Maria's impact on Punta Santiago, Puerto Rico: community needs and mental health assessment six months postimpact. *Disaster Medicine and Public Health Preparedness*, *13*(1), 18–23. <https://doi.org/10.1017/dmp.2018.103>

Fletcher, A., & Knuttila, E. (2016). Gendering Change Canadian Farm Women Respond to Drought. In H. Diaz, M. Hurlbert, & J. Warren (Eds.), *Vulnerability and Adaptation to Drought: The Canadian Prairies and South America*. University of Calgary Press.

Foothills Community Counselling. (2020). Retrieved from <https://highriver.ca/foothills-community-counselling/>

Ford, J. D. (2012). Indigenous health and climate change. *American Journal of Public Health, 102*(7), 1260–1266. <https://doi.org/10.2105/AJPH.2012.300752>

Ford, J. D., Stephenson, E., Cunsolo Willox, A., Edge, V., Farahbakhsh, K., Furgal, C., Harper, S., Chatwood, S., Mauro, I., Pearce, T., Austin, S., Bunce, A., Bussalleu, A., Diaz, J., Finner, K., Gordon, A., Huet, C., Kitching, K., Lardeau, M. P., McDowell, G., … Sherman, M. (2016). Community-based adaptation research in the Canadian Arctic. *Wiley Interdisciplinary Reviews. Climate Change*, *7*(2), 175–191. <https://doi.org/10.1002/wcc.376>

Foresight: Migration and Global Environmental Change. (2011). Final Project Report
The Government Office for Science, London. Retrieved from <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/287717/11-1116-migration-and-global-environmental-change.pdf>

Fritze, J. C., Blashki, G. A., Burke, S., & Wiseman, J. (2008). Hope, despair and transformation: Climate change and the promotion of mental health and well-being. *International Journal of Mental Health Systems*, *2*, 1–10. <https://doi.org/10.1186/1752-4458-2-13>

Galea, S., Brewin, C. R., Gruber, M., Jones, R. T., King, D. W., King, L. A., & Kessler, R. C. (2007). Exposure to hurricane-related stressors and mental illness after Hurricane Katrina. *Archives of General Psychiatry*, *64*(12), 1427–1434.

Gleick, P. H. (2014). Water, Drought, Climate Change, and Conflict in Syria. *Weather, Climate, & Society*, *6*(3), 331–340. <https://doi.org/10.1175/WCAS-D-13-00059.1>

Goldner, E. M., Bilsker, D., & Jenkins, E. (2016). *A concise introduction to mental health in Canada*. Canadian Scholars' Press.

Gosse, K. (2010). Newfoundland begins cleanup of hurricane Igor's path of destruction. *Globe and Mail*. Retrieved from <https://www.theglobeandmail.com/news/national/newfoundland-begins-cleanup-of-hurricane-igors-path-of-destruction/article1213793/>

Government of Alberta. (2013). *Alberta helps families cope with emotional impact of floods*. Retreived from <https://www.alberta.ca/release.cfm?xID=3523164740483-D80A-5566-F819A0C841FEDDEA>

Government of Canada. (2018). *Social determinants of health and health inequities*. Retrieved from <https://www.canada.ca/en/public-health/services/health-promotion/population-health/what-determines-health.html>

Government of Canada. (2020). *Non-insured health benefits for First Nations and Inuit*. Retrieved from <https://www.sac-isc.gc.ca/eng/1572537161086/1572537234517>

Government of Yukon. (2017). *Yukon 'state of play': Analysis of climate change impacts and adaptation.* Retreived from <https://yukon.ca/en/yukon-state-play-analysis-climate-change-impacts-and-adaptation>

Green, D., & Minchin, L. (2014). Living on climate-changed country: Indigenous health, well-being and climate change in remote Australian communities. *EcoHealth*, *11*(2), 263–272. <https://doi.org/10.1007/s10393-013-0892-9>

Hanigan, I. C., Butler, C. D., Kokic, P. N., & Hutchinson, M. F. (2012). Suicide and drought in New South Wales, Australia, 1970-2007. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(35), 13950-13955. <https://doi.org/10.1073/pnas.1112965109>

Harper, S. L., Edge, V. L., Ford, J., Willox, A. C., Wood, M., McEwen, S. A., … Namanya, D. B. (2015). Climate-sensitive health priorities in Nunatsiavut, Canada. *BMC Public Health, 15,* 605. <https://doi.org/10.1186/s12889-015-1874-3>

Hasket, M. E., Smith Scott, S., Nears, K., Grimmet, M. (2008). Lessons from Katrina: Disaster mental health service in the gulf coast region. *Professional Psychology: Research and Practice*, *39*(1), 93–99. <https://doi.org/10.1037/0735-7028.39.1.93>

Hayes, K. (2019). *Mental Health in a changing climate: The Effects on youth, women and newcomers.* Greenbelt Foundation. Retrieved from <https://www.greenbelt.ca/mentalhealth>

Hayes, K., Berry, P., & Ebi, K. (2019). Factors Influencing the Mental Health Consequences of Climate Change in Canada. *International Journal of Environmental Health Research*, *16*(9), 1583. <https://doi.org///doi.org/10.3390/ijerph16091583>

Hayes, K., Blashki, G., Wiseman, J., Burke, S., & Reifels, L. (2018a). Climate change and mental health: Risks, impacts and priority actions. *International Journal of Mental Health Systems*, *12*(1), 1–12. <https://doi.org/10.1186/s13033-018-0210-6>

Hayes, K., & Poland, B. (2018). Addressing mental health in a changing climate: Incorporating mental health indicators into climate change and health vulnerability and adaptation assessments. *International Journal of Environmental Research and Public Health*, *15*(9), 1806. <https://doi.org/10.3390/ijerph15091806>

Hayes, K., Poland, B., Cole, D. C., & Agic, B. (2020). Psychosocial adaptation to climate change in High River, Alberta: implications for policy and practice. *Canadian Journal of Public Health, 111*(6), 880-889. <https://doi.org/10.17269/s41997-020-00380-9>

Hayes, K, Poland, B., Hathaway, M. (2018b). 5 Ways communities are coping with climate anxiety. *YES Magazine*. Retrieved from <https://www.yesmagazine.org/environment/2018/08/22/5-ways-communities-are-coping-with-climate anxiety/>

Health Canada. (2011). *Extreme Heat Events Guidelines: Technical Guide for Health Care Workers*. Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/climat/workers-guide-travailleurs/extreme-heat-chaleur-accablante-eng.pdf>

Health Canada. (2015). *First Nations mental wellness continuum framework*. Ottawa, ON. Retrieved from <https://thunderbirdpf.org/wp-content/uploads/2015/01/24-14-1273-FN-Mental-Wellness-Framework-EN05_low.pdf>

Health Canada. (2020). *Reducing urban heat islands to protect health in Canada: An introduction for public health professionals.* Ottawa, ON. Retreived from <https://www.canada.ca/content/dam/hc-sc/documents/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada/Reducing-Urban-Heat-EN.pdf>

Hetherington, E., McDonald, S., Wu, M., & Tough, S. (2018). Risk and protective factors for mental health and community cohesion after the 2013 Calgary flood. *Disaster Medicine and Public Health Preparedness*, *12*(4), 470-477. <https://doi.org/10.1017/dmp.2017.91>

Howard, C., Rose, C., Hancock, T. (2016). *Lancet countdown 2017 report: Briefing for canadian policymakers*. Lancet Countdown: Tracking Progress on Health and Climate Change and Canadian Public Health Association. Retrieved from <https://www.cpha.ca/sites/default/files/uploads/advocacy/2017_lancet_canada_brief.pdf>

Huang, C., Yang, J., Lu, H., Huang, H., & Yu, L. (2017). Green spaces as an indicator of urban health: Evaluating its changes in 28 mega-cities. *Remote Sensing, 9*(12), 1266. <https://doi.org/10.3390/rs9121266>

Hudson, C. G. (2005). Socioeconomic status and mental illness: Tests of the social causation and selection hypotheses. *American Journal of Orthopsychiatry*, *75*(1), 3-18. <https://doi.org/10.1037/0002-9432.75.1.3>

Hutton, D. (2005). *Psychosocial aspects of climate change in Canada: A review of current literature and research recommendations*. Ottawa, ON: Health Canada.

Is This How You Feel? (2020). Retrieved from <https://www.isthishowyoufeel.com/>

Institute for Environment and Human Security (IEHS). (2015). *5 Facts on Climate Migrants*. United Nations University. Retrieved from <https://ehs.unu.edu/news/news/5-facts-on-climate-migrants.html>

Insurance Board of Canada. (2010). Hurrican Igor causes over $65 million in insured damage. *CISION*. Retreived from <https://www.newswire.ca/news-releases/hurricane-igor-causes-over-65-million-in-insured-damage-546085852.html>

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate change 2014: Impacts, adaptation, and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change* (C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White, Eds.). Cambridge, United Kingdom: Cambridge University Press.

Inuit Tapiriit Kanatami (ITK). (2016). *National Inuit Suicide Prevention Strategy*. Retrieved from <https://www.itk.ca/wp-content/uploads/2016/07/ITK-National-Inuit-Suicide-Prevention-Strategy-2016.pdf>

Jones, L., Asare, J. B., El Masri, M., Mohanraj, A., Sherief, H., & van Ommeren, M. (2009). Severe mental disorders in complex emergencies. *The Lancet, 374*(9690), P654-661. <https://doi.org/10.1016/S0140-6736(09)61253-8>

Kaiser, D., Lamothe, F., Roy, M., & Racinn- Hamel, S. É. (2019). *Vague de chaleur été 2018 à Montréal : enquête épidémiologique. Direction régionale de santé publique du CIUSSS du Centre-Sud-de-l'Île-de-Montréal*. Montréal, QC: Gouvernement du Québec. Retrieved from <https://numerique.banq.qc.ca/patrimoine/details/52327/3737294&docref=irDjexzzxNV8AspydEw39w>

Kessler, R. C., Galea, S., Gruber, M. J., Sampson, N. A., Ursano, R. J., & Wessely, S. (2008). Trends in mental illness and suicidality after Hurricane Katrina. *Molecular Psychiatry*, *13*, 374–384. <https://doi.org/10.1038/sj.mp.4002119>

Kim, Y., Kim, H., Gasparrini, A., Armstrong, B., Honda, Y., Chung, Y., … Hashizume, M. (2019). Suicide and ambient temperature: A multi-country multi-city study. *Environmental Health Perspectives*, *127*(11). <https://doi.org/10.1289/EHP4898>

King, N., Bishop-Williams, K.., Beauchamp, S., Ford, J. D., Berrang-Ford, L., Cunsolo, A., & Harper, S. L. (2018). How do Canadian media report climate change impacts on health? A newspaper review. *Climatic Change, 152*, 581-596. <https://doi.org/10.1007/s10584-018-2311-2>

Kirmayer, L. J., Simpson, C., & Cargo, M. (2003). Healing traditions: Culture, community and mental health promotion with Canadian Aboriginal peoples. *Australasian Psychiatry, 11*(1), S15–S23. <https://doi.org/10.1046/j.1038-5282.2003.02010.xl>

Kirmayer, L. J., Tait, C. L., & Simpson, C. (2009). The Mental Health of Aboriginal Peoples in Canada: Transformations of Identity and Community. *Healing Traditions: The Mental Health of Aboriginal Peoples in Canada*, *45*(7), 607-616. <https://doi.org/10.2307/2077147>

Kirmayer, L. J., & Valaskakis, G. (Eds.). (2009). *Healing Traditions: The Mental Health of Indigenous Peoples in Canada*. Vancouver, BC: UBC Press.

Klinkenberg, M. (2017). Fort McMurray fire evacuees suffering from PTSD symptoms: study. *The Globe and Mail*. Retrieved from <https://www.theglobeandmail.com/news/alberta/many-fort-mcmurray-fire-evacuees-suffering-from-ptsd-symptoms-study/article33764936/>

Koger, S. M., Leslie, K. E., & Hayes, E. D. (2011). Climate Change: Psychological Solutions and Strategies for Change. *Ecopsychology*, *3*(4), 227–235. <https://doi.org/10.1089/eco.2011.0041>

Kumar, U. (Ed.). (2016). *The Routledge international handbook of psychosocial resilience*. Routledge.

Lambert, S. F., & Lawson, G. (2013). Resilience of professional counselors following Hurricanes Katrina and Rita. *Journal of Counseling & Development*, *91*(3), 261–268. <https://doi.org/10.1002/j.1556-6676.2013.00094.x|>

Lee, J., Park, B. J., Tsunetsugu, Y., Ohira, T., Kagawa, T., & Miyazaki, Y. (2011). Effect of forest bathing on physiological and psychological responses in young Japanese male subjects. *Public Health*, *125*(2), 93–100. <https://doi.org/10.1016/j.puhe.2010.09.005>

Lowe, D., Ebi, K. L., Forsberg, B. (2013). Factors increasing vulnerability to health effects before, during, and after floods. *International Journal of Environmental Research and Public Health*, *10*(12), 7015–7067. <https://doi.org/10.3390/ijerph10127015>

Macyshon, J. (2017). Ravaged by floods in 2011, Manitoba First Nation finally welcomes families home. *CTV News*. Retrieved from <https://www.ctvnews.ca/canada/ravaged-by-floods-in-2011-manitoba-first-nation-finally-welcomes-families-home-1.3661089>

Maibach, E., Nisbet, M., & Weathers, M. (2011). *Conveying the human implications of climate change: A climate change communication primer for public health professionals*. Fairfax, VA: George Mason University Center for Climate Change Communication. Retreived from <https://www.climatechangecommunication.org/wp-content/uploads/2016/04/Climate-Communication-Primer-for-Public-Health-Professionals-1.pdf>

Malena-Chan, R., & Gatley, K. (2020). *Ecoanxious Stories*. Retrieved from <https://www.ecoanxious.ca/>

Mann, S. C., & Boger, W. P. (1978). Psychotropic drugs, summer heat and humidity, and hyperpyrexia: A danger restated. *American Journal of Psychiatry*, *135*(9), 1097-1100. <https://doi.org/10.1176/ajp.135.9.1097>

Mantouraa, P., Robergeb, M.-C., Fournierc, L., & Mantoura, P. (2017). A framework for supporting action in population mental health. *Santé Mentale Au Québec*, *XLII*(1), 105–123. Retrieved from <http://www.ncchpp.ca/docs/2017_SMP_PMH_ArticleSMQ_En.pdf>

McCracken, D. (2017). Building citizen capacity. *High River Online*. Retrieced from <https://www.highriveronline.com/local/building-citizen-capacity>

Mental Health Commission of Canada (MHCC). (2016). *Advancing the mental health strategy for Canada.* Retrieved from <https://www.mentalhealthcommission.ca/sites/default/files/2016-08/advancing_the_mental_health_strategy_for_canada_a_framework_for_action.pdf>

Mental Health Commission of Canada (MHCC). (2017). *Strengthening the case for investing in canada's mental health system: Economic considerations.* Retrieved from <https://www.mentalhealthcommission.ca/sites/default/files/2017-03/case_for_investment_eng.pdf>

Mental Health Commission of Canada (MHCC). (2018). *The working mind: The mental health continuum.* Retrieved from <https://theworkingmind.ca/continuum-self-check>

Mental Health Commission of Canada (MHCC). (2020). *Rural and Remote Mental Health in Canada Evidence Brief on Best and Promising Practices.* Retrieved from <https://www.mentalhealthcommission.ca/sites/default/files/2020-05/Rural_remote_mental_health_evidence_brief_eng.pdf>

Middleton, J., Cunsolo, A., Jones-Bitton, A., Shiwak, I., Wood, M., Pollock, N.,... & Harper, S. L. (2020a). "We're people of the snow:" *Weather, climate change, and Inuit mental wellness. Social Science & Medicine*, 262, 113137. <https://doi.org/10.1016/j.socscimed.2020.113137>

Middleton, J., Cunsolo, A., Jones-Bitton, A., Wright, C. J., & Harper, S. L. (2020b). Indigenous mental health in a changing climate: a systematic scoping review of the global literature. *Environmental Research Letters, 15*(5), 053001. Retrieved from <https://iopscience.iop.org/article/10.1088/1748-9326/ab68a9>

Miles-Novelo, A., & Anderson, C. A. (2019). Climate change and psychology: Effects of rapid global warming on violence and aggression. *Current Climate Change Reports, 5*(1), 36-46. <https://doi.org/10.1007/s40641-019-00121-2>

Moroz, N., Moroz, I., & D'Angelo, M. S. (2020, November). Mental health services in Canada: barriers and cost-effective solutions to increase access. In Healthcare Management Forum (Vol. 33, No. 6, pp. 282-287). Sage CA: Los Angeles, CA: SAGE Publications.

Morrissey, S. A., & Reser, J. P. (2007). Natural disasters, climate change and mental health considerations for rural Australia. *Australian Journal of Rural Health, 15*(2), 120-125. <https://doi.org/10.1111/j.1440-1584.2007.00865.x>

Mouallen, O. (2015). The boom, the bust, the darkness: Suicide rate soars in wake of Canada's oil crisis. *The Guardian.* Retrieved from <https://www.theguardian.com/world/2015/dec/14/canada-oil-production-crisis-suicide-alberta>

Naturale, A. (2015). How do we understand disaster-related vicarious trauma, secondary traumatic stress, and compassion fatigue? In G. Quitangon, & M. R. Evces (Eds.), *Vicarious Trauma and Disaster Mental Health* (pp. 93–110). Routledge.

Neria, Y., & Shultz, J. M. (2012). Mental health effects of Hurricane Sandy: Characteristics, potential aftermath, and response. *JAMA*, *308*(24), 2571–2572. doi:10.1001/jama.2012.110700

Nicholls, N., Butler, C. D., & Hanigan, I. (2006). Inter-annual rainfall variations and suicide in New South Wales, Australia, 1964-2001. *International Journal of Biometeorology*, *50*(3), 139-143. <https://doi.org/10.1007/s00484-005-0002-y>

Obradovich, N., Migliorini, R., Paulus, M. P., & Rahwan, I. (2018). Empirical evidence of mental health risks posed by climate change. *Proceedings of the National Academy of Sciences, 115*(43), 10953-10958. <https://doi.org/10.1073/pnas.1801528115>

O'Brien, L. V., Berry, H. L., Coleman, C., & Hanigan, I. C. (2014). Drought as a mental health exposure. *Environmental Research*, *131*, 181–187. <https://doi.org/10.1016/j.envres.2014.03.014>

Ojala, M. (2012). How do children cope with global climate change? Coping strategies, engagement, and well-being. *Journal of Environmental Psychology, 32*(3), 225-233. Retrieved from <https://www.colorado.edu/cumuseum/sites/default/files/attached-files/ojala7.pdf>

Orengo-Aguayo, R., Stewart, R. W., de Arellano, M. A., Suárez-Kindy, J. L., & Young, J. (2019). Disaster Exposure and Mental Health Among Puerto Rican Youths After Hurricane Maria. *JAMA Network Open, 2*(4), e192619. <https://doi.org/10.1001/jamanetworkopen.2019.2619>

Osofsky, J. D., Osofsky, H. J., Kronenberg, M., & Hansel, T. (2010). The aftermath of hurricane Katrina: Mental health considerations and lessons learned. In R. P. Kilmer, V. Gil-Rivas, R. G. Tedeschi, & L. G. Calhoun (Eds.), *Helping families and communities recover from disaster*. Washington, DC: American Psychological Association.

Pacheco, S. E. (2020). Catastrophic effects of climate change on children's health start before birth. *Journal of Clinical Investigation, 130*(2), 562-564. <https://doi.org/https://doi.org/10.1172/JCI135005>

Page, L. A., Hajat, S., Kovats, R. S., & Howard, L. M. (2012). Temperature-related deaths in people with psychosis, dementia and substance misuse. *The British Journal of Psychiatry : The Journal of Mental Science, 200*(6), 485–490. <https://doi.org/10.1192/bjp.bp.111.100404>

Petrasek MacDonald, J., Cunsolo Willox, A., Ford, J. D., Shiwak, I., Wood, M., Wolfrey, C., … the Rigolet Inuit Community Government. (2015). Protective factors for mental health and well-being in a changing climate: Perspectives from Inuit youth in Nunatsiavut, Labrador. *Social Science and Medicine*, *141*, 133-141. <https://doi.org/10.1016/j.socscimed.2015.07.017>

Pihkala, P. (2020). The Cost of Bearing Witness to the Environmental Crisis: Vicarious Traumatization and Dealing with Secondary Traumatic Stress among Environmental Researchers. *Social Epistemology*, *34*(1), 86-100. <https://doi.org/10.1080/02691728.2019.1681560>

Pitts, L. (2015). Hurricane Igor: What it was like on the ground during, and after, the storm. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/newfoundland-labrador/hurricane-igor-what-it-was-like-on-the-ground-during-and-after-the-storm-1.3234201>

Polain, J. D., Berry, H. L., & Hoskin, J. O. (2011). Rapid change, climate adversity and the next "big dry": Older farmers' mental health. *Australian Journal of Rural Health, 19*(5), 239-243. <https://doi.org/10.1111/j.1440-1584.2011.01219.x>

Powers, J. R., Dobson, A. J., Berry, H. L., Graves, A. M., Hanigan, I. C., & Loxton, D. (2015). Lack of association between drought and mental health in a cohort of 45-61 year old rural Australian women. *Australian and New Zealand Journal of Public Health*, *39*(6), 518–523. <https://doi.org/10.1111/1753-6405.12369>

Price, K., Perron, S., & King, N. (2013). Implementation of the montreal heat response plan during the 2010 heat wave. *Canadian Journal of Public Health, 104*(2), e96-e100. <https://doi.org/10.1007/BF03405667>

Public Health Agency of Canada (PHAC). (2014). *Economic Burden of illness in Canada, 2005–2008*. Retrieved from <https://www.canada.ca/content/dam/phac-aspc/migration/phac-aspc/publicat/ebic-femc/2005-2008/assets/pdf/ebic-femc-2005-2008-eng.pdf>

Radu, I. (2018). *Land for Healing: Developing a First Nations Land-based Service Delivery Model*. Bothwell, ON: Thunderbird Partnership Foundation. Retrieved from <https://thunderbirdpf.org/wp-content/uploads/2018/07/Thunderbirdpf-LandforHealing-Document-SQ.pdf>

Radu, I., House, L., & Pashagumskum, E. (2014). Land, life, and knowledge in Chisasibi: Intergenerational healing in the bush. *Decolonization: Indigeneity, Education & Society*, *3*(3), 86–105. Retrieved from <https://www.chisasibiwellness.ca/wp-content/uploads/2018/12/Radu-et-al_Chisasibi-land-based-healing_2014-1.pdf>

Ramsay, T., & Manderson, L. (2011). Resilience, spirituality and posttraumatic growth: reshaping the effects of climate change. In I. Weissbecker (Ed.), *Climate Change and Human Well-being*. New York, NY: Springer.

Ray, S. J. (2020). *A Field Guide to Climate Anxiety: How to Keep Your Cool on a Warming Planet*. Oakland, CA: University of California Press.

Reser, J. P., & Swim, J. K. (2011). Adapting to and coping with the threat and impacts of climate change. *American Psychologist*, *66*(4), 277. <http://doi.org/10.1037/a0023412>

Rhodes, J., & Chan, C. (2010). The Impact of Hurricane Katrina on the Mental and Physical Health of Low-Income Parents in New Orleans. *The American Journal of Orthopsychiatry*, *80*(2), 237–247. <http://doi.org/10.1111/j.1939-0025.2010.01027.x>

Rigby, C. W., Rosen, A., Berry, H. L., & Hart, C. R. (2011). If the land's sick, we're sick: The impact of prolonged drought on the socal and emotional well-being of Aboriginal communities in rural New South Wales. *Australian Journal of Rural Health*, *19*(5). <http://doi.org/10.1111/j.1440-1584.2011.01223.x>

Roberts, S., Arseneault, L., Barratt, B., Beevers, S., Danese, A., Odgers, C. L., … Fisher, H. L. (2019). Exploration of NO 2 and PM 2.5 air pollution and mental health problems using high-resolution data in London-based children from a UK longitudinal cohort study. *Psychiatry Research, 272,* 8-17. <https://doi.org/10.1016/j.psychres.2018.12.050>

Rodriguez, J. J., Kohn, R. (2008). Use of mental health services among disaster survivors. *Current Opinion in Psychiatry*, *21*, 370–378. <https://doi.org/10.1186/1471-2458-7-173>

Ruskin, J., Rasul, R., Schneider, S., Bevilacqua, K., Taioli, E., & Schwartz, R. M. (2018). Lack of access to medical care during Hurricane Sandy and mental health symptoms. *Preventive Medicine Reports*, *10*, 363–369. <https://doi.org/10.1016/j.pmedr.2018.04.014>

Sahni, V., Scott, A. N., Beliveau, M., Varughese, M., Dover, D. C., & Talbot, J. (2016). Public health surveillance response following the southern Alberta floods, 2013. *Canadian Journal of Public Health*, *107*(2), e142–e148. <https://doi.org/10.17269/cjph.107.5188>

Sawatzky, A., Cunsolo, A., Gillis, G., Cook, O., Shiwak, I., Flowers, C., … Harper, S. L. (2018). Profiling the eNuk program: An Inuit-led strategy for monitoring and responding to the impacts of environmental change on health and well-being in Rigolet, Nunatsiavut. *Northern Public Affairs*. Retrieved from <www.northernpublicaffairs.ca/index/volume-5-issue-2-innovations-in-community-health-and-wellness/profiling-the-enuk-program/>

Sawatzky, A., Cunsolo, A., Harper, S., Shiwak, I., Wood, M., & IMHACC Team. (2019). "We have our own way": Exploring pathways for well-being among Inuit in Nunatsiavut, Labrador, Canada. In C. Flemming, & M. Manning (Eds.), *Handbook of Indigenous Well-being.* Routledge.

Sawatzky, A., Cunsolo, A., Jones-Bitton, A., Gillis, D., Wood, M., Flowers, C.,... & Harper, S. L. (2020). "The best scientists are the people that's out there": Inuit-led integrated environment and health monitoring to respond to climate change in the Circumpolar North. *Climatic Change*, 1-22. Retrieved from <https://link.springer.com/article/10.1007/s10584-019-02647-8>

Scaramutti, C., Salas-Wright, C. P., Vos, S. R., & Schwartz, S. J. (2019). The Mental Health Impact of Hurricane Maria on Puerto Ricans in Puerto Rico and Florida. *Disaster Medicine and Public Health Preparedness*, *13*(1). <https://doi.org/10.1017/dmp.2018.151>

Schmidt, L., & Lewis-Reau, A. (2020). *Good Grief Network*. Retrieved from <https://www.goodgriefnetwork.org/>

Schwerdtle, P., Bowen, K., & McMichael, C. (2017). The health impacts of climate-related migration. *BMC Medicine, 16*(1). <https://doi.org/10.1186/s12916-017-0981-7>

Séguin, J. (Ed.). (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity*. Ottawa, ON: Health Canada. Retrieved from <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Shipley, M., & Berry, H. L. (2010). Longing to belong: Personal Social capital and psychological distress in an australian coastal region. *SSRN*, (39). <https://doi.org/10.2139/ssrn.1703238>

Simpson, D. M., Weissbecker, I., & Sephton, S. E. (2011). Extreme weather-related events: Implications for mental health and well-being. In I. Weissbecker (Ed.), *Climate Change and Human Well-being*. New York, NY: Springer.

Standing Committee on Indigenous and Northern Affairs. (2017). *Breaking point: The suicide crisis in Indigenous communities.* Ottawa, ON: House of Commons.

Stanke, C., Murray, V., Amlôt, R., Nurse, J., & Williams, R. (2012). The effects of flooding on mental health: Outcomes and recommendations from a review of the literature. *PLoS Currents*, *4*, 1–17. <https://doi.org/10.1371/4f9f1fa9c3cae>

Stephen, A., Marion, M., Oluwafemi, A., & Wiggins, S. (1999). The effect of season and weather on suicide rates in the elderly in British Columbia. *Canadian Journal of Public Health / Revue Canadienne de Sante'e Publique*, *90*(6), 418–422. Retrieved from <https://www.jstor.org/stable/41994174>

Stern, P.C. (2012). Psychology: Fear and hope in climate messages. *Nature Climate Change, 2,* 572-573. Retrieved from <https://climateaccess.org/system/files/Stern_Fear%20and%20hope.pdf>

Tam, B. Y., Gough, W. A., Edwards, V., & Tsuji, L. J. S. (2013). The impact of climate change on the well-being and lifestyle of a First Nation community in the western James Bay region. *Canadian Geographer*, *57*(4). <https://doi.org/10.1111/j.1541-0064.2013.12033.x>

Tam, T. (2019). *Addressing Stigma: Towards a More Inclusive Health System*. Ottawa, ON: Government of Canada. Retrieved from <https://www.canada.ca/en/public-health/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/addressing-stigma-toward-more-inclusive-health-system.html>

The eNuk Program. (2018). Retrieved from <https://enuk.ca/>

Thompson, R., Hornigold, R., Page, L., & Waite, T. (2018). Associations between high ambient temperatures and heat waves with mental health outcomes: a systematic review. *Public Health*, *161*, 171–191. <https://doi.org/10.1016/j.puhe.2018.06.008>

Toronto Public Health. (2015). *A climate of concern: Climate change and health strategy for Toronto*. Retrieved from <https://www.toronto.ca/legdocs/mmis/2015/hl/bgrd/backgroundfile-81509.pdf>

Trang, P. M., Rocklöv, J., Giang, K. B., Kullgren, G., & Nilsson, M. (2016). Heatwaves and hospital admissions for mental disorders in Northern Vietnam e0155609. *PLoS ONE*, *11*(5), 1–20. <https://doi.org/10.1371/journal.pone.0155609>

Tschakert, P., Ellis, N. R., Anderson, C., Kelly, A., & Obeng, J. (2019). One thousand ways to experience loss: A systematic analysis of climate-related intangible harm from around the world. *Global Environmental Change*, *55*, 58-72. <https://doi.org/10.1016/j.gloenvcha.2018.11.006>

Tschakert, Petra, Barnett, J., Ellis, N., Lawrence, C., Tuana, N., New, M., … Pannell, D. (2017). Climate change and loss, as if people mattered: values, places, and experiences. *Wiley Interdisciplinary Reviews: Climate Change, 8*(5), e476. <https://doi.org/10.1002/wcc.476>

Tucci, J., Micthell, J., Goddard, C. (2007). *Children's fears, hopes and heroes: Modern childhood in Australia*. Australian Childhood Foundation.

Tunstall, S., Tapsell, S., Green, C., Floyd, P., & George, C. (2006). The health effects of flooding: Social research results from England and Wales. *Journal of Water and Health*, *4*(3), 365–380. <https://doi.org/10.2166/wh.2006.031>

Ulrich, R.. (1979). Visual landscapes and psychological well-being. *Landscape Research*, *4*(1), 17–23. doi:10.1080/01426397908705892

United Nations Framework Convention on Climate Change (UNFCCC). (2020). *Report of the executive committee of the Warsaw international mechanism for loss and damage associated with Climate Change Impacts*. Retrieved from <https://unfccc.int/documents/266453>

United Nations International Strategy for Disaster Reduction (UNISDR). (2015). *The human cost of weather related disasters 1995-2015*. Retrieved from <https://reliefweb.int/sites/reliefweb.int/files/resources/COP21_WeatherDisastersReport_2015_FINAL.pdf>

Usher, P. J. (2003). Environment, race and nation reconsidered: Reflections on aboriginal land claims in Canada. *Canadian Geographer*, *47*(4), 365–382. <https://doi.org/10.1111/j.0008-3658.2003.00029.x>

Vestal, C. (2017). 'Katrina brain': The invisible long-term toll of megastorms. *POLITICO*. Retrieved from <https://www.politico.com/agenda/story/2017/10/12/psychological-toll-natural-disasters-000547/>

Vida, S., Durocher, M., Ouarda, T. B., & Gosselin, P. (2012). Relationship between ambient temperature and humidity and visits to mental health emergency departments in Québec. *Psychiatric services (Washington, D.C.)*, *63*(11), 1150–1153. <https://doi.org/10.1176/appi.ps.201100485>

Vins, H., Bell, J., Saha, S., & Hess, J. J. (2015). The mental health outcomes of drought: A systematic review and causal process diagram. *International Journal of Environmental Research and Public Health*, *12*(10), 13251–13275. <https://doi.org/10.3390/ijerph121013251>

Waite, T. D., Chaintarli, K., Beck, C. R., Bone, A., Amlôt, R., Kovats, S., & Oliver, I. (2017). The English national cohort study of flooding and health: cross-sectional analysis of mental health outcomes at year one. *BMC Public Health*, *17*(1), 129. <https://doi.org/10.3390/ijerph121013251>

Wang, X., Lavigne, E., Ouellette-Kuntz, H., & Chen, B. E. (2014). Acute impacts of extreme temperature exposure on emergency room admissions related to mental and behavior disorders in Toronto, Canada. *Journal of Affective Disorders, 155*, 154-161. <https://doi.org/10.1016/j.jad.2013.10.042>

Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., … Costello, A. (2017). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *The Lancet, 391*(10120), 581-630. <https://doi.org/10.1016/S0140-6736(17)32464-9>

Weissbecker, I. (Ed.). (2011). *Climate change and human well-being*. New York, NY: Springer.

Whaley, A. (2009). Trauma among survivors of hurricane Katrina: Considerations and recommendations for mental health care. *Journal of Loss and Trauma*, *14*, 459–476. <https://doi.org/10.1080/15325020902925480>

Whitfield, G. P., Meehan, L. A., Maizlish, N., & Wendel, A. M. (2017). The integrated transport and health impact modeling tool in Nashville, Tennessee, USA: Implementation steps and lessons learned. *Journal of Transport and Health, 5,* 171-181. <https://doi.org/10.1016/j.jth.2016.06.009>

Williams, L., Fletcher, A., Hanson, C., Neapole, J., & Pollack, M. (2018). *Women and Climate Change Impacts and Action in Canada: Feminist, Indigenous, and Intersectional Perspectives*. Canadian Research Institue for the Advancement of Women and the Alliance for Intergenerational Resilience. Retrieved from <https://www.criaw-icref.ca/images/userfiles/files/Women and Climate Change_FINAL.pdf>

World Health Organization (WHO). (2018). *Mental health: Strengthening our response*. Retrieved from <https://www.who.int/news-room/fact-sheets/detail/mental-health-strengthening-our-response>

Yusa, A., Berry, P., Cheng, J. J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health, 12*(7), 8359-8412. <https://doi.org/10.3390/ijerph120708359>

Zakreski, D. (2019). Crystal meth crisis on Saskatchewan First Nation traced to 2015 wildfire evacuation. *CBC News*. Retreived from <https://www.cbc.ca/news/canada/saskatoon/montreal-lake-meth-crisis-wildfire-evacuation-1.5134061>

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., & Kharin, V.V. (2019). Changes in Temperature and Precipitation Across Canada. In E. Bush, & D. S. Lemmen (Eds.), *Canada's Changing Climate Report* (pp 112-193). Ottawa, ON: Environment and Climate Change Canada.

Zhao, X., Maibach, E., Gandy, J., Witte, J., Cullen, H., Klinger, B. A., & Pyle, A. (2014). Climate change education through TV weathercasts: Results of a field experiment. *Bulletin of the American Meteorological Society*, *95*(1), 117–130. <https://doi.org/10.1175/BAMS-D-12-00144.1>

Zupancic, T., Kingsley, M., Jason, T., &, & Macfarlane, R. (2013). *Green city: Why nature matters to health - an evidence review.* Toronto, ON: Toronto Public Health. Retreived from <https://niagaraknowledgeexchange.com/resources-publications/green-city-why-nature-matters-to-health-an-evidence-review/>

Zwiebach, L., Rhodes, J., & Roemer, L. (2010). Resource loss, resource gain, and mental health among survivors of Hurricane Katrina. *Journal of Traumatic Stress, 23*(6), 751-758. <https://doi.org/10.1002/jts.20579>

CHAPTER 5

Air Quality

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Authors

Marika Egyed, Health Canada

Phil Blagden, Health Canada

Contributing Authors

David Plummer, Environment and Climate Change Canada

Paul Makar, Environment and Climate Change Canada

Carlyn Matz, Health Canada

Mike Flannigan, University of Alberta

Morgan MacNeill, Health Canada

Eric Lavigne, Health Canada

Benny Ling, Health Canada

Diana Valencia Lopez, Health Canada

Betty Edwards, Health Canada

Radenko Pavlovic, Environment and Climate Change Canada

Jacinthe Racine, Environment and Climate Change Canada

Pierre Raymond, Health Canada

Robyn Rittmaster, Health Canada

Aaron Wilson, Health Canada

Guoliang Xi, Health Canada

Suggested Citation

Egyed, M., Blagden, P., Plummer, D., Makar, P., Matz, C., Flannigan, M., MacNeill, M., Lavigne, E., Ling, B., Lopez, D. V., Edwards, B., Pavlovic, R., Racine, J., Raymond, P., Rittmaster, R., Wilson, A., & Xi, G. (2022). Air Quality. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

Summary

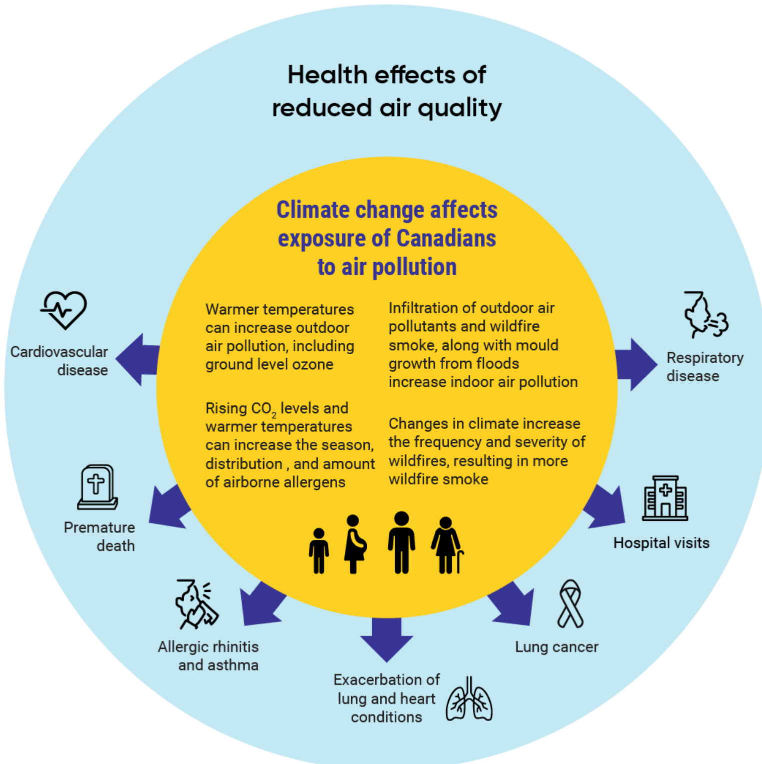
Climate change and air quality are intimately linked: changes in climate are affecting air quality in Canada, and several air pollutants contribute to climate change. Exposure to key air pollutants, including fine particulate matter and ozone, increases the risk of adverse health outcomes, ranging from respiratory symptoms to development of disease and premature death. A warming climate is expected to worsen air pollution levels in Canada. As the frequency and severity of wildfires are expected to increase due to climate change, emissions from wildfires represent one of the most significant climate-related risks to air quality in Canada. Climate change can also affect indoor air quality when elevated levels of outdoor air pollutants infiltrate buildings or when mould accumulates following extreme weather events, such as floods. Changes in the climate are affecting airborne allergens such as pollen by expanding the geographic distribution of plant species, extending pollen seasons, and increasing pollen counts.

Some groups are at increased risk of health impacts related to air pollution, including children, seniors, Indigenous Peoples, those with pre-existing conditions such as asthma or cardiac disease, and populations living in high air pollution areas. Mitigation efforts to reduce emissions of greenhouse gases can have substantial population health co-benefits related to improved air quality. These co-benefits can help offset the costs of climate mitigation, providing support for accelerated implementation of mitigation policies. Adaptation efforts that would prevent or alleviate the climate-related health impacts of air pollution include limiting exposure to air pollutants, including through the use of emergency shelters during wildfires; providing daily forecasts of air quality, wildfire smoke, and aeroallergens, such as the Air Quality Health Index; implementing flood prevention and ensuring that buildings have adequate ventilation and air filtration.

Key Messages

- Climate change and air quality are linked: overall, a warmer climate is expected to worsen air pollution in Canada, and some air pollutants contribute to climate change. If air pollution emissions remain unchanged, a warming climate will likely increase ozone levels in heavily populated and industrialized areas, including Southern Ontario and Southwestern Quebec. Projected effects on fine particulate matter are more modest and uncertain.
- The health impacts of air pollution in Canada, including premature death and disease, are expected to worsen in the future due to the influence of climate change. Unless these impacts are offset by reducing air pollution, hundreds of deaths annually are expected to result by mid-century. Today, air pollution is a leading environmental cause of death and illness in Canada, resulting in an estimated 15,300 deaths a year, with an economic value of $114 billion annually.

- Canada needs to prepare for a future with more wildfires. Increasing wildfire emissions are one of the most significant climate-related risks to air quality in Canada. Wildfire smoke, which can spread over vast areas of the country, contributed to an estimated 620 to 2700 deaths annually in Canada from 2013 to 2018. The public health burden of wildfire smoke is expected to increase in the future due to climate change.
- Climate change will increase the length of airborne allergen seasons, pollen counts, and the geographical distribution of allergens. Respiratory allergies and asthma are expected to affect more people more often in the future, increasing costs to the health system.
- Climate change can affect indoor air quality through increased infiltration of outdoor pollutants and allergens, and as a result of weather events such as floods that cause mould growth in buildings. At the same time, energy retrofits of buildings without adequate ventilation can reduce indoor air quality. Key adaptation strategies for indoor air include ventilation, filtration, and controlling pollutant sources.
- Daily forecasts of air quality, wildfire smoke, and airborne allergens presented in accessible formats, such as the Air Quality Health Index, are important tools to protect community health and a key adaptation strategy to inform populations at higher risk of health impacts resulting from a changing climate.
- Mitigation measures targeting climate pollutants, including methane and black carbon (soot), can have important immediate and long-term co-benefits for the health of local populations by reducing air pollution. The air quality benefits of these mitigation measures can help to offset the costs of climate action. Climate mitigation measures that improve air quality will also help avoid thousands of deaths annually in Canada by the middle of the century.



Health risks of climate change impacts on air pollution.

Overview of Climate-Related Health Impacts Associated with Air Quality

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Air quality	• Higher levels of airborne particulate matter related to smoke from wildfires • Increased ground-level ozone (and potentially particulate matter) due to warming • Higher levels of airborne particulate matter related to droughts • Increased mould and chemical contaminants in indoor environments due to flooding, effects on ambient air quality and increased releases from indoor sources of air pollution • Extended season and geographical distribution of pollen, and increased production of pollen by plants and trees • Warming and changes to precipitation affecting growth and ranges of air/aerosol or droplet-borne pathogens	• Air quality–related respiratory and cardiovascular disease and premature deaths • Exacerbation of chronic respiratory diseases, such as asthma and chronic obstructive pulmonary disease • Lung cancer • Development and exacerbation of allergies • Eye, nose, and throat irritation, and shortness of breath • Exacerbation of mental health impacts • Impacts on health infrastructures and services • Impacts on health and social services • Risks from infectious diseases acquired by inhalation from environmental sources (e.g., cryptococcosis)

5.1 Introduction

Climate change and air quality are intimately linked in multiple ways that can have repercussions for human health. Changes in climate, such as increasing temperatures, can influence the levels of air pollutants that affect Canadians. Conversely, some air pollutants contribute to climate change and warming of the atmosphere. In addition, a changing climate is expected to create conditions that affect the frequency and severity of wildfires, an important source of air pollution, and the levels of aeroallergens such as pollen, which affect allergic diseases. A changing climate can also affect indoor air quality: elevated levels of outdoor air pollution (e.g., smog, wildfire smoke, and aeroallergens) can infiltrate into buildings; actions that increase energy efficiency of buildings without adequate ventilation can result in accumulation of indoor-generated air pollution; and extreme weather events such as flooding can lead to the presence of mould indoors.

Climate pollutants and air pollutants are often emitted from the same sources, such as those relating to the combustion of fossil fuels. As a result, greenhouse gas (GHG) mitigation strategies targeting reductions in climate pollutants can have important local health co-benefits due to accompanying reductions in air pollutant emissions.

This chapter first summarizes the effects of air pollution on health and describes how climate change and air quality are interrelated. It then describes the expected effects of a warming climate on air pollution health impacts in Canada, as outdoor air pollutant concentrations, aeroallergens, and indoor air quality are influenced by the changing climate. Consideration is given to populations at greater risk from air pollution, such as children, seniors, those with underlying health conditions, and Indigenous Peoples. Future wildfire activity under climate change, as well as the potential health co-benefits associated with mitigating GHG emissions, are highlighted. To help decision makers plan for climate change impacts on the health of Canadians, potential adaptation strategies are discussed.

5.2 Methods and Approach

The information presented in this chapter focuses on impacts in Canada, with provincial or regional information provided, where available. Results from studies done in the United States are also reviewed, as often only limited information specific to Canada is available, and the two countries are generally similar in multiple ways (e.g., economic development, population demographics, and air pollution emission controls). Overall, an emphasis has been placed on studies published from 2005 to 2019. Most of the literature reviewed was drawn from peer-reviewed English language journals and identified through searches of citation databases (i.e., PubMed, Medline, Scopus, and Google Scholar) and supplemented with manual scanning of reference lists in key papers. Both primary studies and review articles were consulted. In addition, relevant documents retrieved from the grey literature, including reports and web content from governments, agencies, and organizations, were reviewed.

This chapter also includes two new analyses conducted for this report. The first is an investigation of Canadian air pollution health impacts associated with climate change and the potential air pollution health co-benefits of GHG mitigation. The second focuses on the health impacts from wildfire smoke during recent years to better understand the implications of a changing climate on this air pollution source.

5.3 Health Effects of Outdoor Air Pollution

Air pollution is a leading environmental cause of death, both globally and in Canada (IHME, 2019), and the 11th largest cause of death overall in Canada (Alam et al., 2019). It is estimated that current levels of three major air pollutants — fine particulate matter ($PM_{2.5}$),[1] ozone, and nitrogen dioxide (NO_2) — together cause about 15,300 premature deaths in Canada annually, with an economic value of $114 billion (Health Canada, 2021). In addition, these air pollutants are estimated to result in many non-fatal health outcomes, including thousands of hospital visits and millions of days with asthma symptoms annually in Canada; thus, they represent an important population health issue. The scientific evidence indicates that there is no exposure threshold below which there is no risk for many of these health effects. Any incremental increase in air pollutant concentration, including a small increase, is associated with an increased risk of adverse health outcomes in the population. Hence, even in Canada, where air pollution levels are relatively low compared to many other countries, air pollution results in a considerable burden of disease.

The health effects of air pollution have been extensively studied and are well documented in the peer-reviewed scientific literature, which has been reviewed in depth by Health Canada (Health Canada, 2013; Health Canada, 2016), the US Environmental Protection Agency (US EPA) (US EPA, 2019; US EPA, 2020b), and by international organizations such as the World Health Organization (WHO, 2020). It is recognized that exposure to key air pollutants, including $PM_{2.5}$ and ozone, results in increased risk of a wide variety of adverse health outcomes in the population, ranging from respiratory symptoms to development of disease and premature death. This section provides an overview of the health effects of ozone and $PM_{2.5}$ to help understand current and possible future risks to the health of Canadians from climate change.

5.3.1 Particulate Matter

Particulate matter (PM) is a complex mixture of very small solid particles and liquid droplets made up of many different chemicals, including elemental carbon, organic compounds, metals, sulphates, and nitrates. These particles are small enough to remain suspended in the atmosphere for an appreciable period of time. PM is emitted directly from sources (primary PM, e.g., black carbon or soot) or formed in the atmosphere from precursor compounds that undergo chemical reactions (secondary PM). Both primary PM and

1 $PM_{2.5}$ is used to denote particles with a mass median diameter of 2.5 microns or less. $PM_{2.5}$ can penetrate deep in the human lung (Health Canada, 2013). Particulate matter is also frequently referred to as "aerosols" or "aerosol particles," particularly when discussing climate effects.

secondary PM precursors have a large variety of natural and anthropogenic sources, such as wildfires, motor vehicle exhaust, and coal combustion. The health effects of PM are directly associated with the size of the particles, as smaller particles penetrate deeper into the lungs. $PM_{2.5}$ is of significant concern for human health, has been extensively researched and reviewed, and is causally associated with the greatest range of health effects of any of the major (or "criteria") air pollutants.

Risk assessments published by Health Canada (2013) and the US EPA (2019) have evaluated the weight of evidence of health effects from short-term and long-term exposure to $PM_{2.5}$, and their conclusions are summarized here. Evidence indicates that short-term exposure (hours to days) to ambient $PM_{2.5}$ increases the risk of premature death, including all-cause, cardiovascular, and respiratory mortality. In addition, short-term exposure increases the risk of adverse cardiovascular and respiratory effects, including aggravation of pre-existing cardiovascular and respiratory diseases (e.g., asthma or chronic obstructive pulmonary disease [COPD]), changes in cardiac and lung function, increased respiratory symptoms, and deterioration in indicators of cardiovascular health. Short-term exposure also results in increased medical interventions. For example, population-based studies show that increases in short-term $PM_{2.5}$ exposure are associated with increases in emergency room visits and hospital admissions relating to respiratory and cardiovascular conditions.

Overall, the evidence indicates that long-term exposure (months to years) to ambient $PM_{2.5}$ increases the risk of non-accidental and cardiovascular mortality, and it may also be associated with respiratory mortality. As well, long-term $PM_{2.5}$ exposure increases the risk of adverse respiratory effects, including increased respiratory symptoms and effects on lung development in children, as well as cardiovascular effects, such as health parameters relating to atherosclerosis progression. Chronic exposure to $PM_{2.5}$ increases the risk of lung cancer, and the International Agency for Research on Cancer has classified outdoor PM as carcinogenic in humans (IARC, 2016).

In addition to the extensive evidence examining respiratory and cardiovascular outcomes of $PM_{2.5}$, there is emerging evidence that long-term exposure to $PM_{2.5}$ may be associated with adverse effects on the nervous system, including dementia (Fu et al., 2019). Exposure to $PM_{2.5}$ has also been increasingly associated with other health effects, including metabolic diseases such as diabetes (Chen et al., 2013a) and pregnancy outcomes such as low birth weight (Stieb et al., 2016; Lavigne et al., 2019).

5.3.2 Ozone

Ozone is a gas that is not directly emitted by air pollution sources. Rather, it forms in the atmosphere from reactions between precursor compounds and sunlight. The weight of evidence of health effects of short-term and long-term exposure to ozone have been evaluated by Health Canada (2013) and the US EPA (2020a), the conclusions of which are summarized here. Short-term exposure to ozone increases the risk of non-accidental and cardiopulmonary mortality. The evidence from short-term ozone-exposure studies in humans also demonstrates reduced lung function, increased respiratory symptoms (e.g., cough, shortness of breath), and airway hyper-responsiveness. Epidemiological studies provide evidence of exacerbation of asthma and COPD, respiratory infections, and increases in hospitalizations and emergency room visits for respiratory conditions such as asthma. There is also evidence that short-term ozone exposure is associated with metabolic effects and may also be associated with adverse effects on the cardiovascular system. Long-term exposure to ozone has been associated with reduced lung function growth in children (Gauderman et al., 2000), onset of asthma in subgroups that spend more time outdoors (e.g., children, outdoor workers), and increased respiratory symptoms in children with asthma. There is some evidence that long-term ozone exposure may contribute to premature mortality, in particular from respiratory causes (Turner et al., 2016).

5.3.3 Populations at Higher Risk

Evidence indicates that various subpopulations are at increased risk of health effects from poor air quality (Health Canada, 2013; US EPA, 2019; US EPA, 2020a). Increased risk of PM-related health effects has been identified for older adults and young children, as well as for individuals with pre-existing cardiovascular or pulmonary diseases, or genetic factors that make them more sensitive to the effects of PM. Similarly, some individuals have increased sensitivity to ozone exposure due to underlying health conditions, age, how they spend their time, or genetics. Specifically, ozone exposure increases health risks among children, older adults, subgroups that spend increased time outdoors, individuals with asthma or COPD, and individuals with polymorphisms in genes associated with oxidative stress responses and inflammation. Overall, it has been estimated that about one-third of the Canadian population has at least one risk factor that increases their susceptibility to air pollution (Stieb et al., 2019).

Populations living in areas with higher levels of air pollution are also at increased risk for adverse health effects. Studies of populations in large urban centres in Canada suggest that material and social deprivation are associated with increased exposure to air pollution (Pinault et al., 2016a; Pinault et al., 2017). In addition, children living in low-income areas, racialized populations, and immigrants are exposed to higher levels of air pollution than children in high-income areas, White populations, and non-immigrants, respectively (Pinault et al., 2016b; Pinault et al., 2017).

Indigenous Peoples[2] in Canada may also be more sensitive to adverse health effects from poor outdoor air quality. Overall, the burden of chronic respiratory disease, including asthma and COPD, has been reported to be disproportionally higher in First Nations people (Carriere et al., 2017) and in Métis people (Gershon et al., 2014). In addition, higher rates of lower respiratory tract infections have been reported in First Nations and Inuit children (Kovesi, 2012; McCuskee et al., 2014). This can increase health risks from air pollution. In addition, the risk of exposure to poor air quality may be elevated for Indigenous Peoples due to multiple factors, including overcrowded housing, inadequate ventilation, exposure to smoke from wood heating, and the geographic proximity of many Indigenous communities to forests and, therefore, increased risks from wildfire smoke (Reading & Halseth, 2013; NCCAH, 2017). The existing health and social inequities experienced by Indigenous populations can increase health risks related to poor outdoor and indoor air quality. Many of these inequities are underpinned by systemic racism and colonization (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada and Chapter 9: Climate Change and Health Equity).

2 The term Indigenous is used in this chapter to collectively refer to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples as defined under Section 35 of the *Constitution Act, 1982*. Wherever possible, clear distinctions are made between these three distinct, constitutionally recognized groups.

5.4 Interactions Between Climate Change and Outdoor Air Pollution

Many of the human activities that emit carbon dioxide (CO_2), the main driver of climate change, also emit compounds that contribute to outdoor air pollution. For example, in addition to climate pollutants such as CO_2 and methane, fossil fuel combustion also emits air pollutants, including $PM_{2.5}$, nitrogen oxides (NO_x, including NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), and volatile organic compounds (VOCs). Reactions among these pollutants may form additional $PM_{2.5}$ and ground-level ozone. Some of these air pollutants can modify the radiative balance of the Earth, affecting climate, and are commonly referred to as short-lived climate forcers (SLCFs), as these compounds have a much shorter residence time in the atmosphere than CO_2. This section reviews the linkages among different SLCFs, climate change, and air quality, with a focus on PM, methane, and ozone. An overview of these linkages is presented in Figure 5.1.

The impacts of an SLCF on climate are quantified using estimates of their "radiative forcing," defined as "the net change in the energy balance of the Earth system due to some imposed perturbation" (Myhre et al., 2013, p. 664). An SLCF that produces a positive radiative forcing will result in some increase in the near-surface temperature, while ones producing a negative radiative forcing will have a net cooling effect. However, the efficacy of SLCFs in producing near-surface temperature changes for a given radiative forcing varies. Many forcing agents produce rapid adjustments in various components of the climate system — the effects of aerosols on clouds, for example — and the estimates of radiative forcing discussed here typically include these rapid adjustments, except where stated.

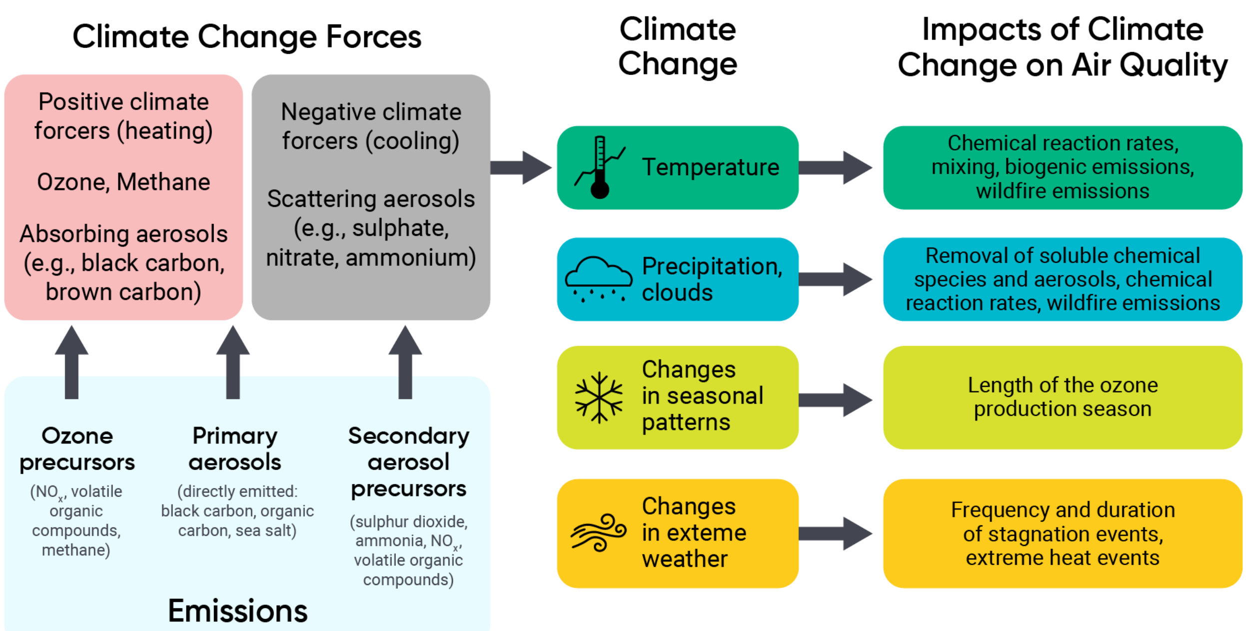


Figure 5.1 Linkages between air quality and climate change. The box colour for the SLCFs indicates either a new positive radiative forcing (red; warming) or a net negative radiative forcing (grey; cooling). Source: Adapted from Ravishankara et al., 2012.

5.4.1 Particulate Matter Effects on Climate

PM can affect climate through direct interactions with radiation, predominantly through scattering or absorption of incoming solar radiation (sunlight). Sulphate, nitrate, ammonium, and secondary organic aerosol particulates predominantly scatter incoming solar radiation, some of which is reflected back into space; therefore, these PM species have a net cooling effect on climate (Boucher et al., 2013). Conversely, PM species that absorb incoming solar radiation, such as black carbon and certain types of organic particulates referred to as brown carbon, have a net warming effect (Bond et al., 2013). The presence of clouds influences these effects (Chand et al., 2009), and, under clear skies, so does the nature of the Earth's underlying surface. PM over highly reflective surfaces such as snow has a stronger net warming effect than over less reflective surfaces because of the relatively larger fraction of incoming solar radiation that would have been reflected back to space without the presence of PM (Haywood & Shine, 1995). In addition, the mix of compounds within individual aerosol particles can also affect the direct radiative effects of PM. For example, absorption of solar radiation by black carbon is enhanced when PM is coated by more weakly absorbing compounds, such as sulphates (Jacobson, 2001; Liu et al., 2017).

PM can also affect climate through its effects on clouds, due to its role as the "seeds" upon which water may condense in either liquid or solid form — acting as cloud condensation nuclei and ice nuclei, respectively. Aside from the mass of particles in the atmosphere, there is also strong evidence that the number of particles influences cloud formation, with increased atmospheric particle number concentrations (total number of particles per unit volume of air) resulting in liquid water clouds with a larger number concentration of smaller cloud droplets, making the clouds more reflective and producing a cooling effect on climate (Boucher et al., 2013). However, PM–cloud interactions are subject to a large number of feedback processes that can locally modify the magnitude and direction of the radiative effects of these interactions, notably through changing precipitation production, which may alter the lifetime or spatial extent of the cloud, and changes involving ice particles in clouds (Fan et al., 2016). For these reasons, the effects of PM on clouds and climate are still uncertain (Seinfeld et al., 2016).

The Fifth Assessment Report[3] of the Intergovernmental Panel on Climate Change (IPCC) assessed the global net radiative forcing from anthropogenic PM, including through both direct radiative effects and aerosol–cloud interactions, at −0.90 (5% to 95% confidence interval [CI] −1.9 to −0.1) W/m^2 (i.e., a net cooling effect). This likely offsets a significant fraction of the estimated +2.83 (5% to 95% CI +2.54 to +3.12) W/m^2 radiative forcing due to the change in concentration of the well-mixed GHGs[4] (CO_2, methane, nitrous oxide, and halocarbons) between 1750 and 2011. However, the net forcing from PM combines significant positive forcing (warming) from black carbon emitted from fossil fuel and biofuel use, and negative forcing (cooling) from sulphates, nitrates, and primary and secondary organic aerosols. The net forcing from PM mentioned above does not include additional positive forcing from black carbon deposited on snow, estimated at +0.04 W/m^2, which has a two to four times larger impact on surface temperatures than CO_2 per unit radiative forcing (Myhre et al., 2013; Skiles et al., 2018).

3 The uncertainties in the estimates of radiative forcing quoted here are the 5% to 95% confidence interval as given by the IPCC Fifth Assessment Report.

4 Well-mixed GHGs are those with long residency time in the atmosphere, which results in their having a relatively homogeneous concentration throughout the troposphere.

Due to the short atmospheric lifetime (approximately 1 week) and highly variable spatial distribution of PM, impacts on radiation can be much larger on regional scales than the global average estimates given above. The chemical composition of PM influences the pathway and fate of incoming solar radiation as it travels through the atmosphere. Both PM that strongly scatters and PM that strongly absorbs incoming radiation reduce the amount of solar radiation reaching the Earth's surface. However, only the latter will warm the atmospheric layer where it occurs. These effects could have significant impacts on surface temperatures and rainfall by reducing the amount of energy absorbed at the surface and, in the case of absorbing PM, heating the atmosphere aloft (Ramanathan et al., 2005; Liu et al., 2012). Modelling studies have shown that, due to the response of the global wind and weather patterns, the effects of SLCFs on climate are not limited to the regions where the emissions occur and may be even larger in regions well removed from the emission sources (Shindell et al., 2015; Kasoar et al., 2016).

5.4.2 Methane and Ozone Effects on Climate

Methane, with an atmospheric lifetime of approximately 9.1 years (Prather et al., 2012), is relatively well mixed throughout the atmosphere and is emitted from a large variety of sources (e.g., natural wetlands, geological seeps, rice cultivation, ruminants, and fossil fuel extraction and use) with an approximately equal contribution from natural and anthropogenic sources at the global scale (Saunois et al., 2016). Methane acts directly as a GHG, with an estimated radiative forcing of +0.48 (5% to 95% CI +0.43 to +0.53) W/m^2 due to the approximately 150% increase in concentrations over the period 1750 to 2011 (Myhre et al., 2013). Methane is also chemically reactive in the atmosphere, participating in the photochemical production of ozone. Ozone, in addition to being an air pollutant, acts as a GHG (Forster & Shine, 1997), and methane, therefore, makes additional contributions to climate forcing through changes in ozone.

Ozone is formed photochemically in the lower atmosphere from precursor compounds, including methane, other VOCs, and NO_x. Ozone is a highly reactive gas, and few reliable measurements are available from before the 1950s (Cooper et al., 2014). As a result, estimates of the change in ground-level ozone and the effects of tropospheric ozone on climate are based on numerical models and are more uncertain than for the long-lived GHG gases (e.g., CO_2). These estimates show that the increase in ozone from pre-industrial levels due to precursor emissions (methane, CO, non-methane VOCs, and NO_x) has resulted in an estimated radiative forcing of +0.50 (5% to 95% CI +0.30 to 0.70) W/m^2, of which +0.24 (5% to 95% CI +0.11 to +0.37) W/m^2 is attributed to ozone from methane (Myhre et al., 2013).

5.4.3 Effects of Climate Change on Air Quality

Changes in climate can have significant effects on air quality. Studies show a strong correlation between temperature and ground-level ozone (Camalier et al., 2007). This relationship results from various factors: direct temperature effects on chemical reactions that produce ozone; increases in biogenic emissions of ozone precursors (e.g., VOC emissions from vegetation) with temperature; and the correlation of higher temperatures with meteorological conditions that are conducive to the production of ozone (Steiner et al., 2006; Schnell & Prather, 2017). While tropospheric ozone in industrial regions in some seasons is expected to increase with increasing temperatures, climate change alone is expected to result in a decrease in the global background concentration[5] of ozone, as increases in water vapour reduce levels of ozone through increased photochemical destruction in remote locations (Wu et al., 2008a; Stevenson et al., 2013).

The direct impacts of increased temperature on PM vary by season. Warmer temperatures in winter will result in a larger fraction of certain PM components remaining in the gas phase, resulting in lower PM concentrations. However, warmer temperatures in summer will favour the increased production of sulphates and higher PM concentrations (Dawson et al., 2007). Observations across the United States suggest additional contributions to PM concentrations result from other temperature-related factors (Tai et al., 2010). In particular, increased emissions of VOCs from biogenic sources, such as trees, with increasing temperature have been shown to have a strong impact on the formation of organic components of PM (Day & Pandis, 2011).

Climate change includes many complex changes beyond increasing temperature. By more rapidly warming the Arctic, climate change may lead to a greater persistence of hot and dry conditions associated with slow-moving high-pressure systems (Coumou et al., 2018). Summertime episodes of poor air quality over Southeastern Canada and the Northeastern United States are frequently associated with these large, slow-moving high-pressure systems and are brought to an end by the passage of a mid-latitude cyclone and associated cold front. Less frequent summertime mid-latitude cyclones have been observed in the recent past, negatively affecting air quality (Leibensperger et al., 2008), and less frequent mid-latitude cyclone passage has been projected under future climate scenarios in several studies (Mickley et al., 2004; Wu et al., 2008b). However, the magnitude of these specific effects on future changes in air pollution is uncertain. Tai et al. (2012) found that the changes in the frequency of mid-latitude cyclone passage had only a small impact on PM, while Horton et al. (2014), from an analysis of 15 different climate models, found relatively small increases in stagnation events, which may lead to higher pollutant concentrations for 2080 to 2099 along the west coast of North America, Northeastern United States, and Southeastern Canada.

5.4.4 Air Quality Projections Under a Changing Climate

A large number of studies have used regional-scale air quality models, combined with future climate projections, to estimate future changes in tropospheric ozone and PM across North America. It should be noted that projections of future air quality depend on model projections of changes in the physical climate, and these changes are more uncertain at regional (sub-continental and smaller) scales for a variety of reasons (Deser et al., 2012; Mearns et al., 2013; Giorgi & Gutowski, 2015). Future air quality will also be affected by changes in air pollutant and precursor emissions. Many studies estimate the effects of climate change alone by making future projections using constant, present-day emissions of air pollutants. The impact of climate change alone on air quality, discussed in this section, is frequently referred to as "the climate penalty" (Wu et al., 2008b).

While differences in modelling assumptions and scenarios make detailed comparisons difficult, some general conclusions can be drawn. Available studies generally find that, relative to current conditions,

5 The "background concentration" of ozone refers to the concentration of ozone found in remote regions, far from significant anthropogenic emission sources. The background concentration varies with latitude, altitude, and season and is, nonetheless, significantly influenced by anthropogenic sources.

climate change will cause small increases across large parts of North America of 2 to 3 parts per billion by volume in the daytime average ozone concentration during the summer (June to August) by the middle of the century (Hogrefe et al., 2004; Nolte et al., 2008; Lam et al., 2011; Kelly et al., 2012). Isolated increases of about 5 parts per billion by volume were also found across different modelling studies. The largest increases were projected over industrialized regions, such as the Northeastern United States and adjacent regions of Southeastern Canada. These studies have also found some evidence for a larger impact of climate change on days with the highest ozone concentrations (Hogrefe et al., 2004; Nolte et al., 2008) and indications that climate change may lengthen the ozone season (Nolte et al., 2008; Trail et al., 2014).

Estimates of the impact of climate change alone on PM are more uncertain, as there are fewer studies, and the physical and chemical processes affecting PM are more complex and more sensitive to changes in physical climate variables that climate models represent poorly, such as the frequency of precipitation. Tagaris et al. (2007) found decreases of 10% to 20% (1 to 2 µg/m^3) in $PM_{2.5}$ over central and southeastern parts of the United States by about 2050, due to higher precipitation, although only three summers were simulated. Conversely, Kelly et al. (2012) simulated 10 summers leading to 2050 and found the effects of climate change alone resulted in increases in summer $PM_{2.5}$ of 0.5 to 1.0 µg/m^3 over much of the Eastern United States, extending into Southwestern Ontario. Increases of 0.3 to 0.5 µg/m^3 were projected over the broader region of Southern Ontario and Southern Quebec. The increases in $PM_{2.5}$ resulted from the net effect of increases in sulphates and secondary organic aerosols and decreases in nitrates. These changes can be contrasted with those found by Trail et al. (2014), who projected decreases in summer $PM_{2.5}$ of 1 to 2 µg/m^3 for periods around 2050 across most of the Central United States to the Great Lakes, due to increased dispersion of pollutants in the atmosphere because of projected changes in wind speed and precipitation. These results demonstrate the level of uncertainty in our current understanding of certain aspects of changes in physical climate and associated air quality projections, as represented by existing models. For changes in annual average $PM_{2.5}$, the available studies suggest very small changes in regional average values (Tagaris et al., 2007; Lam et al., 2011; Trail et al., 2014).

Two important caveats to the preceding discussion are worth noting. First, ozone and PM precursor emissions have been reduced significantly over the recent past in the United States and Canada because of emissions controls put in place to reduce the environmental and human health impacts of air pollution (Amann et al., 2013; Stieb et al., 2015; Fann et al., 2017; Jiang et al., 2018; Zhang et al., 2018). Air pollutant emissions are projected to decrease further over the coming decades as a result of air quality regulations, and available projections show significant net improvements in air quality can be realized in the future, accounting for the combined effects of anticipated reductions in air pollutant emissions and the negative impact of climate change (Tagaris et al., 2007; Nolte et al., 2008; Lam et al., 2011; Kelly et al., 2012; Pfister et al., 2014; Trail et al., 2014; Yahya et al., 2017). However, additional reductions in air pollution emissions would be required to counteract the effect of the climate penalty. Second, future ozone concentrations in North America will be affected by changes in the global concentration of methane (Yahya et al., 2017). Increases in the concentrations of methane result in a higher global background concentration of ozone (Stevenson et al., 2013), which affects ozone concentrations in North America, as regional-scale episodes of high ozone build on top of the global background.

Another impact of climate change on air quality is the expected increase in the length and severity of the wildfire season (Flannigan et al., 2013). Estimates of the effects of climate change on wildfire emissions of black and organic carbon aerosols suggest increases of 80% to 150% by 2050 (compared to 1997 to 2001) over the Western United States (Yue et al., 2013), with an increase in summer average $PM_{2.5}$ concentrations of 20% to 60% (Val Martin et al., 2015). These projections were based on increases in the average annual area burned each year of between 25% and nearly 170%, which are comparable to estimates of the increase in area burned by mid-century for Canada (Boulanger et al., 2014). Note that the Val Martin et al. (2015) study did not include any increase in wildfires in the Eastern United States because any climate change effect was found to be negligible, while projections of wildfires in Canada show increases from coast to coast (Boulanger et al., 2014; Wang et al., 2017). For more information on the impact of climate change on wildfires in Canada and the associated health impacts, see section 5.6 Climate Change and Air Pollution from Wildfires.

5.4.5 Air Quality Policies and Climate Change Mitigation

Because of the relatively short time that air pollutants remain in the atmosphere, reductions in their emissions quickly affect their atmospheric concentrations and the associated radiative forcing of these compounds. Actions to reduce certain air pollutants that are SLCFs, such as black carbon, are therefore recognized as a way to reduce climate warming over the near term (CCAC, 2020). This would allow more time for international CO_2 mitigation efforts to have an impact before critical temperature thresholds are crossed, while also simultaneously reducing the health and environmental burden of air pollution (IPCC, 2018). Shindell et al. (2012) projected a reduction in global mean warming of 0.5°C by 2050, relative to pre-industrial levels, resulting from a suite of controls on methane and black carbon emissions, and estimated additional, significant benefits for human health and agricultural yields. A smaller cooling benefit of 0.22°C by 2050 from a range of emission controls designed to maximize the climate benefit — largely targeting methane and black carbon — was found by Stohl et al. (2015). The authors also estimated that a warming of nearly 0.7°C would result from the complete removal of land-based anthropogenic SO_2 sources, illustrating the significant cooling effect of sulphate PM from SO_2 precursor emissions.

These results demonstrate the need to evaluate climate change and air quality policies in an integrated manner. Targeting SLCFs that have a net warming effect on climate, namely methane and black carbon, would have simultaneous benefits for climate and air quality. Conversely, certain actions designed to improve air quality may have unintended negative consequences for climate change (Stohl et al., 2015; Partanen et al., 2018). However, the strategic application of air pollution emission controls can have significant co-benefits for climate change, and well-designed GHG mitigation strategies, such as those targeting reductions in the use of fossil fuels, can have clear co-benefits for air quality and, hence, population health (Vandyck et al., 2018). Co-benefits for health associated with GHG reductions are reviewed in section 5.5 Air Pollution Health Impacts Due to Climate Change and the Health Co-Benefits of Greenhouse Gas Mitigation and also highlighted in Chapter 10: Adaptation and Health System Resilience of this report.

5.4.6 Key Uncertainties

One of the most significant risks to air quality throughout Canada associated with climate change is the projected increase in emissions from wildfires. An improved understanding of the effects of climate change on wildfires requires further development of the capacity to simulate interactions between climate and fire risk, taking into account anthropogenic influences such as fire management through suppression, for example, in terrestrial carbon cycle models. A second significant uncertainty in projections of climate change effects on air quality is the impact of future changes in biogenic emissions. As discussed above, increasing biogenic emissions due to warmer temperatures is an important mechanism by which climate change negatively affects air quality. However, the likely effects of higher CO_2 and water stress, as well as changes in the distribution of vegetation types on biogenic emissions, are not well understood (Fiore et al., 2015). Last, many of the studies estimating the impact of climate change on air quality have been based on only a few years of simulation because of the computational cost of the models. The short time periods make it difficult to remove the influence of random year-to-year variability from the effects of climate change (Barnes et al., 2016) or to robustly analyze climate change impacts on more extreme, but less frequent, climate events.

5.5 Air Pollution Health Impacts Due to Climate Change and the Health Co-Benefits of Greenhouse Gas Mitigation

Exposure to air pollutants can cause a range of adverse health effects, and even small increases in exposure are associated with an increase in risk (see section 5.3 Health Effects of Outdoor Air Pollution). It is anticipated that climate change will worsen air quality both globally and in Canada, due to the climate penalty (see section 5.4 Interactions Between Climate Change and Outdoor Air Pollution). Studies have tried to estimate the effect of the climate penalty on two key air pollutants that have major health impacts, ozone and $PM_{2.5}$, under possible future climates (Ebi & McGregor, 2008; Gao et al., 2013; Turnock et al., 2019). Conversely, many strategies that target long-lived GHG and SLCF emission reductions, such as reducing the use of fossil fuels, can be expected to reduce air pollutant emissions and improve air quality. The associated population health benefits are referred to as “air pollution health co-benefits” because they are not the primary motive behind development of those policies. Consequently, efforts undertaken to mitigate climate change in Canada may also have important air pollution health co-benefits. Many initiatives to reduce climate change are underway at global (e.g., the Paris Agreement [UNFCCC, 2015]), national (e.g., *A Healthy Environment and a Healthy Economy* [ECCC, 2020]), provincial (e.g., *Plan d’action 2013-2020 sur les changements climatiques* [Ministère de l'Environnement et *Lutte contre les changements climatiques, 2012*]), and municipal (e.g., *Climate 2050 Strategic Framework* [Metro Vancouver, 2018]) levels.

Scientists can quantify the number of population health impacts, such as premature deaths or asthma episodes, attributable to a given increase or decrease in air pollution. Economists estimate the social welfare value of these health impacts, including such things as medical costs, reduced workplace productivity, and the effects of increased mortality risk. These methods allow for estimation of the health impacts and associated monetary value of both the costs of air pollution increases under a warming climate and of the air pollution health co-benefits of mitigating climate pollutants. It is important to note that modelled air pollution health impacts or benefits of individual scenarios are likely underestimated, as not all adverse health outcomes that have been associated with air pollution exposure can be quantified and valued in this manner.

This section of the chapter provides a review of published studies that have assessed the air pollution health impacts of the climate penalty and the potential air pollution health co-benefits of climate mitigation, including the associated economic valuation of those outcomes. It also presents information on the health impacts of the climate penalty and potential health co-benefits of GHG mitigation in Canada, including those associated with eliminating coal-fired electricity generation in Canada.

5.5.1 Air Pollution Health Impacts Due to Climate Change

Studies have investigated how a changing climate could influence future population health impacts of air pollution. Researchers have assessed these health impacts both regionally and globally, under various climate projection scenarios, including the Representative Concentration Pathways (RCPs)[6] and the Special Report on Emissions Scenarios (SRES)[7] published by the IPCC, and for multiple future time periods. Most studies have examined the influence of climate change on ozone, and some have also addressed $PM_{2.5}$. Both premature mortality and morbidity outcomes have been considered. In the studies reviewed here, the authors estimated the incremental air pollution health impacts in the future due to climate change alone (i.e., the impact of a warming climate on air pollution concentrations), keeping other factors constant.

More recent studies have used the RCPs described in the Fifth Assessment Report of the IPCC (2014) and other publications (van Vuuren et al., 2011; van Vuuren & Carter, 2014) to model future climate change projections. The RCPs, identified as RCP2.6, RCP4.5, RCP6.0, and RCP8.5 (referring to different levels of radiative forcing in watts per square metre), represent global climate policy scenarios ranging from more stringent (RCP2.6) to less stringent (RCP8.5) in terms of GHG reductions and concentration trajectories. The RCPs also include projected policies to control air pollution. The more stringent RCP scenarios are also associated with lower air pollutant emissions globally and in Canada, given that many changes in sector activities to reduce GHG emissions (e.g., transition to cleaner energy sources) would also reduce air pollution emissions. The four RCP scenarios project average global temperature increases for 2081 to 2100 (relative to 1986 to 2005) of 1.0°C, 1.8°C, 2.2°C, and 3.7°C, respectively. The RCPs are more in-depth explorations of the impacts of potential mitigation strategies on GHG emissions and are an extension and further development of the GHG emissions-based SRES projections used in previous IPCC assessment reports (IPCC, 2014).

There are no recent published analyses from Canada using the RCP scenarios, but findings have been published for the United States and for global analyses. In a national analysis, Fann et al. (2015) estimated

6 The Representative Concentration Pathways (RCPs) are four different plausible consequences of future climate policy scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) with emission and concentration trajectories of GHGs and other air pollutants and land-use pathways (IPCC, 2014).

7 The SRESs describe emission projection scenarios organized into four storylines — A1 (subgroup A1B), A2, B1, and B2 — describing plausible futures according to assumptions for various driving forces, such as social and economic development, technology innovation, and environmental changes (Nakicenovic et.al, 2000).

that summer average eight-hour daily maximum ozone concentrations would increase by about 1 to 5 ppb for parts of the United States in the near future (2030) due to climate change, under RCP6.0 and RCP8.5 scenarios. This analysis compared air quality impacts under the 2030 climate, as projected by the RCPs, with air quality impacts under climatic conditions in 2000. The ozone-related health outcomes in 2030 are presented in Table 5.1. The ranges in the projections reflect estimates of the health effects of ozone from multiple epidemiological studies. Overall, health impacts and the associated societal costs under RCP8.5 are projected to be an order of magnitude higher than under RCP6.0.

Table 5.1 Projected increases in annual ozone-related health impacts (counts) in 2030 in the United States under two climate scenarios

CLIMATE PROJECTION	PREMATURE DEATHS	HOSPITAL ADMISSIONS	EMERGENCY ROOM VISITS	ACUTE RESPIRATORY SYMPTOMS	MISSED DAYS OF SCHOOL	TOTAL ECONOMIC VALUATION (IN 2010 USD)
RCP6.0	37–170	360	89	210,000	67,000	0.32–1.4 billion
RCP8.5	420–1900	3900	1200	1,900,000	650,000	3.6–15 billion

Source: Fann et al., 2015

Much lower US health impacts for the year 2050 (less than 100 ozone-related premature deaths) were reported in a separate analysis of the climate penalty under RCP4.5 and RCP8.5 (Stowell et al., 2017).

Climate change impacts on both ozone and $PM_{2.5}$ health effects under the RCP8.5 scenario have also been assessed globally, with estimates of 43,600 and 215,000 excess deaths annually by 2100 due to ozone and $PM_{2.5}$ increases, respectively, including almost 10,000 deaths in North America. Global impacts in the near term (2030) were estimated to be almost 60,000 excess deaths annually for the two pollutants combined (Silva et al., 2017). Multiple models show an increase in $PM_{2.5}$ health risks due to the climate penalty in nine of the 10 regions of the world, including North America (Park et al., 2020).

Several investigators have applied the older SRES A1B scenario, which is roughly comparable to RCP6.0 and estimates a global temperature increase of 1.59°C in 2050, to project the air pollution health impacts of climate change. These studies estimate hundreds of ozone-related and several thousand $PM_{2.5}$-related deaths annually in 2050 in the United States due to the warming climate, along with thousands of hospital visits, bronchitis incidents, and asthma attacks (Selin et al., 2009; Tagaris et al., 2009). Higher estimates of ozone and $PM_{2.5}$-related deaths attributable to climate change were reported for the year 2090, with 13,000 deaths in North America and more than 100,000 deaths globally (Fang et al., 2013). A study of 50 US cities under the SRES A2 scenario in the 2050s, which predicts a rise in average summer temperature for the Eastern United

States of 1.6°C to 3.2°C, projected an increase in mortality (0.11% to 0.27%) and hospital admissions for asthma (2.1%) and COPD (0.2% to 1.6%) due to ozone increases under the future climate (Bell et al., 2007).

A Canadian analysis estimated the air pollution health impacts for a hypothetical increase of 4°C in ambient temperatures for 2002, with anthropogenic air pollution emissions held at 2002 levels (Séguin, 2008). Nationally, increases in summer ozone concentrations due to the higher temperature were associated with 156 excess premature deaths and a total economic value of $750 million due to mortality and morbidity outcomes. This increased to 658 premature deaths ($3.2 billion) when increases in biogenic emissions, expected under a warmer climate, were also included. However, the same study projected, with considerable uncertainty, a net reduction in $PM_{2.5}$ concentrations under the warmer climate, so that the net effect of the two pollutants under a 4°C increase was estimated to be an excess of approximately 300 premature deaths and a social cost of $1.4 billion.

Overall, these studies show that climate change is expected to worsen air quality and cause considerable deaths and illnesses related to air pollution, with hundreds to thousands of excess annual deaths in North America over this century and 100,000 annual excess deaths estimated globally by 2100. Studies that examined both ozone and $PM_{2.5}$ generally estimated that effects of climate change on $PM_{2.5}$-related health outcomes are about an order of magnitude higher than those associated with ozone.

5.5.2 Air Pollution Health Co-Benefits of Mitigation of Greenhouse Gas Emissions

Mitigation measures to reduce GHGs and SLCFs help stabilize the climate by reducing pollutants that play a role in increasing global temperature and accelerating climate change. However, climate change mitigation strategies can also have a range of indirect health co-benefits (Markandya et al., 2018). Key among these are health co-benefits from reductions in air pollution because of the following: climate mitigation will limit the climate penalty; some climate pollutants (e.g., black carbon, ozone) contribute to air pollution either directly or as precursors; and changes in industrial and transportation activities to reduce long-lived GHG and/or SLCF emissions can also reduce co-emitted conventional air pollutants (Smith et al., 2014). For example, the widespread use of electric vehicles powered by low-carbon energy can be a strategy for GHG mitigation that could also result in improved air quality. Consequently, climate change mitigation measures represent an opportunity to integrate objectives to stabilize the climate with those to reduce air pollution health impacts, which may offset the costs of implementing the measures (Thompson et al., 2016).

Studies examining air pollution health co-benefits associated with GHG mitigation strategies typically compare a policy scenario that includes strong GHG mitigation and accompanying reductions in air pollutant emissions with a scenario with limited GHG mitigation and associated higher air pollutant emissions. Economic valuation of air pollution health co-benefits allows co-benefits to be incorporated into a broader climate change framework, and the cost-effectiveness and potential optimization of various GHG mitigation measures, which can impose an economic burden on society, can be examined. Studies report monetized health co-benefits as total dollar value or as the marginal benefit per tonne of CO_2 equivalent that is reduced. Both $PM_{2.5}$- and ozone-related health co-benefits have been evaluated in the studies reviewed below, unless otherwise stated.

In a global analysis of GHG mitigation measures associated with RCP4.5, it was estimated that Canadian air pollution health co-benefits would range from about 4500 to 6500 avoided premature deaths annually between 2030 and 2100, relative to the reference scenario associated with the RCP projections (West et al., 2013) (Table 5.2). US co-benefits were estimated to be about an order of magnitude higher (West et al., 2013; Zhang et al., 2017). Globally, changes in emissions were estimated to avoid 0.5 million, 1.3 million, and 2.2 million deaths from combined exposure to ozone and $PM_{2.5}$ in 2030, 2050, and 2100, respectively. The global average monetized marginal health co-benefits were estimated to be \$50 to \$380 per tonne of CO_2 (tCO_2) (in 2005 USD), which exceed the marginal GHG abatement costs in 2030 and 2050 in this analysis, and partially offset the costs in 2100 (West et al., 2013). For the United States, the marginal value of avoided ozone- and $PM_{2.5}$-related deaths was estimated to be \$45 to \$137/tCO_2 (in 2005 USD) (Zhang et al., 2017).

Table 5.2 Air pollution health co-benefits associated with the projected scenario of RCP4.5 (annual avoided premature deaths)

STUDY	2030		2050		2100	
	OZONE	$PM_{2.5}$	OZONE	$PM_{2.5}$	OZONE	$PM_{2.5}$
Canada (West et al., 2013)	368	4270	792	5750	1180	2880
United States (West et al., 2013)	2440	19,300	7550	29,500	24,800	35,400
United States (Zhang et al., 2017)			8000	16,000		
Global (West et al., 2013)	0.5 million		1.3 million		2.2 million	

Other studies have evaluated the avoided air pollution deaths associated with climate mitigation pathways based on specific targets for increases in global mean surface temperature in the future compared to a reference scenario. The United States air pollution heath co-benefits of reducing the climate penalty were estimated for two climate mitigation scenarios, reflecting a 2.5°C and 2.0°C increase in global mean surface temperature (Saari et al., 2019). The two mitigation scenarios reduced the combined ozone and $PM_{2.5}$ health impacts by thousands and tens of thousands of deaths in 2050 and 2100, respectively, with 40% greater $PM_{2.5}$ benefits by 2100, under the more stringent policy compared to the less stringent policy. In 2100, air pollution (ozone and $PM_{2.5}$) risks associated with climate change were attenuated by 70% to 88% in the policy scenarios. Similarly, United States health co-benefits of limiting global warming in 2100 to a 1.5°C rise was estimated to result in 11,000 and 52,000 avoided premature deaths across the United States in 2050 and 2100, respectively, compared to a reference scenario with a 6°C increase in global mean surface temperature. These health co-benefits were valued at 150 billion USD and 1.3 trillion USD (in 2005 USD), respectively, which were equivalent to a rate of $25 (95% CI $9–$42) per tonne of CO_2 equivalent (tCO_2e) and $122 (95% CI $45–$207)/tCO_2e, respectively (Garcia-Menendez et al., 2015).

In a global analysis, Vandyck et al. (2018) examined the air quality implications in 2100 of two GHG mitigation scenarios, the first based on GHG emission reductions implied by the Nationally Determined Contributions,[8] leading to a 2.5°C to 3.2°C rise in global mean temperature by 2100, and the second a 2°C rise by 2100. Globally, avoided deaths due to air pollution in 2050 were estimated at 0.3 to 0.5 million for the Nationally Determined Contributions scenario and 0.7 to 1.5 million for the 2°C scenario, including about 20,000 to 25,000 avoided deaths in the United States. The timing of taking action can affect the magnitude of the accrued health co-benefits. For example, it was estimated that about 150 million deaths due to air pollution globally could be avoided over this century if carbon emission reductions to limit warming to 2ºC are implemented sooner rather than later in the 21st century (Shindell et al., 2018).

Another global study specifically examined the potential air pollution health co-benefits of meeting the Paris Agreement temperature change targets of 1.5°C and 2°C, and compared them to the associated mitigation costs of the climate policy scenarios (Markandya et al., 2018). Globally, the economic value of the health co-benefits were estimated to outweigh the mitigation costs for all scenarios examined, with the ratio of health co-benefits to climate change mitigation costs ranging from 1.4 to 2.45. The greatest potential health co-benefits were observed for China and India, but significant co-benefits were also estimated for the European Union and the United States. Overall, climate change mitigation measures to meet the targets established in the Paris Agreement can be cost-effective under the modelled scenarios and, depending on geographical regions, when air quality associated health co-benefits are considered.

Other studies have estimated thousands of avoided deaths due to ozone for North America and hundreds of thousands globally under various climate change mitigation scenarios, including those targeting methane (West et al., 2007; West et al., 2012). The latter were valued at $13 to $17/$tCO_2e$ (2005 USD) in 2030, which outweighed the costs of measures to reduce methane emissions (West et al., 2012).

Some studies have examined the co-benefits of climate change mitigation strategies targeting specific SLCFs or emission sectors. The annual health co-benefits of full electrification of the vehicle fleet in the Greater Toronto and Hamilton Area (Canada) were estimated at 260 and 330 avoided deaths, based on electricity

8 Nationally Determined Contributions are country-specific emission reduction pledges to meet the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC, 2015).

derived from natural gas or from renewables, respectively (Gai et al., 2020). The North American health co-benefits of ambitious clean energy and clean transportation scenarios in the United States were estimated at 175,000 and 120,000 avoided deaths due to air pollution, for the 2015 to 2030 period, respectively, with additional annual benefits thereafter (Shindell et al., 2016). The majority of benefits were from $PM_{2.5}$ reductions, with a smaller fraction from ozone reductions, and 3% to 4% of all benefits (thousands of avoided deaths for 2015 to 2030 period) were estimated for Canada. Near-term US benefits of the policies were valued at 250 billion USD (95% CI 140 billion to 1.05 trillion USD) annually.

A global analysis of strategies to reduce methane and black carbon reported that implementation of the measures would avoid 0.7 to 4.7 million deaths per year globally, with the largest impact attributable to black carbon reductions, and a marginal benefit of 700 to 5000 USD per tonne of methane reduction (Shindell et al., 2012). Carbon policies for the United States addressing clean electricity production, on-road transportation, and an economy-wide cap-and-trade system were estimated to have air pollution health co-benefits associated with $PM_{2.5}$ and ozone reductions that would offset approximately 26% to 1050% of GHG mitigation costs (Thompson et al., 2014). The marginal health co-benefits of $PM_{2.5}$ reductions under the cap-and-trade scenario were estimated at \$6/tCO_2, which exceeded the implementation costs, and at \$8/tCO_2 (in 2005 USD) under the clean energy scenario, which partially offset the implementation costs (Saari et al., 2015). Marginal health co-benefits of \$148/tCO_2 (in 2006 USD) compared to GHG mitigation costs of \$126/tCO_2 under a clean energy scenario, and marginal health co-benefits of \$80/tCO_2 compared to costs of \$15/tCO_2 under the cap-and-trade scenario were reported for a subnational carbon policy in the Northeastern United States. It was noted that costs varied widely due to regional differences in energy consumption (Thompson et al., 2016).

It is important to consider all aspects of emission changes when evaluating the health co-benefits of climate change mitigation strategies. The US air pollution health co-benefits associated with electric vehicle (EV) adoption were found to vary, depending on the source mix of electricity generation (Peters et al., 2020). It was estimated that 25% of EV use powered by the current US electricity grid mix would result in 437 (95% CI 295 to 578) avoided premature deaths due to $PM_{2.5}$ and 98 (95% CI 33 to 162) due to ozone reductions annually, with a total value of about 16.8 billion USD. The health co-benefits were estimated to be about twice as high for the same EV adoption rate if the fraction of emission-free energy sources in the grid mix was doubled, although the associated reduction in CO_2 emissions would only increase by about 10%.

Overall, studies of the potential air pollution health co-benefits associated with climate mitigation scenarios targeting maximum increases in global mean temperature of about 1.5°C to 3°C consistently indicate that substantial health benefits would be realized. Annually, the burden of disease would be reduced by up to tens of thousands of premature deaths related to $PM_{2.5}$ and ozone in the United States in 2050 and 2100, and by up to 1 million to 2 million premature deaths globally. When directly compared in a study, more stringent mitigation policies confer greater co-benefits, and there is evidence that larger co-benefits will be realized if policies are implemented sooner rather than later. Air pollution health co-benefits represent a significant public health gain for individual countries and globally, and the socio-economic value can contribute to or even offset the costs of mitigation. Moreover, the joint consideration of climate change and air pollution mitigation options provides a framework to optimize the overall public health benefits and to identify potential unintended consequences, such as inadvertent risks to health. This was made evident following the promotion of diesel-fuelled vehicles in some countries because of their lower GHG emissions, which resulted in elevated emissions of air pollutants (Cames & Helmers, 2013; Haines, 2017).

Box 5.1 The elimination of coal-fired power in Canada: A case study of air pollution health co-benefits

In 2012, the Government of Canada published the *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations* (Government of Canada, 2012). These regulations set a CO_2 emission performance standard for new coal-fired electricity generation units and for those reaching the end of their useful lifespan of 50 years. The objective was to ensure a permanent transition to power generation options that emitted low amounts or no CO_2, such as renewable energy or high-efficiency natural gas, and to ensure that no new high-emitting units would be built in Canada. In 2010, Alberta, Ontario, Saskatchewan, Nova Scotia, New Brunswick, and Manitoba had coal-fired power generation capacity, in decreasing order of magnitude.

It was estimated that during the 2015 to 2035 period the Regulations would result in avoiding 6820 megawatts of coal-fired electricity production, with 74% in Alberta, 14% in Nova Scotia, and 11% in Saskatchewan. This would result in emissions reductions of 219 Mt CO_2 equivalent, which was valued at $5.6 billion (in 2010 CAD), based on the social cost of carbon[9] (Government of Canada, 2012).

In addition to emitting GHGs, coal-fired power generation is a source of air pollutant emissions. The air quality and health co-benefits of the reductions in air pollution emissions associated with the Regulations were estimated by the Government of Canada. The following cumulative reductions in air pollutant emissions were estimated for 2015 to 2035: 1156 kt SO_x, 546 kt NO_x, 9 kt $PM_{2.5}$, and 48 kt CO. Air quality modelling was undertaken to see how these changes in emissions would affect air pollutant concentrations.

For the 2015 to 2035 period, it was estimated that the incremental improvements in air quality associated with the Regulations would result in avoiding 900 premature deaths, 800 hospital visits, 120,000 asthma episodes, and 2.7 million episode-days when individuals experience breathing difficulty or must reduce activity. Of these cumulative impacts, 590, 140, 80, and 57 avoided deaths were estimated for Alberta, Saskatchewan, Manitoba, and Ontario, respectively. The national health co-benefits were estimated to have a value in 2015 of $4.2 billion (in 2010$), of which about 70% were attributable to reductions in ambient $PM_{2.5}$ and about 26% to reductions in ambient ozone. The air pollution health co-benefits of $4.2 billion contributed a significant portion of the estimated value of the overall benefits of the Regulations ($23.3 billion), which was found to outweigh the estimated associated costs of $16.1 billion (Government of Canada, 2012). The Regulations were later amended to accelerate the phase-out of conventional coal-fired power in Canada by 2030. It was estimated that the associated improvements in air quality from 2019 to 2055 would result in an additional 260 avoided premature deaths and 40,000 avoided asthma episodes, with a total socio-economic value of $1.2 billion (Government of Canada, 2018).

This case study illustrates that the air pollution health co-benefits of GHG mitigation strategies can represent a substantial value to Canadians, although reducing air pollution may not be the primary goal of the regulation or policy in question. In addition, while some of the climate change benefits of GHG reductions may be fully realized only over the medium to long term (Zickfeld & Herrington, 2015), air pollution health co-benefits start immediately following the reduction of emissions, accrue over time, and occur in the area where mitigation is implemented.

9 The social cost of carbon is a monetary measure of the global damage expected from climate change from one additional tonne of CO_2 emissions in a given year.

5.5.3 Canadian Research Highlight: Quantifying Canadian Air Pollution Health Impacts of a Warming Climate and the Potential Health Co-Benefits of a Greenhouse Gas Mitigation Pathway

Health Canada undertook an analysis of the potential air pollution health impacts in Canada due to the climate penalty and the potential health co-benefits of a specific GHG mitigation pathway for the purposes of this assessment report. In a previous study, scientists at Environment and Climate Change Canada modelled mid-century air quality in North America to examine the influence of both a warming climate and GHG emission controls (Kelly et al., 2012). Air quality estimates were made using a unified regional air-quality modelling system (AURAMS), specifically, a comprehensive Canadian system. Specifically, air pollution concentrations were modelled for the June to August period under the current climate (based on meteorological data from 1997 to 2006) and under a future climate in 2041 to 2050 (based on meteorological conditions in SRES A2). Air pollutant emissions, which were derived from the 2002 Canadian emissions inventory, were held constant between the two scenarios in order to examine the impact of changing climatic conditions alone. Biogenic emissions and the effect of temperature on those emissions were included, but wildfire emission changes associated with climate change were not addressed. In addition, the study estimated air pollutant concentrations under the same 2041 to 2050 future climate, with a 2050 emissions inventory informed by RCP6.0 (a moderate GHG mitigation scenario), which was used to scale North American air pollutant emissions from 2002 to 2050 levels (Kelly et al., 2012). RCP6.0 was chosen in part due to the high level of detail available in its accompanying emissions activity changes, allowing a more precise calculation of the air pollutant reductions associated with the GHG-emitting activity reductions. This scaling reflects both air pollutant emission reductions associated with GHG mitigation as well as assumed air pollution controls. Air pollutant concentrations for each scenario were estimated on a national grid at 45 km resolution, and effects on both ozone and $PM_{2.5}$ were considered. As noted in section 5.4 Interactions Between Climate Change and Outdoor Air Pollution, effects of a changing climate on $PM_{2.5}$ are more complex and less well studied than effects on ozone. Therefore, projections of changes in $PM_{2.5}$ are more uncertain.

For the current analysis, the air quality output from the three scenarios modelled by Kelly et al. (2012) was used as input for Health Canada's Air Quality Benefits Assessment Tool (AQBAT 3.0). AQBAT is a national model used to estimate the human health (mortality and morbidity outcomes) and welfare benefits or damages associated with incremental changes in ambient concentrations of air pollutants, including $PM_{2.5}$ and ozone, in Canada (Health Canada, 2019). AQBAT includes concentration-response functions (CRFs), which characterize the increase in per capita risk of a given adverse health outcome per unit increase in ambient air pollutant concentration, based on published scientific studies. AQBAT estimates health impacts by combining the following parameters: the baseline risk of the adverse outcome in the population, population counts, CRFs, and the change in air pollutant concentrations between the scenarios. In addition, AQBAT provides economic valuation estimates for the health outcomes; these consider the potential social welfare consequences of the health outcomes, including medical costs, reduced workplace productivity, pain and suffering, and the effects of increased mortality risk.

The air pollutant concentration estimates from these three scenarios were used to answer the following questions.

What would the incremental air pollution health impacts in Canada be in 2050 due to:

- a changing climate, if air pollution precursor emissions remain unchanged (i.e., the climate penalty)?
- reductions in air pollution precursor emissions associated with the RCP6.0 projection, under future climate conditions?
- a changing climate and reductions in air pollution emissions associated with the RCP6.0 projection, compared to recent climatic conditions and emissions?

The Canadian population health impacts calculated for 2050 (June to August) and the associated economic valuation estimates are presented in Tables 5.3 and 5.4.

Table 5.3 National, provincial, and territorial ozone and $PM_{2.5}$ premature deaths and valuation for June to August[a]

REGION	CHANGE IN NUMBER OF PREMATURE DEATHS (ECONOMIC VALUATION)		
	IMPACT OF CHANGING CLIMATE IN 2050[b]	IMPACT OF REDUCED AIR POLLUTANT EMISSIONS AS PER RCP6.0 IN 2050[c]	IMPACT OF CHANGING CLIMATE AND REDUCED AIR POLLUTANT EMISSIONS AS PER RCP6.0 IN 2050[d]
Canada	850 ($2,700,000,000)	−5,200 (−$16,000,000,000)	−4,400 (−$14,000,000,000)
British Columbia	−56 (−$170,000,000)	−81 (−$250,000,000)	−140 (−$420,000,000)
Alberta	−9 (−$27,000,000)	−220 (−$680,000,000)	−230 (−$710,000,000)
Saskatchewan	9 ($29,000,000)	−58 (−$180,000,000)	−49 (−$150,000,000)
Manitoba	15 ($48,000,000)	−62 (−$190,000,000)	−47 (−$150,000,000)
Ontario	620 ($1,900,000,000)	−2,900 (−$9,100,000,000)	−2,300 (−$7,300,000,000)
Quebec	270 ($830,000,000)	−1,500 (−$4,700,000,000)	−1,200 (−$3,900,000,000)
New Brunswick	18 ($56,000,000)	−120 (−$380,000,000)	−110 (−$330,000,000)

REGION	CHANGE IN NUMBER OF PREMATURE DEATHS (ECONOMIC VALUATION)		
	IMPACT OF CHANGING CLIMATE IN 2050[b]	IMPACT OF REDUCED AIR POLLUTANT EMISSIONS AS PER RCP6.0 IN 2050[c]	IMPACT OF CHANGING CLIMATE AND REDUCED AIR POLLUTANT EMISSIONS AS PER RCP6.0 IN 2050[d]
Nova Scotia	−5 (−$16,000,000)	−160 (−$500,000,000)	−170 (−$520,000,000)
Prince Edward Island	4 ($12,000,000)	−30 (−$94,000,000)	−26 (−$82,000,000)
Newfoundland and Labrador	−9 (−$28,000,000)	−50 (−$150,000,000)	−59 (−$180,000,000)
Yukon	<1	<1	<1
Northwest Territories	<1	<1	<1
Nunavut	<1	<1	<1

a. Counts and valuations represent mean estimates of premature mortality. Counts and valuation estimates are rounded to the nearest integer and given to a maximum of two significant figures. Valuations are in 2018 Canadian dollars and discounted from 2050 to 2019 using a 3% discount rate. Totals may not add up due to rounding.

b. Impact of a changing climate: (2045 climate @ 2002 emissions) – (2002 climate @ 2002 emissions)

c. Impact of reducing air pollutant emissions as per RCP6.0: (2045 climate @ 2002 emissions) – (2045 climate @ 2045 RCP6.0 emissions)

d. Impact of changing climate and reducing air pollutant emissions as per RCP6.0: (2045 climate @ 2045 RCP6.0 emissions) – (2002 climate @ 2002 emissions)

This analysis estimates that the impact of a warming climate in 2050 would result in 850 excess deaths across the country in the summer months, with clear regional differences. Most of the deaths would occur in Ontario (620) and Quebec (270), and some regions would experience small reductions in air pollution and the associated health impacts (e.g., British Columbia). This is consistent with the air quality changes projected by Kelly et al. (2012), which estimate for North America that the largest increases in ozone and $PM_{2.5}$ would occur in industrialized regions such as the Northeastern United States and adjacent regions of Southeastern Canada. Reductions in air pollutant emissions associated with projections under the RCP6.0 scenario would have national population health benefits of about 5200 avoided premature deaths annually in 2050, with benefits in all provinces but particularly in Ontario (2900 avoided premature deaths) and Quebec (1500 avoided premature deaths). These reflect the air pollution health co-benefits of the GHG mitigation strategies in RCP6.0, along with the assumptions in RCP6.0 of more stringent air pollution controls globally over time. The final scenario examined considered the effect of both a warming climate and air pollutant emission reductions. The results show that the benefits of air pollution mitigation are attenuated by the negative effects of a warmer climate. As indicated above, modelled projections of changes in $PM_{2.5}$ concentrations are considered to be more uncertain than those for ozone, which is also true for the health impacts derived from those projections.

Table 5.4 Canadian morbidity and mortality impacts (counts) and economic valuation due to ozone and $PM_{2.5}$ for June to August[a]

HEALTH END POINT	POLLUTANT	IMPACT OF CHANGING CLIMATE IN 2050[b]	IMPACT OF REDUCED AIR POLLUTANT EMISSIONS TO RCP6.0 IN 2050[c]	IMPACT OF CHANGING CLIMATE AND REDUCED AIR POLLUTANT EMISSIONS TO RCP6.0 IN 2050[d]
		Mortality		
Mortality	Ozone	610	−3500	−3000
Mortality	$PM_{2.5}$	250	−1700	−1400
Mortality	Ozone + $PM_{2.5}$	850	−5200	−4400
		Morbidity		
Acute respiratory symptom days	Ozone, $PM_{2.5}$	1,900,000	−12,000,000	−9,600,000
Adult chronic bronchitis cases	$PM_{2.5}$	160	−1100	−900
Asthma symptom days	Ozone, $PM_{2.5}$	160,000	−920,000	−770,000

HEALTH END POINT	POLLUTANT	IMPACT OF CHANGING CLIMATE IN 2050[b]	IMPACT OF REDUCED AIR POLLUTANT EMISSIONS TO RCP6.0 IN 2050[c]	IMPACT OF CHANGING CLIMATE AND REDUCED AIR POLLUTANT EMISSIONS TO RCP6.0 IN 2050[d]
Child acute bronchitis episodes	$PM_{2.5}$	670	−4400	−3700
Respiratory and cardiac emergency room visits	Ozone, $PM_{2.5}$	970	−6000	−5000
Respiratory and cardiac hospital admissions	Ozone, $PM_{2.5}$	210	−1300	−1100
Restricted activity days	$PM_{2.5}$	210,000	−1,500,000	−1,200,000
Minor restricted activity days	Ozone	340,000	−2,000,000	−1,600,000
Valuation (mean [2.5th percentile, 97.5th percentile])				
All premature deaths	Ozone, $PM_{2.5}$	$2.7 billion [$0.92 billion, $5.1 billion]	−$16 billion [−$5.7 billion, −$31 billion]	−$14 billion [−$4.8 billion, −$26 billion]
All end points	Ozone, $PM_{2.5}$	$2.7 billion [$0.97 billion, $5.2 billion]	−$17 billion [−$6.0 billion, −$32 billion]	−$14 billion [−$5.0 billion, −$27 billion]

a. Counts represent mean estimates of health outcomes. Counts and valuation estimates are rounded to the nearest integer and given to a maximum of two significant figures. Valuations are in 2018 Canadian dollars and discounted from 2050 to 2019 using a 3% discount rate. Totals may not add up due to rounding.

b. Impact of a changing climate: (2045 climate @ 2002 emissions) – (2002 climate @ 2002 emissions)

c. Impact of reducing air pollutant emissions to RCP6.0: (2045 climate @ 2002 emissions) – (2045 climate @ 2045 RCP6.0 emissions)

d. Impact of changing climate and reducing air pollutant emissions to RCP6.0: (2045 climate @ 2045 RCP6.0 emissions) – (2002 climate @ 2002 emissions)

Exposure to ozone and $PM_{2.5}$ also increases the risk of multiple non-fatal outcomes, such as asthma symptoms and cardiorespiratory hospital admissions. These represent important aspects of population health. In this analysis, the effect of the climate penalty on worsening air quality is estimated to result in 1.9 million acute respiratory symptom days and tens of thousands of asthma symptom days and restricted activity days, contributing to a substantial public health burden. This burden is in contrast to the larger annual health co-benefits that would result from air pollution reductions associated with the RCP6.0 scenario, including thousands of avoided cardiorespiratory hospital visits, as well as respiratory illnesses. About 70% of the mortality impacts are attributable to estimated changes in ambient ozone concentrations, with the remainder attributable to $PM_{2.5}$.

The economic value of the damage to health due to air pollution in Canada associated with a warming climate, based on analysis of the summer period in 2050, is estimated to be $2.7 billion, with a range of $0.97 billion to $5.2 billion, representing the 2.5th to the 97.5th percentile. This primarily reflects the value associated with increased risk of premature death. Importantly, this analysis also shows the potentially large socio-economic co-benefits that could be realized from air quality improvements delineated in the RCP6.0 projection, which were estimated to be $17 billion, with a range of $6.0 billion to $32 billion, representing the 2.5th to 97.5th percentile, in 2050.

5.5.4 Conclusion

Overall, the scientific evidence shows that climate change will affect atmospheric processes and, consequently, air quality. Multiple studies estimate that hundreds to thousands of ozone-related deaths may result annually in the United States during this century as a result of a warming climate. Fewer studies have examined $PM_{2.5}$ health impacts, but those that have suggest that $PM_{2.5}$ health impacts will be about one order of magnitude larger than those from ozone (Tagaris et al., 2009; Fang et al., 2013; Silva et al., 2017). Only one study was identified that included an analysis of health impacts in Canada. This focused only on ozone health impacts and estimated that the climate penalty under SRES A1B would result in 45 excess annual deaths in Canada in 2050 (Selin et al., 2009). In a new analysis for Canada conducted for this national assessment report, the net summer season health impacts in 2050 due to the climate penalty are estimated to be 850 excess deaths due to air pollution (total value of impacts $2.7 billion), with approximately 70% of those due to ozone and the remainder to $PM_{2.5}$, and with the vast majority of health impacts occurring in Ontario and Quebec. Note that this analysis did not include the air quality and health impacts resulting from wildfire smoke, which is discussed later in this chapter.

Strategies to mitigate GHG emissions can result in significant air pollution health co-benefits, the societal value of which can, in turn, offset the costs of GHG mitigation measures. Again, studies in the scientific literature generally estimate the $PM_{2.5}$ co-benefits to be about an order of magnitude larger than those from ozone reductions. The new Canadian analysis, presented above, estimates net benefits of following the RCP6.0 pathway to be about 5200 avoided deaths for the summer season for a single year in 2050, mainly in Ontario and Quebec, with a total value of benefits of $17 billion. Air pollution co-benefits are anticipated for each year following GHG emission reductions, and the cumulative benefits over decades would be expected to be much larger.

Air pollution health co-benefits of climate change mitigation represent important potential near-term gains and are realized locally, where mitigation measures are implemented. The incorporation of health co-benefits into a climate change framework can provide justification for more stringent or accelerated climate change mitigation measures or incentives to implement actions on climate change (Shindell et al., 2018). Appropriate analyses could allow for the strategic selection of climate mitigation pathways in Canada that also optimally target reductions in population health impacts due to air pollution, given the health and economic burden these represent to society. It would also allow for identification of potential unintended adverse health consequences.

5.5.5 Key Uncertainties

The modelling of air quality in future scenarios under the effects of climate change represents a challenge, due to inherent uncertainties with respect to global atmospheric dynamics and chemistry, downscaling from global to regional scales, chemical–climate interactions, emissions projections, and meteorological conditions (Tagaris et al., 2009; Fang et al., 2013; Silva et al., 2016; Zhang et al., 2017). Most studies relevant to Canada have focused only on ozone, while fewer analyses have captured $PM_{2.5}$ impacts. Modelled population health impacts are likely underestimated, as not all health outcomes that have been associated with air pollution exposure (e.g., neurological outcomes) can currently be quantified. Variability in the CRFs and monetization of health outcomes used in different studies may influence results (West et al., 2013; Thompson et al., 2014; Silva et al., 2017). Furthermore, the studies undertaken to date have largely used different approaches, assumptions, and modelling methodologies to investigate different questions, limiting the ability to synthesize the information.

5.6 Climate Change and Air Pollution from Wildfires

5.6.1 Wildfires in Canada in a Changing Climate

On average, 7000 wildfires burn about 2.5 million hectares — about half the size of Nova Scotia — every year in Canada. The area burned by wildfire in Canada has doubled since the early 1970s, and this has been attributed to human-caused climate change (Gillett et al., 2004). For example, human influences on the climate were found to be an important contributor to the severity of the 2017 wildfire season in Canada (Kirchmeier-Young et al., 2019). The increase in area burned results in higher air pollution emissions from wildfires, as well as greater associated health risks to humans (Reisen et al., 2015; Matz et al., 2020). The four factors that influence wildfire emissions include area burned, fuel consumed, combustion completeness (efficiency), and emission factor, which is the amount of pollutant released, measured in grams per kilogram.

The Canadian climate is warming, and this is having profound and immediate impacts on fire activity in Canada. The reasons for increasing wildfire activity due to rising temperatures are threefold. First, warmer temperatures extend the fire season, and a longer fire season has already been observed in parts of Canada. For example, interior British Columbia, Alberta, and Northern Ontario have longer fire seasons today than in 1959 to 2000 (Albert-Green et al., 2013; Hanes et al., 2019). Second, warmer conditions result in increased lightning, and, all things being equal, more lightning will result in more fire (Romps et al., 2014). Third, warmer temperatures lead to drier fuels, unless there is a significant increase in precipitation (Flannigan et al., 2016). Almost all future climate change scenarios for Canada do not have sufficient increases in precipitation to compensate for the drying effect from warmer temperatures. Drier fuels make it is easier for fire to start, spread, and burn more intensely, which, in turn, makes the fires more difficult to control or to extinguish and results in greater air pollution emissions.

Wildfire activity varies temporally and spatially. For the period 1959 to 2015, the number of large fires and area burned by wildfire increased in Western Canada (Hanes et al., 2019). This trend is expected to continue, with the largest increase in wildfires and smoke projected for Western Canada through to 2050. Increasing fire activity is anticipated across all of Canada in the last half of this century (Flannigan et al., 2005; Flannigan et al., 2009).

Scientists are investigating whether recent increases in wildfires in Canada are a direct result of climate change. The observed increases in large wildfires are consistent with what is anticipated with climate change (Flannigan et al., 2009; Hanes et al., 2019). Recent research suggests that extreme fire risk in Western Canada during the last decade increased by 1.5 to 6 times due to human-caused climate change (Kirchmeier-Young et al., 2017). Tan et al. (2019) suggested that extreme spring fire weather in Western Canada in 2016 was very likely an outcome of human-caused climate warming, which increased the occurrence of a weather pattern associated with warmer and drier conditions. Kirchmeier-Young et al. (2019) suggested that human-caused climate change increases the area burned by a factor of seven to 11 times during extreme fire seasons, such as the 2017 fire season in British Columbia.

Amiro et al. (2009) suggested a doubling of wildfire emissions in Canada by the end of this century using the Canadian Global Circulation Model. The increases were largely due to increases in area burned rather than increases in the fuel burned per unit of area (known as depth of burn). Recent research, using three global circulation models (HadGEM2, CanESM2, and CSIRO-MK3.6.0) and three RCP scenarios (2.6, 4.5, and 8.5), however, suggested that the proportion of days in the fire seasons with the potential for significant fuel consumption (depth of burn) by wildfire will increase across Canada's forests, more than doubling for British Columbia and the rest of the boreal forest by 2100 (Wotton et al., 2017). The doubling of fuel consumption due to depth of burn only may occur as early as the 2030s in British Columbia. Wotton et al. (2017) suggested that the proportion of days with high-intensity wildfires that are difficult to impossible to extinguish will increase by two to three times for British Columbia and the boreal forest by 2100.

Smoke from wildfires can travel long distances and significantly affect communities that can be 1000 km or more from the fire. As a result, large population centres are not immune to the adverse health impacts from wildfire smoke, although they may be in an area with low wildfire risk (Matz et al., 2020). In addition, Indigenous communities, which may be in close proximity to forests, may be more affected by wildfires and the need for and effects of evacuation (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada).

Given projected increases in wildfire activity, the potential for interactions between society and fire in Canada (such as more evacuations of communities) will increase. Overall, Canadians need to be prepared for a future with more wildfires and increased levels of wildfire air pollution due to the changing climate.

5.6.2 Health Effects of Air Pollution from Wildfires

Wildfire emissions contain many different air pollutants, including PM, CO, NO_X, methane, polycyclic aromatic hydrocarbons, and VOCs, and contribute to the formation of ozone and secondary PM (Naeher et al., 2007). The health effects of some of these air pollutants are discussed in section 5.3 Health Effects of Outdoor Air Pollution. For each wildfire, the exact composition of the smoke is highly variable and determined by many factors, including type of vegetation burning (e.g., wet or green vegetation versus dead or dry vegetation), type of combustion (e.g., flaming versus smoldering conditions), and weather conditions (Adetona et al., 2016; Black et al., 2017).

The health effects of wildfire smoke are an active area of research and have been well reviewed, as they are an important global issue (Benmarhnia et al., 2013; Youssouf et al., 2014; Liu et al., 2015; Adetona et al., 2016; Reid et al., 2016; Black et al., 2017; Cascio, 2018). These reviews considered studies conducted around the world, including in North America, South America, Europe, Australia, and Asia. The methods used to assess exposure to wildfire smoke varied across the individual studies and included use of land-based PM monitors, satellite imagery, air quality modelling, comparison of fire versus non-fire periods, and self-reports. Based on these reviews, epidemiological studies have identified that exposure to wildfire smoke is associated with an increase in all-cause mortality; however, more studies are required to identify which specific causes of mortality are most affected. In addition, the literature indicates a strong association between exposure to wildfire smoke and respiratory morbidity, specifically exacerbations of asthma and COPD, and increased respiratory infections. Numerous studies have reported significant increases in health care utilization, including hospital admissions, emergency room visits, physician visits, and/or medication use, for these respiratory conditions associated with an increase in wildfire smoke. For cardiovascular morbidity, including health outcomes such as myocardial infarction, stroke, heart failure, and heart rhythm disturbances, the association with wildfire smoke remains inconclusive, due to a small number of studies indicating an effect and many studies reporting null findings. Many studies reported no association with cardiovascular diseases as a group, and the results are inconsistent among the studies evaluating specific outcomes. A small number of studies have evaluated other health effects, including birth outcomes, mental health, and diabetes, although further research is required to assess the impact of wildfire smoke on these and other health effects.

Studies conducted in Canada on the health effects of wildfire smoke exposure support the conclusions of the reviews discussed above. Specifically, these studies have identified increased asthma-related physician visits (Henderson et al., 2011; McLean et al., 2015; Dodd et al., 2018a), asthma medication dispensed (Henderson et al., 2011; Elliot et al., 2013; McLean et al., 2015), and respiratory-related physician visits and hospital admissions (Henderson et al., 2011; Dodd et al., 2018a) associated with exposure to wildfire smoke. However, no associations were observed for cardiovascular-related physician visits or hospital admissions (Henderson et al., 2011; Dodd et al., 2018a).

How wildfire smoke causes health effects is not fully understood, although the evidence suggests the mechanisms may be similar to those identified for ambient PM. Studies in humans and animals exposed to wildfire or wood smoke have suggested that the health effects result from increased oxidative stress and inflammatory responses, as well as possible interaction of particulates with the autonomic nervous system and a possible reduction in immune responses (Adetona et al., 2016; Reid et al., 2016; Black et al., 2017; Cascio, 2018).

5.6.3 The Health Burden of Wildfire Smoke in Recent Years

Health impact analyses have estimated the health burden of wildfires attributable to the increase in air pollutant concentrations from wildfire smoke. On a global scale for 1997 to 2006, the average annual mortality attributable to $PM_{2.5}$ from landscape fire smoke was estimated at 339,000 deaths (interquartile range 260,000 to 600,000) (Johnston et al., 2012). For this study, landscape fires included forest, grass, and peat fires, and were associated with an estimated annual wildfire-$PM_{2.5}$ exposure concentration of 0 to 45 μg/m^3 and a population-weighted average concentration of 2.1 μg/m^3. The greatest impacts were noted for sub-Saharan Africa (157,000 premature deaths) and Southeast Asia (110,000 premature deaths). The importance of climatic variability on wildfire activities was also evident from the sensitivity analysis of strong La Niña and El Niño years. During the El Niño period, associated with dry conditions and greater fire activity, the estimated annual global mortality attributable to $PM_{2.5}$ from landscape fire smoke was estimated at 532,000, compared to an estimate of 262,000 for the La Niña period.

In a national assessment for the continental United States, wildfire episodes in 2008 to 2012 were associated with an annual population-weighted mean wildfire-$PM_{2.5}$ exposure of 0.6 to 1.1 μg/m^3, depending on the wildfire activity of a given year (Fann et al., 2018). These annual wildfire-$PM_{2.5}$ exposures were associated with an estimated 1500 to 2500 premature deaths from short-term exposure; 8700 to 32,000 premature deaths from long-term exposure; 3900 to 8500 respiratory hospital admissions; and 1700 to 2800 cardiovascular hospital admissions. The economic valuation over the five-year period was 63 billion USD (in 2010 USD) for the short-term premature deaths and combined hospital admissions. The long-term premature deaths had a valuation of 450 billion USD (in 2010 USD) across the five-year period. There was considerable regional variation in wildfire smoke exposure and attributable health impacts, with greater wildfire activity occurring in the western and southeastern states.

There is only limited information quantifying the health and associated monetary impacts from wildfire-related air pollution in Canada in the published literature. A 2001 fire in Chisholm, Alberta, was used as a case study to estimate the acute health impacts associated with short-term increases in $PM_{2.5}$ (Rittmaster et al., 2006; Rittmaster et al., 2008). This seven-day fire burned approximately 116,000 ha and had significant impacts on the air quality of Edmonton (160 km south of Chisholm), Red Deer (125 km south of Edmonton), and the surrounding area. Health damage associated with $PM_{2.5}$ concentrations above the Canada Wide Standard of 30 μg/m^3, which was applicable at the time, were estimated to be \$2 million to \$3 million (in 1996 CAD).

5.6.4 Quantifying Recent Canadian Air Pollution Health Impacts from Wildfire Smoke

As discussed in section 5.6.1 Wildfires in Canada in a Changing Climate, wildfire activity in Canada is expected to increase under a warming climate. Currently, there is too much uncertainty to predict with sufficient accuracy where in Canada wildfires will occur by mid-century and hence to estimate the population health impacts of wildfires under potential future climates. However, it is informative to assess the current air pollution health impacts from wildfires to better understand the magnitude of this population health issue. Health Canada and Environment and Climate Change Canada undertook an analysis of the Canadian air quality and human health impacts of air pollution from wildfires in recent years, the results of which are presented in this section (Matz et al., 2020).

Although intermittent in nature, wildfire smoke is recognized as a major contributor to air quality issues in North America. To provide forecast guidance for air quality alerts that could reduce air pollution exposure and protect human health during a wildfire smoke event, Environment and Climate Change Canada developed FireWork, a comprehensive operational air quality forecast system based on near-real-time biomass-burning emissions data. This system delivers operational forecasts of modelled air pollutant concentrations from biomass burning, in particular $PM_{2.5}$, on a daily basis over North America (Pavlovic et al., 2016).

A multi-year retrospective analysis of FireWork wildfire-$PM_{2.5}$ forecasts was conducted to estimate Canadian population exposure to $PM_{2.5}$ from wildfires (Munoz-Alpizar et al., 2017). Emissions from wildfires across North America were included in the modelling, which was limited to a five-month period from May to September, for calendar years 2013 to 2018. Due to substantial changes to the modelling grid used for 2016, there is a high level of uncertainty in the model output. As such, the results for that year were excluded from further analysis.

Comparisons of average monthly forecasted surface $PM_{2.5}$ concentrations due to wildfires for the 2013 to 2018 period showed large year-to-year variations in both the timing and the spatial locations of impacts (see Figure 5.2). Additionally, wildfires can sometimes affect the same location many times during a single season. The frequent presence of wildfire-$PM_{2.5}$, especially in Western North America, has implications for regional achievement of $PM_{2.5}$ air quality standards. The percent of Canadian landmass with wildfire-$PM_{2.5}$ and the percent of the Canadian population affected by wildfire-$PM_{2.5}$ above specified concentrations are provided in Figure 5.3. For 2013 to 2017, more than 60% of the landmass of Canada had average (May to September) wildfire-$PM_{2.5}$ concentrations of 0.2 μg/m^3 or more, affecting more than 90% of the population and demonstrating the widespread nature of wildfire smoke. Additionally, for 2013 to 2018, approximately 25% to 40% of the land mass of Canada had average wildfire-$PM_{2.5}$ concentrations of 1 μg/m^3 or more, affecting approximately 20% to 30% of the population. At the higher-threshold concentration levels, the percentages of landmass and population affected were further reduced. Since the population of Canada is not evenly distributed over the large landmass, the proximity of fire activity to population centres is a key determinant of the population affected by higher wildfire-$PM_{2.5}$ levels. For example, in 2017, the wildfire activity and smoke plume affected large population centres in British Columbia, and the proportion of the population affected was greater than the proportion of the landmass. Data for the provinces and territories with wildfire-$PM_{2.5}$ concentrations of 1 μg/m^3 or more, affecting more than 5% of the landmass and more than 5% of the population, for 2013 to 2018, are presented in Figure 5.4. In multiple years between 2013 and 2018, about

60% to 100% of the landmass and over 80% of the population in the four Western provinces and the Northwest Territories experienced average (May to September) wildfire-$PM_{2.5}$ concentrations of at least 1 μg/m^3.

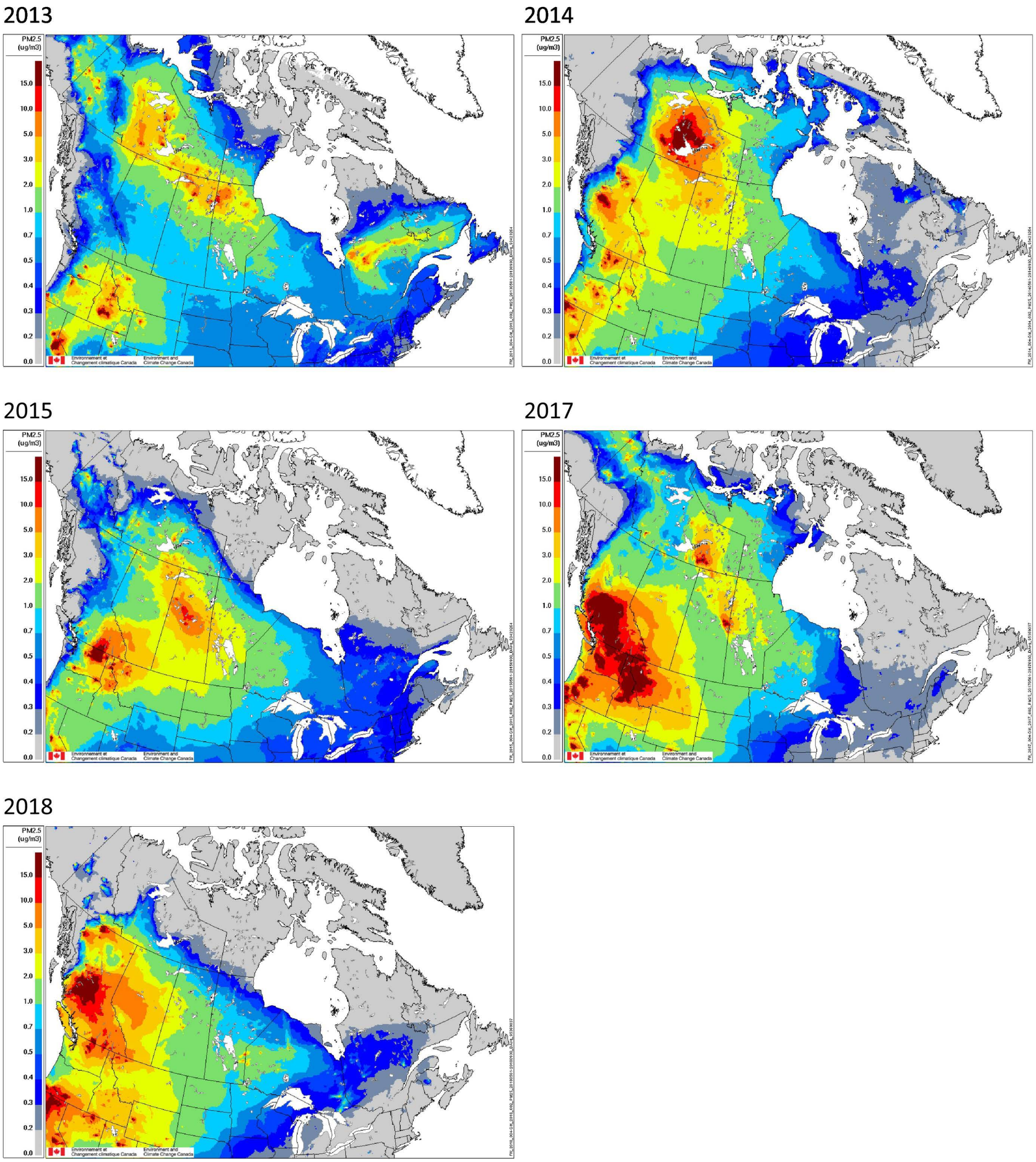


Figure 5.2 Wildfire $PM_{2.5}$ concentrations (May to September) for 2013 to 2018 in Canada. The colours on the maps show a range from grey to deep red indicating a range of wildfire-$PM_{2.5}$ from 0.0 to 15.0 μg/m^3. Source: Matz et al., 2020.

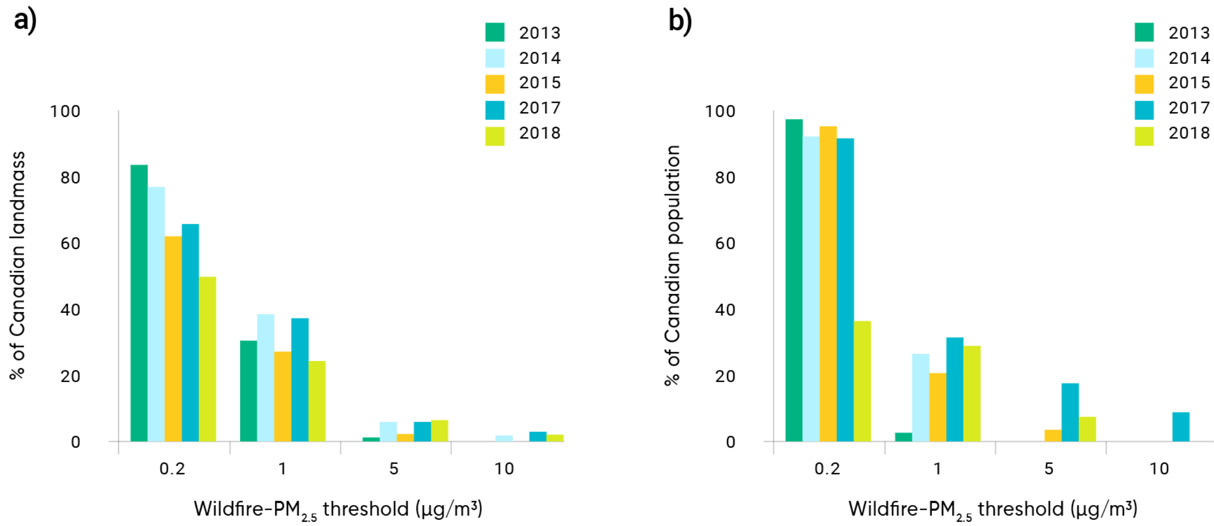


Figure 5.3 Percent of Canadian landmass and of Canadian population with average (May to September) wildfire-$PM_{2.5}$ concentrations above given thresholds. Panel A shows the percent of Canadian landmass with average May to September wildfire-$PM_{2.5}$ concentrations above given thresholds, and panel B shows the percent of population with May to September wildfire-$PM_{2.5}$ concentrations above given thresholds. Source: Matz et al., 2020.

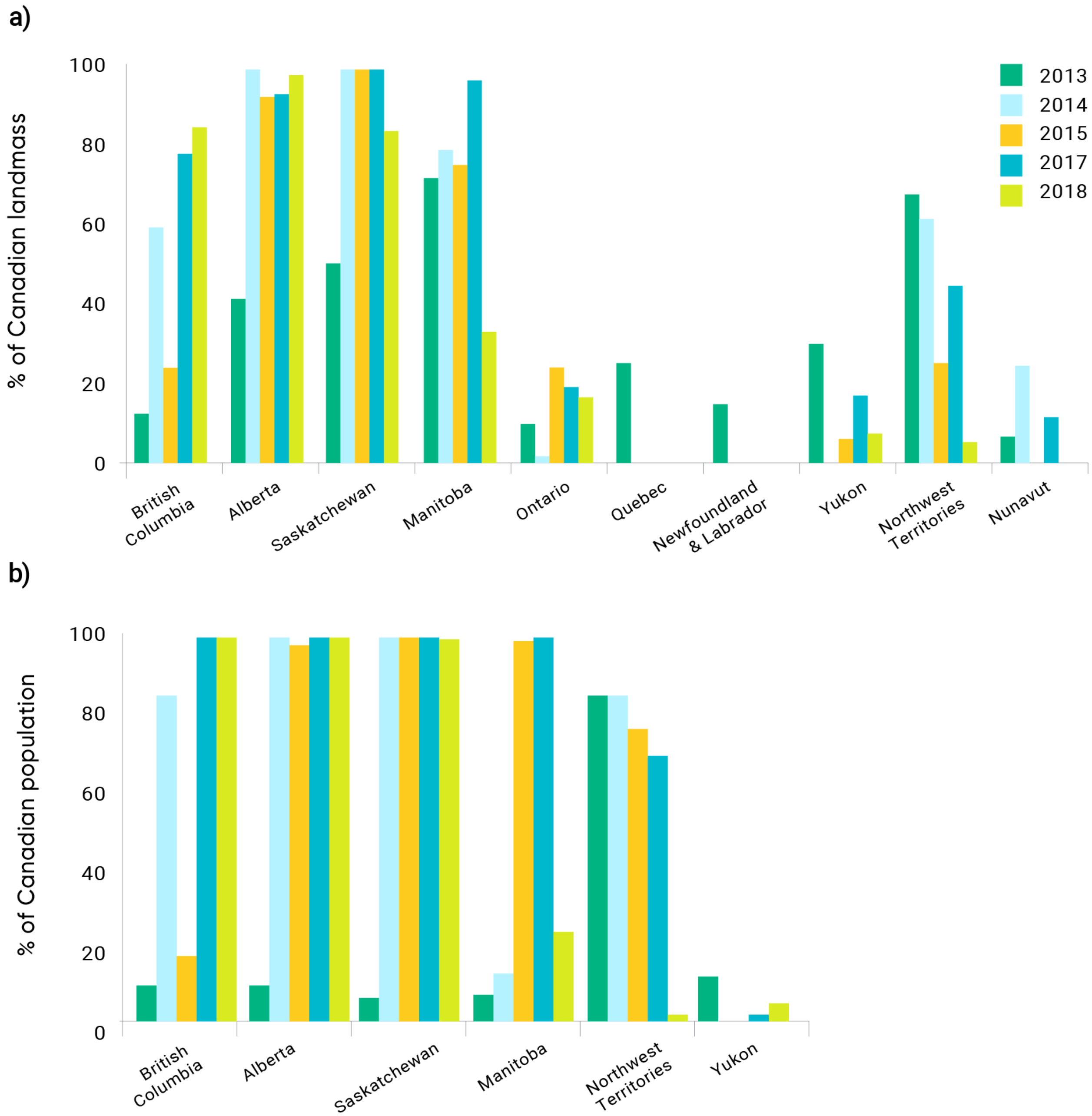


Figure 5.4 Percent of landmass and percent of population by province and territory with average (May to September) wildfire-$PM_{2.5}$ concentrations ≥1 μg/m^3 for 2013 to 2018. Panel A shows the percent of landmass with average wildfire-$PM_{2.5}$ concentrations of 1 μg/m^3 or more for 2013 to 2018 (May to September). Panel B shows the percent of the population exposed to average wildfire-$PM_{2.5}$ concentrations of 1 μg/m^3 or more for 2013 to 2018 (May to September). Only provinces and territories affected at more than 5% (of landmass or population) are included in the panels. Source: Matz et al., 2020.

The Canadian population health impacts attributable to wildfire $PM_{2.5}$ for 2013 to 2015 and 2017 to 2018 were estimated using Health Canada's AQBAT 3.0. The mortality and morbidity results, including the economic valuation, are presented in Table 5.5 and Table 5.6. Nationally, 54 to 240 premature deaths due to short-term exposure and 570 to 2500 premature deaths due to long-term exposure per year were attributable to wildfire-$PM_{2.5}$, as well as many non-fatal cardiorespiratory health outcomes. The most frequent morbidities were days with acute respiratory symptoms and days with restricted activity. The substantial year-to-year variation in wildfire activity is reflected in the health impact analysis, with the greatest impacts estimated for 2017 and much smaller estimates for 2013. This variability is also driven by whether the air pollution plume from the fires disperses over highly populated areas. Over the five calendar years assessed, the economic value of the population health impacts was estimated at $410 million to $1.8 billion per year for acute health impacts and $4.3 to $19 billion per year for chronic health impacts.

Table 5.5 Acute health impacts and economic valuation[a] from wildfire $PM_{2.5}$, for 2013 to 2015 and 2017 to 2018

	2013	2014	2015	2017	2018
Acute mortality	54	70	97	240	131
Acute mortality valuation[b]	**$410 million** [$120 million–$830 million]	**$520 million** [$160 million–$1.1 billion]	**$730 million** [$220 million–$1.5 billion]	**$1.8 billion** [$530 million–$3.7 billion]	**$980 million** [$280 million–$2.0 billion]
Acute respiratory symptom days	1,400,000	1,900,000	2,500,000	6,100,000	3,400,000
Asthma symptom days[c]	100,000	140,000	190,000	420,000	240,000
Child acute bronchitis episodes	2,600	3,400	4,600	10,000	6,000
Respiratory emergency room visits	170	230	310	710	420
Respiratory hospital admissions	34	45	61	140	83

	2013	2014	2015	2017	2018
Cardiac emergency room visits	60	75	110	250	140
Cardiac hospital admissions	46	57	80	190	110
Restricted activity days	750,000	1,000,000	1,400,000	3,200,000	1,800,000
Acute morbidity valuation[b]	**$73 million** [$13 million–$177 million]	**$97 million** [$17 million–$240 million]	**$131 million** [$24 million–$320 million]	**$310 million** [$58 million–$750 million]	**$170 million** [$33 million–$420 million]

a. The dollar values in Table 5.5 are socio-economic values associated with small changes in the risk of various health outcomes. AQBAT provides economic valuation estimates of those health impacts, considering the potential social, economic, and public welfare consequences of the health outcomes, including medical costs, reduced workplace productivity, pain and suffering, and the impacts of increased mortality risk.

b. Values represent mean valuation of multiple iterations; [2.5th–97.5th percentiles].

c. Asthma symptom days are only estimated for children (five to 19 years of age).

Table 5.6 Chronic health impacts and economic valuation[a] from wildfire $PM_{2.5}$, for 2013 to 2015 and 2017 to 2018

	2013	2014	2015	2017	2018
Chronic mortality	570	730	1000	2500	1400
Chronic mortality valuation[b]	**$4.3 billion** [$1.5 billion-$8.2 billion	**$5.5 billion** [$2.0 billion–$11 billion]	**$7.6 billion** [$2.7 billion–$15 billion]	**$19 billion** [$6.7 billion–$35 billion]	**$10 billion** [$3.8 billion–$20 billion]
Adult chronic bronchitis cases	530	710	960	2300	1300
Chronic morbidity valuation[b]	**$230 million** [$0–$620 million]	**$320 million** [$0–$830 million]	**$420 million** [$0–$1.1 billion]	**$1.0 billion** [$0–$2.6 billion]	**$560 million** [$0–$1.5 billion]

a. The dollar values in Table 5.6 are socio-economic values associated with small changes in the risk of various health outcomes. AQBAT provides economic valuation estimates of those health impacts, considering the potential social, economic and public welfare consequences of the health outcomes, including medical costs, reduced workplace productivity, pain and suffering, and the impacts of increased mortality risk.

b. Values represent mean valuation of multiple iterations; [2.5th – 97.5th percentiles].

A breakdown of estimated national premature deaths, by province and territory, is provided in Table 5.7. In 2013, the greatest impacts were estimated for Ontario and Quebec, reflecting the wildfire activity in Northwestern Quebec that year. For the other years (2014 to 2018), the greatest impacts were estimated in the provinces of British Columbia and Alberta, reflecting the substantial wildfire activity in Western Canada and in the United States during these years. During this period, health impacts were also noted for Saskatchewan, Manitoba, Ontario, and Quebec, indicating that the long-range transport of wildfire-$PM_{2.5}$ can affect population health at great distances from the wildfire locations.

Table 5.7 Estimated premature deaths from acute and chronic exposure to wildfire $PM_{2.5}$, by province and territory, for 2013 to 2015 and 2017 to 2018

	2013		2014		2015		2017		2018	
	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC
Canada	54	570	70	730	97	1000	240	2500	131	1400
British Columbia	6	59	23	240	25	260	170	1700	69	720
Alberta	7	71	19	200	28	290	42	440	42	430
Saskatchewan	3	30	6	60	9	96	6	62	5	53
Manitoba	3	35	4	37	7	74	4	45	4	40
Ontario	19	200	11	110	17	180	10	110	6	66
Quebec	15	150	7	69	10	100	7	71	5	49
New Brunswick	1	9	0	4	1	6	0	5	0	4
Prince Edward Island	0	1	0	0	0	1	0	1	0	1
Nova Scotia	1	8	0	3	1	5	0	5	0	3
Newfoundland and Labrador	1	6	0	1	0	2	0	1	0	1
Yukon	0	1	0	0	0	0	0	1	0	0

	2013		2014		2015		2017		2018	
	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC	ACUTE	CHRONIC
Northwest Territories	0	2	1	5	0	1	0	1	0	0
Nunavut	0	0	0	0	0	0	0	0	0	0

5.6.5 Air Pollution Health Impacts of Wildfire Smoke Under Climate Change

In recent studies, projected wildfire activity under climate change scenarios has been used to estimate population exposures to wildfire smoke and health impacts in the future. Mills et al. (2018) projected wildfire smoke exposure across the continental United States under RCP4.5 and RCP8.5 for the years 2050 and 2090. In 2050, a projected 3 million more people would be exposed to wildfire smoke under RCP8.5 compared to RCP4.5 and the difference would increase to 10 million in 2090. Significant regional variation is noted across the country, with the greatest air quality impacts in the northeast and southwest. The study methods took a conservative approach and did not capture long-range transport of wildfire smoke. Ford et al. (2018) also considered the RCP4.5 and RCP8.5 scenarios to model wildfire and biomass burning, and $PM_{2.5}$ emissions for the continental United States. Annual average wildfire $PM_{2.5}$ emissions were estimated to increase due to projected increases in emissions during the peak fire season and lengthening of the fire season, for 2050 and 2100. The largest projected increases in emissions were noted for the Southeastern United States and along the Canadian border. Additionally, due to projected decreases in anthropogenic sources of $PM_{2.5}$ under RCP4.5 and RCP8.5, the relative contributions of fire-$PM_{2.5}$ were projected to increase from approximately 25% in 2000 to approximately 50% in 2050 and 2100. From a modelled baseline of 17,000 premature deaths attributable to fire-$PM_{2.5}$ in 2000, projections estimated increases in deaths to 42,000 (RCP4.5) or 32,000 (RCP8.5) by 2050, and 32,000 (RCP4.5) or 44,000 (RCP8.5) by 2100.

Liu et al. (2016) used projections of wildfire $PM_{2.5}$, based on the SRES A1B climate scenario to estimate respiratory hospital admissions for seniors across the Western United States. Short-term increases in $PM_{2.5}$ from wildfires were associated with an increase of 178 respiratory hospital admissions for people 65 years or older for 2046 to 2051 compared to 2004 to 2009. The estimates were greatest for the population centres in Southern and Central California, Western Washington, Central Colorado, and Central Utah.

5.6.6 Populations at Higher Risk

For some of the air pollutants associated with wildfire smoke, such as PM, numerous epidemiological studies have identified populations that may be at increased risk (see section 5.3 Health Effects of Outdoor Air Pollution). In comparison, fewer studies have investigated possible populations or conditions that may increase the risk of adverse health effects from exposure to wildfire smoke. Limited evidence suggests that young children, seniors, people with pre-existing conditions such as asthma or COPD, and people with lower socio-economic status may be at increased risk (Liu et al., 2015; Reid et al., 2016). A recent review of North American studies reported evidence of a greater effect of wildfire smoke on women compared to men for health care utilization due to respiratory effects in healthy adults and in those with COPD (Kondo et al., 2019). The review also reported a slightly lower relative risk for health care utilization for respiratory effects in youth compared to adults, but the data were insufficient to assess any effect modification due to income, education, access to care, or other personal characteristics. Further research is needed to better identify the subpopulations at greatest risk to the health effects of wildfire smoke.

Indigenous populations may be more sensitive to health effects from wildfire air pollution (see Chapter 2: Climate Change and Indigenous People's Health in Canada). In Canada, First Nations and Métis people have a higher burden of chronic respiratory diseases such as asthma and COPD (Gershon et al., 2014; Carrière et al., 2017), making them more susceptible to the adverse effects of air pollution overall. A Canadian study suggested that adverse respiratory outcomes, including emergency room visits and clinic visits for cough, asthma, and pneumonia, increased during the prolonged 2014 wildfire season in the Northwest Territories compared to the previous two years, although this study was not specific to Indigenous Peoples (Dodd et al., 2018a). In addition, Indigenous populations living in remote locations may be at increased risk of exposure to wildfire smoke due to proximity.

Given their occupation, wildland firefighters are exposed more frequently and to greater levels of wildfire smoke than the general public. Studies of firefighters have indicated acute health effects of wildfire smoke exposure, including reduced lung function, lung inflammation, pulmonary and systemic oxidative stress, and respiratory symptoms (Youssouf et al., 2014; Adetona et al., 2016; Black et al., 2017; Groot et al., 2019). However, the long-term effects of cumulative occupational exposure to wildfire smoke have not been identified.

5.6.7 Conclusion

Scientific studies have identified numerous adverse health effects associated with wildfire smoke, including premature mortality and respiratory health effects. In addition, new research is evaluating possible associations with cardiovascular health effects, as well as with birth outcomes, mental health outcomes, and diabetes. Furthermore, significant population health impacts attributable to wildfire $PM_{2.5}$ have been estimated for Canada, the United States, and globally. Specifically, for the Canadian population over the period from 2013 to 2018, 620 to 2700 deaths per year were attributed to $PM_{2.5}$ from wildfires, along with many non-fatal adverse health outcomes. Climate change is anticipated to increase the number and severity of wildfires in Canada and globally, due to greater fire activity and lengthening of the fire season. The increased emissions from wildfires will result in a greater public health burden from air pollution and will require expanded adaptation efforts by public health agencies and other government organizations.

5.6.8 Key Uncertainties

Although increasing fire activity is expected in Canada over this century, it is difficult to estimate population health impacts under future climate change scenarios, as population exposure will depend on the location and size of individual fires, as well as meteorological conditions, all of which are hard to predict with the required spatial resolution. Air quality modelling includes inherent uncertainties, given the complexity of atmospheric processes. In addition, modelled population health impacts are likely underestimated, as not all health outcomes that have been associated with air pollution exposure can be quantified and included in the analysis. In addition, epidemiological studies of the health effects of wildfire air pollution specifically are still limited, and effects on health may differ from those caused by exposure to ambient air pollution. There is global recognition of the increasing importance of wildfire smoke as a source of air pollution exposure, and investigation of the health effects attributable to wildfire smoke is an active area of research. This may result in the development of source-specific CRFs for use in health impact assessments.

5.7 Adaptation and Risk Mitigation for Health Effects of Outdoor Air Pollution

In addition to strategies targeting reductions in air pollution emissions, there are multiple initiatives to help reduce exposure to and, hence, health risks from outdoor air pollution in Canada. These address outdoor air pollution in general, and, more recently, specific actions regarding wildfire smoke. There have been reductions in the number of smog-based advisories in recent years in Canada and the United States as a result of reductions in air pollution emissions, but the frequency of wildfire smoke episodes has increased. Given that climate change can contribute to the deterioration of air quality and increased wildfires, these measures take on added importance in the protection of public health.

5.7.1 Outdoor Air Pollution

Canada developed the Air Quality Health Index (AQHI) to convey the health risks of air pollution to the public on a day-to-day basis and inform decisions to protect health. The AQHI forecast is designed to help Canadians know when to monitor their symptoms, limit their exposure to air pollution, and make other behavioural changes, such as adjusting their exercise activities. The index represents the combined impact of the air pollution mixture and conveys health risks in relative terms. Rather than anchoring the index to threshold values derived from air quality standards, the AQHI calculates risks from epidemiological analysis of the population health impacts associated with short-term (daily) exposure to air pollutants, with a value of 10 based upon the highest-risk day observed during the period 1998 to 2001. The formula incorporates concentrations of NO_2, ozone, and $PM_{2.5}$ according to their contribution to increasing the risk of mortality from non-accidental causes (Stieb et al., 2008). The AQHI is reported on a scale of 1 to 10+, and the higher the number, the higher the health risk (see Figure 5.5). The AQHI is therefore an initiative to reduce the risk of air pollution that promotes adaptation through behavioural change; it has garnered international attention for its efficacy and clarity (Chen et al., 2013b; Oakes et al., 2014; Du et al., 2020).

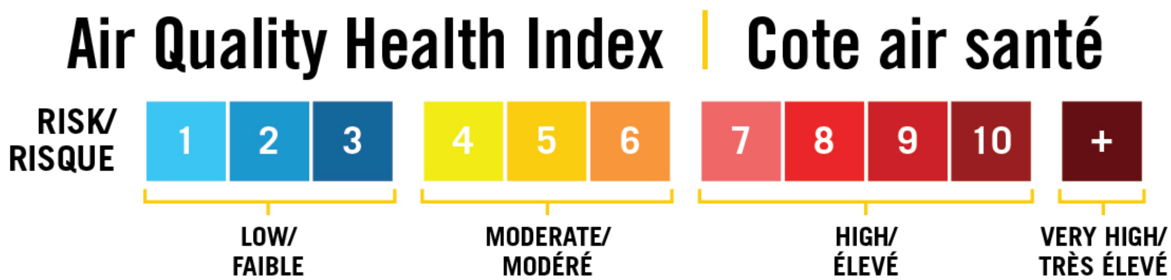


Figure 5.5 Air Quality Health Index scale. Source: Government of Canada, 2019b.

The usefulness of the AQHI as a tool for adaptation depends on the ability to anticipate air quality conditions. Environment and Climate Change Canada forecasts the AQHI across the country (Government of Canada, 2019a), accompanying weather forecasts in all regions except Quebec, which is the only province or territory that has not adopted the AQHI. As part of its Info-Smog program, Quebec has an air quality index that calculates a subindex for each pollutant relative to a provincial air quality standard (Government of Canada, 2019b).

Health messages and health protection advice communicated through the AQHI distinguish between the general population and the populations that may experience increased risk (Table 5.8). People with heart and lung conditions are described as most affected by air pollution, while other populations at higher risk include those with diabetes, young children, seniors, and people who are active outdoors. Advice to reduce exposure is primarily directed at avoiding elevated exposure to air pollution by changing schedules and relocating activities (e.g., indoors or outdoors and away from traffic), while, at the same time, encouraging appropriate exercise activities. Individuals are encouraged to check the AQHI forecast and become familiar with how their health may be affected at different AQHI values (e.g., recognizing when they experience symptoms). Those who may be at increased risk are encouraged to monitor their symptoms and limit outdoor activities at higher AQHI values. In addition to the information accompanying the AQHI forecasts, some provinces, municipalities, and media outlets post AQHI guides and information on webpages and provide adaptation advice to the public. The Air Health Check awareness campaign, which ran from 2015 to 2019, disseminated additional information on factors that increase vulnerability, symptoms, and protective actions (Scout Environmental, 2019).

Bilateral arrangements between federal and local authorities govern local air quality alerts, also called advisories, warnings, and special air quality statements. Air quality alerts may be based upon a forecast AQHI of seven or above (high risk), or when a specific pollutant exceeds a concentration chosen by the province. The health protection messages for advisories are generally consistent with the AQHI messaging for high or very high risk. However, they may be more detailed, including advice to avoid traffic, stay inside where there is central air conditioning, have an adequate supply of medication on hand, and reduce generation of air pollutants indoors, along with messages advising personal actions to reduce pollution, such as limiting vehicle use and outdoor combustion (OMECP, 2010). The Quebec Info-Smog program issues advisories when a pollutant reaches, or is forecast to reach, the “poor” category and makes use of similar risk reduction messages (Santé Montréal, 2017).

Table 5.8 AQHI health messages

HEALTH RISK	AIR QUALITY HEALTH INDEX	HEALTH MESSAGES	
		AT-RISK POPULATION*	GENERAL POPULATION
Low	1–3	Enjoy your usual outdoor activities.	Ideal air quality for outdoor activities.
Moderate	4–6	Consider reducing or rescheduling strenuous activities outdoors if you are experiencing symptoms.	No need to modify your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	7–10	Reduce or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	Consider reducing or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very high	Above 10	Avoid strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	Reduce or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

* People with heart or breathing problems are at greater risk. Follow your doctor's usual advice about exercising and managing your condition.

Source: Government of Canada, 2015

The AQHI does not measure the effects of odour, pollen, dust, heat, or humidity on human health. Additive health effects have been observed between heat and air pollution, leading to increases in mortality and hospital admissions for cardiovascular and respiratory diseases (European Academies' Science Advisory Council, 2019). However, seasonal and regional variations in heat responses, as well as other factors, have thus far precluded consideration of a combined index for heat and air quality or the incorporation of a heat indicator into the AQHI. Only minimal messaging on the combined risk of air pollution and heat is included in AQHI factsheets. When air quality and heat warnings are issued simultaneously, messages acknowledge the combined risks of the two hazards; however, integrated adaptation messaging has not been established. Some local jurisdictions have been using ad hoc combinations of content from Health Canada's work on extreme heat and air pollution (Anderson, 2016), and there is a need to develop joint messaging.

There is no direct experimental evidence to demonstrate the effectiveness of air quality forecast programs such as the AQHI in reducing population health risks. However, many studies show that health risks increase with increasing exposure to air pollution and, therefore, actions that effectively reduce exposure will reduce risk (Abelsohn & Stieb, 2011). Several studies have investigated the effectiveness of air quality advisory programs in altering behaviour (Wen et al., 2009; Spurr et al., 2014; Radisic et al., 2016). They found that individuals who were more vulnerable to air pollution (e.g., asthma sufferers) and those with more knowledge of air pollution were more likely to respond to the information provided. However, few studies have been able to address the question of whether incidence of illness decreases. A study of the impact of phone messaging of alerts to sensitive patients, with follow-up interviews on actions and symptoms, did not detect an effect on health (Mehiriz & Gosselin, 2019). Another study investigated the impact of air quality advisories in Toronto and found that the announcement of alerts was associated with a reduction of emergency department visits for asthma by 25% but could not detect an effect for any other health outcome (Chen et al., 2018).

Enhancing urban green spaces can play a role as an adaptive measure to deal with climate change, while also providing potential health and social co-benefits. There has been considerable research indicating a positive association between exposure to green space and improved health outcomes, such as hypertension and cardiovascular end points (Twohig-Bennett & Jones, 2018). More recently, researchers are attempting to elucidate how green space and air pollution, two key elements of the urban environment, interact to affect health. There is emerging evidence that increased green space may attenuate the effect of air pollution (Crouse et al., 2019). For example, urban green space can provide an environment away from higher-pollution microenvironments (such as near roadways), where people can go, including to exercise. Green infrastructure, such as vegetation barriers along busy roadways, can reduce the transfer of air pollutants to nearby environments (Baldauf, 2016). Green space can also provide a cooling effect to help reduce the urban health island effect (see Chapter 3: Natural Hazards) and function as a carbon sink.

5.7.2 Wildfire Smoke

Wildfire smoke has become a frequent summertime feature of air quality conditions over large areas in Canada, particularly in Western Canada, with resulting attention to public health impacts and adaptation measures. Models suggest that wildfires will continue to increase in both severity and frequency due to climate change (see section 5.6 Climate Change and Air Pollution from Wildfires). Adaptation measures in response to wildfire smoke are primarily related to warning individuals and providing them with the means to reduce their exposure, particularly those who may be at increased risk of related health impacts. A qualitative study of the health impacts of the 2014 wildfires in the Northwest Territories observed a decrease in mental and emotional health among the majority of interviewees and recommended comprehensive planning and education to reduce risks in Indigenous and other communities (Dodd et al., 2018b).

Recent years have seen advances in air quality modelling to incorporate wildfire smoke into air quality forecasts. Environment and Climate Change Canada developed its FireWork model as part of its operational air quality forecast system and produces twice-daily forecasts of wildfire $PM_{2.5}$ for the next 48 hours. The model output is incorporated into air quality forecasts. Maps and animations of predicted smoke paths are produced, and air quality alerts are issued when necessary (Government of Canada, 2019c). The relative cohesion of a smoke plume over large distances means that wildfire episodes present particular challenges to forecasting and to the adoption of appropriate adaptive measures.

Currently, the AQHI formula is being evaluated for effectiveness in the context of wildfires. Concerns have arisen that, during smoke events, the AQHI readings do not correspond to the sensory experiences of the public in the area. An analysis was conducted with data from British Columbia, and an AQHI+ version of the index, using a formula based on one-hour $PM_{2.5}$ only, was determined to have a better fit to asthma outcomes and respiratory physician visits, although not to mortality and cardiovascular outcomes. The new version is now used in British Columbia throughout the year, in conjunction with the AQHI (Yao et al., 2019). The Northwest Territories has developed a self-assessment guide for wildfire smoke and health, based on visibility (NT HSS, 2016a).

Extreme ambient $PM_{2.5}$ concentrations can occur, and adaptive measures that go beyond the risk reduction advice associated with the AQHI may be required. The British Columbia Centre for Disease Control (BC CDC) carried out an analysis of public health responses to wildfire events and identified 13 priorities for action. While all are relevant to adaptation to smoke events, three are of particular interest: developing guidance for clean air shelters that can be used during smoke events; engaging public health practitioners in wildfire emergency response; and raising public awareness of protective actions (Maguet, 2018). Evidence reviews of air filtration in institutions were conducted (Keefe, 2014), the use of clean air shelters was explored (Barn, 2014), and advice on outdoor activities and the use of protective masks was developed (BC CDC, 2014). A series of public information factsheets were developed in 2019 (BC CDC, 2019). The Manitoba Office of Disaster Management has developed guidelines for protecting community health and well-being from wildfires (Manitoba Health, 2019), as have the Northwest Territories (NT HSS, 2016b). The federal government, as well as several provinces and territories, have reports, web pages, and factsheets that advise the public on matters relating to health protection and risk reduction (OHLTC, n.d.; Saskatchewan Environment Public Health and Safety, n.d.; Nova Scotia Department of Health and Wellness, 2018; NT HSS, 2018; Alberta Health Services, 2019; Government of Canada, 2019d; Ministère de l'Environnement et Lutte contre les changements climatique, 2019; Yukon Health and Social Services, 2019; Health Canada, 2020).

5.8 Impacts of Climate Change on Indoor Air Quality and Health

Canadians spend approximately 90% of their time indoors (Leech et al., 2002; Matz et al., 2014). Exposure to poor indoor air quality has been shown to cause or exacerbate a wide range of health effects, such as asthma, allergies, COPD, and other respiratory diseases, and certain commonly measured indoor air pollutants are recognized carcinogens (Zhang & Smith, 2003; Dales et al., 2008a; Hulin et al., 2012). Climate change, along with efforts to mitigate GHG emissions, can affect indoor air quality in a number of ways that have the potential to significantly affect human health in Canada.

5.8.1 Building Airtightness

Building airtightness (also called envelope airtightness), defined as the resistance to inward or outward air leakage through unintentional leakage points or areas in the building envelope, is an important consideration for indoor air quality. Nearly two-thirds of energy use in residential and commercial buildings in Canada is for heating and cooling (NRCan, 2018). Since the early 1980s, the energy efficiency of Canadian homes has dramatically improved as a result of updated building codes as well as energy efficiency certification programs, including R-2000 and Energy Star (Hamlin & Gusdorf, 1997; Parekh et al., 2007). However, an increase in airtightness often comes at the expense of natural ventilation. Furthermore, the increased use of air conditioning (NRCan, 2016), which may continue to grow due to warm temperatures associated with climate change, can result in reduced natural ventilation, which can increase the accumulation of indoor-generated air pollutants such as VOCs and $PM_{2.5}$. Increased airtightness can also trap moisture inside homes, resulting in mould and the proliferation of dust mites (Bone et al., 2010). Heat-recovery ventilators offer an energy efficient means of providing adequate ventilation in homes (CMHC, 1998; Health Canada, 2018), and their use has been associated with improved health, for example, reductions in respiratory disorder symptoms, among occupants, according to Canadian and international studies (Leech et al., 2004; Kovesi et al., 2009; Maidment et al., 2014). As efforts continue in Canada to increase residential energy efficiency in order to support GHG mitigation, it is important to ensure that homes remain sufficiently ventilated to avoid poor indoor air quality and prevent adverse health outcomes associated with inadequate ventilation (Hernberg et al., 2014; Sharpe et al., 2015). Inadequate ventilation could also have implications for the transmission of infectious respiratory diseases, such as tuberculosis, which is a particular concern for First Nations (on- and off-reserve) and Inuit communities (Beggs et al., 2003).

5.8.2 Impact of Changing Ambient Conditions on the Indoor Environment

Changes to the outdoor environment due to climate change can alter air quality in the indoor environment. For example, higher outdoor ozone concentrations can result in higher concentrations of indoor pollutants, such as formaldehyde, acrolein, other aldehydes, acids, and ultrafine particles, as outdoor ozone has been shown to react with other compounds as it moves indoors (Nazaroff & Weschler, 2004; Weschler, 2006). Furthermore, ambient conditions, such as temperature, relative humidity, and wind speed, can also influence indoor air quality. For example, higher wintertime outdoor temperatures contribute to lower ventilation rates by reducing infiltration that results from rising warm air within a building, and strong wind gusts increase ventilation rates by creating a pressure differential between the inside and the outside of a building (Health Canada, 2018). Increased indoor temperatures resulting from higher outdoor temperatures have also been associated with higher air pollutant emissions rates from building materials and higher indoor VOC concentrations in homes (Wallace et al., 1996; Heroux et al., 2010; Xiong et al., 2013). Conversely, adaptive measures, such as increased home airtightness and increased use of air conditioning, could reduce the impact of poor ambient conditions on indoor air quality, although retaining pollutants from indoor sources may be an issue if ventilation is inadequate. Overall, these interactions are complex, variable, and influenced by building parameters and local factors.

5.8.3 Extreme Weather Events and Wildfires

Climate change in Canada has increased the frequency of some extreme weather events (e.g., extreme heat events, heavy precipitation events) and is expected to continue to do so in the future (Bush & Lemmen, 2019) (see Chapter 3: Natural Hazards). These events can have a variety of indoor air quality impacts that adversely affect human health. Power outages associated with extreme weather events, such as floods or severe wind or ice storms, may result in individuals using portable gas-powered generators, oil and gas space heaters, fireplaces, and/or candles indoors (Warren & Lemmen, 2014). These devices can lead to high levels of indoor air pollutants, such as CO, $PM_{2.5}$, black carbon, ultrafine particles, NO_2, and polycyclic aromatic hydrocarbons, which have been associated with a range of adverse health effects, including increased risk of death. For example, in 1998, 28 deaths reported during an ice storm that resulted in large power outages across much of Eastern Canada were largely attributed to CO poisoning (Hartling et al., 1998; Berry et al., 2008). Power outages can also lead to the failure of mechanical ventilation systems, resulting in under-ventilated homes and buildings and, consequently, the build-up of air pollutants generated indoors (IOM, 2011). As the climate continues to change, extreme weather events are expected to increase the risk of impacts to energy infrastructure across Canada (CEA, 2018), indicating a need for adaptive measures to mitigate the adverse health effects of deteriorating indoor air quality as a result of power outages.

Climate change is also projected to result in a higher frequency of heavy precipitation events, as well as increased storm surges and coastal flooding in Canada (Bush & Lemmen, 2019) (see Chapter 3: Natural Hazards and Chapter 7: Water Quality, Quantity, and Security). Such events can result in flooding and water intruding into indoor space, creating conditions favourable to the growth of bacteria and fungi such as mould (Health Canada, 2007). For example, Hurricane Katrina in 2005 resulted in extensive proliferation of mould inside many homes in the affected regions of Louisiana (Solomon et al., 2005). Exposure to mould has been associated with eye, nose, and throat irritation; coughing and phlegm build-up; wheezing and shortness of breath; as well as increased prevalence of asthma symptoms (Health Canada, 2007). Furthermore, intrusion of water indoors can result in water damage to building materials and higher air pollutant emission rates from damp building materials (Korpi et al., 1998; Wolkoff, 1998; Huang et al., 2016). In 2013, a major flood in Alberta resulted in the evacuation of 100,000 residences and caused insured property damage that exceeded $1.74 billion

(Insurance Bureau of Canada, 2013). Finally, renovations or repairs that follow interior water damage can result in higher VOC exposures due to emissions from new building materials (Weschler, 2009; ECA, 2013).

Wildfire events may also increase in severity and frequency under a changing climate, which could worsen both indoor and outdoor air pollution in affected areas (see section 5.6 Climate Change and Air Pollution from Wildfires). The impact of wildfire smoke on the indoor environment depends on a variety of housing characteristics; therefore, certain residences may be more affected than others. As wildfires become more prevalent, adaptive housing measures, such as air conditioners and stand-alone air cleaners, should be employed to protect occupants against the adverse health effects of wildfire smoke. For example, the infiltration of PM has been shown to be higher in parts of Canada with moderate climates where air conditioning use is less prevalent and houses are often less airtight (Clark et al., 2010). Moreover, infiltration of PM is lower in newer homes and residences with air cleaners (Barn et al., 2008; Hystad et al., 2009; Clark et al., 2010; MacNeill et al., 2012; Kearney et al., 2014; MacNeill et al., 2014; Wheeler et al., 2014).

In an emergency situation, people may need to congregate in a cleaner-air shelter. However, such shelters can pose unique indoor air quality challenges related to elevated CO_2 levels, indoor temperatures, and relative humidity (Barn, 2014; Keefe, 2014; US EPA, 2016) due to high occupancy. Maintaining clean air in a shelter during periods of high ambient air pollution can require specific strategies such as filtration, air cleaning, and air conditioning (Health Canada, 2020). Public health risks from infectious diseases are also a concern when sheltering people during emergencies. Public health protection during the 2020 COVID-19 pandemic has required approaches to cleaner-air shelters to be adjusted, including guidance regarding screening of symptomatic individuals, implementation of physical distancing, and provision of prevention supplies (US CDC, 2020).

5.8.4 Populations at Higher Risk

People with pre-existing health conditions are especially susceptible to the health impacts of poor indoor air quality (Dales et al., 2008a; To et al., 2009; Potera, 2011; Fann et al., 2016). Children have also been shown to be more susceptible to environmental pollutants (Faustman et al., 2000), and aging can lead to the deterioration of immune defences and lung function, as well as a predisposition to respiratory infections (Viegi et al., 2009).

Other factors, such as an individual's ability to adapt to or mitigate the adverse effects of climate change on their indoor environment can also influence their vulnerability to related health impacts. People who live in multi-family dwellings and/or rent their home may not be able to control temperature or humidity levels, which can influence indoor air quality by increasing pollutant emissions from building materials or enhancing the growth of mould, respectively. Renters may not be able to make modifications to their home to protect against water intrusion and infiltration of wildfire smoke (IOM, 2011; Romero-Lankao et al., 2014). In addition, those who lack financial resources or knowledge may not be able to take the necessary protective actions when faced with changes to their indoor air quality as a result of climate change (IOM, 2011). Poorly designed and poorly maintained dwellings can cause increased exposure to chemicals, moulds, and pathogens; poorly vented combustion apparatus contributes to acute and chronic disease; and exposure to environmental tobacco smoke is a significant health risk to adults and children (Sequel et al., 2017). Geographic location can also increase an individual's vulnerability to health impacts, as certain areas will be more prone to extreme climate-related events such as flooding or wildfires (see Chapter 3: Natural Hazards).

First Nations, Inuit, and Métis peoples may experience disproportionate health impacts from poor indoor air quality, given the existing unequal burden of illness in some Indigenous communities. For example, First Nations and Inuit children have been shown to have increased rates of severe lower respiratory tract infections requiring hospitalization (Kovesi, 2012; McCuskee et al., 2014) and an increased prevalence of bronchiectasis was reported in Inuit children (Das & Kovesi, 2015). Smoking is more prevalent among Indigenous populations, with 27% of off-reserve First Nations, 26% of Métis, and 49% of Inuit people aged 12 and older smoking daily, compared to 15% of non-Indigenous people (Statistics Canada, 2015). Importantly, while high-risk behaviours, such as smoking, have adverse health impacts, their prevalence is symptomatic of "deeper social and economic issues, as well as the legacy of colonialism" (ITK, 2014).

In Canada, tuberculosis rates are four times higher among Métis people, 57 times higher among First Nations people living on reserve, 24 times higher among First Nations people living off reserve, and 284 times higher among Inuit compared to Canadian-born non-Indigenous people (PHAC, 2018; Vachon et al., 2018). In addition, heart disease has been found to be 1.5 times higher among First Nations adults living on reserve compared with the general Canadian population (Indigenous Services Canada, 2018). These existing health inequities can compound the health risks related to climate change impacts on indoor air quality.

First Nations, Inuit, and Métis peoples commonly experience higher rates of poverty, overcrowding in homes, and poor housing quality (Adelson, 2005; NCCAH, 2017; Statistics Canada, 2017), which can increase the risk of health impacts from poor indoor air quality. For example, 27% of First Nations people with registered or "Treaty Indian" status and 26% of Inuit lived in a dwelling in need of major repairs in 2016 (Statistics Canada, 2017), and more than half of adults in First Nations communities reported the presence of mould or mildew in their homes (Health Canada, 2014). Similarly, the 2011 census indicated that, among Inuit, one-third of all dwellings were in need of major repairs in comparison to 14% of Métis homes and 7% for the overall Canadian population (NCCAH, 2017). Climate change impacts on indoor air quality are expected to exacerbate health risks related to poor quality and overcrowded housing.

5.8.5 Adaptation

Adaptation strategies to address indoor air quality in Canada require a multi-faceted risk management approach that incorporates pollution source control, ventilation, and filtration (Poulin et al., 2016). Increasing the airtightness of building envelopes can contribute to a build-up of indoor air pollutants in the absence of adequate ventilation. This can be addressed through the installation and proper maintenance of mechanical ventilation systems (IOM, 2011; Poulin et al., 2016; Health Canada, 2018) as well as by reducing or eliminating indoor sources of air pollutants, for example, through the use of low-VOC products (Poulin et al., 2016). In addition, the influence of deteriorating ambient conditions can be reduced by ensuring a tightly sealed building envelope, using air conditioning and stand-alone air cleaning devices, as well as by installing high-efficiency filters on furnaces. Many of these measures may be inaccessible to some individuals and subpopulations across the country, including Indigenous communities, due to social inequities that result in inadequate housing, low socio-economic status, and insufficient resources to implement protective measures. Government actions to improve ambient air quality will also help to improve air quality in the indoor environment (Poulin et al., 2016).

Flood-prevention measures can also mitigate or reduce home damage from flood and other water infiltration events (Warren & Lemmen, 2014). Furthermore, installation of CO alarms in every residence can help prevent deaths from CO poisoning during power outages. Finally, targeted actions such as increased poison control and other medical services, as well as support for building and infrastructure improvements, provided to rural, geographically affected, or low-income communities can help protect those who may be at increased risk.

5.8.6 Key Uncertainties

There are several key uncertainties regarding the magnitude of climate change impacts on indoor air quality in Canada. For example, climate change may affect patterns of activity, resulting in people spending more time indoors in some conditions and more time outdoors in others. The Canadian housing stock may change as environmental sustainability and climate resilience are increasingly considered. This might include more construction that meets standards such as net zero (buildings that generate as much on-site renewable energy as they consume [Singh et al., 2019]) or passive homes (ultralow-energy building design [Wright & Klingenberg, 2015]), or result in the development of novel building materials engineered to withstand water damage or increase fire resistance. It also remains unclear whether the new adaptive strategies available to homeowners will be adopted and implemented, what forces will drive them (e.g., costs, insurance requirements, etc.), and whether they will be sufficient to mitigate the indoor air quality issues associated with climate change.

5.9 Impacts of Climate Change on Aeroallergens

5.9.1 Impact of Climate Change on Pollen Concentrations, Distribution, and Seasonal Length in Canada

The levels of aeroallergens, including tree pollen, grass pollen, ragweed pollen, and fungal spores are increasing in specific regions of the world and in Canada, and some of this increase has been linked to climate change (Ariano et al., 2010; Sierra-Heredia et al., 2018; Ziska et al., 2019). The timing and seasonal length of aeroallergens, as well as the production and allergenic content of pollen grains, will continue to be affected by climate change (see Figure 5.6) (Ariano et al., 2010; Ziska & Beggs, 2012; Bonofiglio et al., 2013).

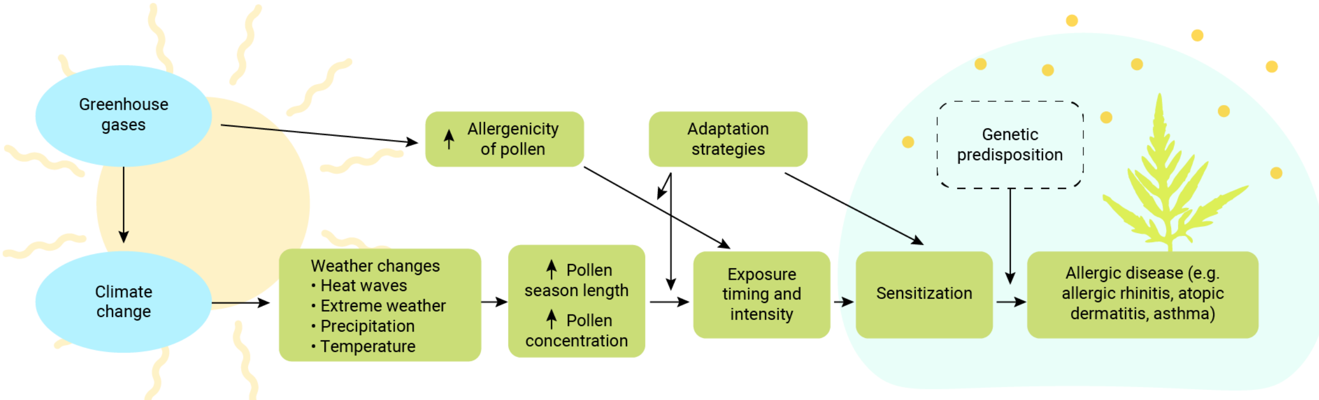


Figure 5.6 Effects of climate change on aeroallergens in Canada.

Due to climate change and related increases in CO_2 emissions, temperatures will increase and, as a result, aeroallergen seasons will start earlier and end later (Traidl-Hoffmann et al., 2003; D'Amato et al., 2014; Rice et al., 2014; D'Amato et al., 2016). In North America, the ragweed pollen season was found to have increased by 27 days between 1995 and 2009 due to warming temperatures (Takaro et al., 2013). In addition, increases in the atmospheric concentrations of CO_2 can affect the reproductive processes of plants, which will increase the production of pollen (Taylor et al., 2007; Shea et al., 2008; Ariano et al., 2010; Ariano et al., 2015; Bjerg et al., 2016). Moreover, there is evidence that higher growing temperatures and increased CO_2 emissions can increase the allergenicity (ability to induce an allergic response) of pollen, and climate change will enhance this effect (Beggs, 2004; Stach et al., 2007). Climate change will also affect regional changes in meteorological variables (e.g., humidity, precipitation, and temperature) linked to pollen dispersal and deposition (D'Amato et al., 2015). These regional climate changes will also affect plant distribution, as species that could not survive in previously hostile environments can potentially thrive because of changes in temperature and precipitation (Stach et al., 2007). Changes in the dispersal patterns of aeroallergens, longer pollen seasons, greater production of pollen grains, and increased allergenicity will lead to changes in human exposure and possibly in sensitization of individuals to allergens (Breton et al., 2006; Reid & Gamble, 2009; Bonofiglio et al., 2013). The magnitude of the impact on aeroallergens and related health effects depends, in part, on the effectiveness of adaptation actions. Adaptation strategies can help to reduce exposure to aeroallergens; for instance, research conducted in the province of Quebec showed that reducing pollen-producing plants in an area could reduce exposure to aeroallergens (Demers & Gosselin, 2019).

5.9.2 Health Effects of Changes in Aeroallergens Under Climate Change Scenarios

Approximately 20% to 25% of the Canadian population is affected by allergic rhinitis, which is most commonly due to pollen allergy (Vaitla & Drewe, 2011; Keith et al., 2012). Asthma affects between 12% to 25% of Canadian children and is estimated to affect about 3 million Canadians overall (Asher et al., 2006; Gershon et al., 2010; Ismaila et al., 2013; Sierra-Heredia et al., 2018). About two-thirds of asthmatic individuals are allergic to aeroallergens, which act as triggers for asthma exacerbations (Lafeuille et al., 2013). A number of studies in Canada have evaluated the health effects of day-to-day fluctuations in aeroallergens. Ambient aeroallergens, including tree pollen, grass pollen, ragweed pollen, and fungal spores, have been associated with increased risk of asthma-related and allergic rhinitis-related emergency department visits and hospitalizations in cities across Canada (Dales et al., 2000; Cakmak et al., 2002; Dales et al., 2004; Dales et al., 2008b; Heguy et al., 2008), as well as an increased risk of myocardial infarction among the elderly (Weichenthal et al., 2016), and earlier delivery among term pregnancies (Lavigne et al., 2017). In addition, high aeroallergen counts during the gestational period have been associated with increased risk of atopic disease in the child later in life (Lowe et al., 2012). As climate change continues to intensify, it is anticipated that allergy sufferers will experience increased exposure to aeroallergens in Canada. The incidence and prevalence of respiratory allergies and asthma are therefore projected to increase, which will be associated with an increase in health care expenses to treat these conditions (Sierra-Heredia et al., 2018).

5.9.3 Adaptation

For individuals suffering from seasonal aeroallergens, aeroallergen alert systems that provide knowledge of current or forecast pollen levels may aid in efforts to choose the right medications to treat symptoms (Lougheed et al., 2010; D'Amato et al., 2015). Health care providers can discuss optimal therapies for allergic rhinitis with their patients. For example, there is evidence that efficacies of prescribed and over-the-counter medications for allergic rhinitis are enhanced if they are taken consistently or before symptom onset (Kim et al., 2008; Keith et al., 2012). In addition, reminders and warnings that the aeroallergen season is approaching may allow Canadians to ensure that they have visited a health care provider, refilled prescriptions, and begun taking preventive medications according to their management plan (Johnston et al., 2018).

An aeroallergen alert system is also a beneficial communication strategy to advise people at risk to control their exposure when aeroallergen levels are high (Sierra-Heredia et al., 2018). In Canada, daily aeroallergen forecasts are provided by Aerobiology Research Laboratories (ARL) through the Weather Network (Aerobiology Research Laboratories, 2019a; The Weather Network, 2019). A free application provided by ARL can also be downloaded on a smart phone in order to obtain forecasts of pollen and fungal spores (Aerobiology Research Laboratories, 2019b). Other potential risk-mitigation strategies at a population level include the greening of cities with trees and species that minimize allergenicity for people exposed (Fuertes et al., 2016; Carinanos et al., 2017; Fong et al., 2018). Strategies in the province of Quebec have shown that engaging various partners at the municipal level in synchronizing their ragweed-control actions can reduce exposure to ragweed pollen (Demers & Gosselin, 2019). This includes mowing regularly, applying low-impact herbicides, and planting a competitive plant cover to prevent the spread of ragweed.

5.9.4 Key Uncertainties

Although several studies have identified health effects associated with exposure to aeroallergens, key uncertainties remain. A better understanding of the spatial coverage of aeroallergens and interactions with air pollutants and urban green spaces is needed to provide information that at-risk populations can use to modify their exposures and to shape urban greening initiatives (D'Amato et al., 2015; Sierra-Heredia et al., 2018). Additional information on the health benefits and effectiveness of adaptation strategies, such as the use of alert systems and aeroallergen control actions, is also needed. Further studies examining long-term impacts of climate change on aeroallergens would help to explain regional differences and increase understanding of the key characteristics of climate change on pollen load and seasonal length (Ziska et al., 2019). Projections of the impacts of climate change on future levels of aeroallergens are also required.

5.10 Conclusion

5.10.1 Climate Change and Air Quality Health Impacts in Canada

Climate change and air quality are intimately linked; a warming climate can worsen air pollution (i.e., the climate penalty), and some air pollutants, including ozone and components of $PM_{2.5}$, can affect the climate and enhance warming. GHGs and air pollutants are also derived from common sources linked to fossil fuel combustion; therefore, strategies to address one may have important co-benefits of reducing emissions of the other.

Air pollution is the leading environmental cause of death in Canada, contributing to an estimated 15,300 deaths annually, along with many non-fatal outcomes (Health Canada, 2021). Recent research indicates that the adverse effects of air pollution extend beyond cardiorespiratory impacts, linking exposure to varied outcomes such as diabetes, dementia, and reproductive health. Even small increases in exposure to air pollution are associated with an increased risk of adverse health impacts. The broad range of adverse health effects caused by air pollution, along with the ubiquitous and involuntary nature of air pollution exposure, highlight the importance of air quality management as a key public health issue.

Studies that have quantified the climate penalty in terms of air pollution health impacts under various climate projections have focused primarily on ozone, with some addressing $PM_{2.5}$ as well. Analyses undertaken for this assessment estimate hundreds of excess annual deaths due to air pollution in 2050, associated with the impact of climate change on air pollution, primarily in Ontario and Quebec, with a net social value of $2.7 billion. Similarly, studies in the United States have reported hundreds to thousands of excess annual air pollution deaths later this century associated with a warming climate.

Importantly, many studies have reported the considerable potential air pollution health co-benefits of pursuing climate change mitigation strategies that target either long-lived climate pollutants (e.g., CO_2) or short-lived climate forcers (e.g., black carbon or methane). Although climate benefits of near-term GHG emission reductions may only be realized in the mid- to long-term and generally occur globally, the public health benefits of the associated reductions in air pollutant emissions would be realized immediately and locally where the emission reductions are implemented. In addition, these benefits can have a large social value, which can offset a portion of the GHG mitigation costs. Incorporating air quality health co-benefits into climate change mitigation policy provides additional justification for pursuing more stringent or accelerated reduction measures to address climate change. Joint consideration of options to reduce both GHG and air pollution emissions would contribute to the strategic development of policies that optimize both and help to avoid unintended negative consequences, such as inadvertent increases in air pollution emissions from implementation of GHG mitigation strategies.

Wildfires have become an important source of air pollution in Canada, and increasing wildfire emissions due to climate change represent one of the most significant risks to air quality. It is expected that wildfire frequency, severity, and distribution will change under a warming climate, resulting in higher emissions, and the evidence suggests that some of the current increased wildfire activity can already be attributed to climate change. Exposure to wildfire smoke affects respiratory health, while the evidence for cardiovascular outcomes remains inconclusive. A Canadian analysis estimates 620 to 2700 annual deaths attributable to wildfire emissions during the 2013 to 2018 period, with an annual net social value ranging from $4.7 billion to $21 billion, as well as many non-fatal cardiorespiratory effects. Overall, the greatest impacts were noted in British Columbia and Alberta, although during the 2013 fire season the greatest impacts were reported in Ontario and Quebec. Although the highest air pollution concentrations are expected to occur closer to the fires, smoke plumes can spread over vast areas of the country, affecting population centres far from the sources. For example, 20% to 30% of the Canadian population was exposed to average wildfire $PM_{2.5}$ concentrations of 1 $\mu g/m^3$ or more during the May to September season in 2014, 2015, 2017, and 2018. The current air pollution health impacts of wildfire smoke are expected to increase under climate change, making this an important public health issue.

Canadians spend 90% of their time indoors, and climate change is expected to impact indoor air quality in a variety of ways. It is anticipated that climate change will include more frequent extreme weather events, which raise the risk of health effects from mould due to flooding, smoke from wildfires, and indoor air pollution from the inappropriate use of combustion sources, among other impacts. In addition, increased home airtightness associated with improved energy efficiency requires sufficient ventilation to ensure pollutants do not accumulate indoors. Conversely, under conditions of poor outdoor air pollution, impacts on indoor air quality can be mitigated through increased home airtightness and the use of air conditioning and filtration. Economic resources are typically needed to take protective measures, such as increasing home airtightness and ventilation. Thus, low-income households and socially disadvantaged communities may face challenges with implementing such measures.

Ambient levels of aeroallergens, including pollen and fungal spores, have been associated with increased risk of asthma-related and allergic rhinitis-related hospital visits in Canada, as well as other adverse effects. Warming temperatures, changing weather conditions, and rising atmospheric CO_2 levels result in increases in pollen counts, season length, and allergenicity, as well as changes to species distribution. Asthma affects about 3 million Canadians, including 12% to 25% of children, while approximately one-quarter of Canadians suffer from allergic rhinitis. Both of these conditions are commonly triggered by aeroallergens. The incidence and prevalence of asthma and allergic rhinitis are projected to increase with climate change.

5.10.2 Populations at Higher Risk

The scientific evidence indicates that multiple subpopulations are at increased risk from the adverse health effects of air pollution and aeroallergens and would therefore likely be more affected by worsening outdoor air pollution, wildfire smoke, indoor air pollution, and airborne allergen concentrations resulting from a changing climate.

Some groups are more susceptible to air pollutants due to age (children and seniors), pre-existing disease (e.g., asthma, COPD, or heart disease) or genetic predispositions. Growing evidence of air pollution effects on reproductive outcomes, diabetes, and progression of cardiac disease, among other health effects, suggests that a large proportion of the population may be at elevated risk. Other groups may be at higher risk due to elevated exposures because of where they live or how much time they spend outdoors, including for occupational purposes. A recent study estimates that one-third of the Canadian population has a least one risk factor making them at greater risk than the general population to the adverse effects of ozone and $PM_{2.5}$, highlighting the need for risk communication and interventions to manage air quality to target both highly exposed and more susceptible populations (Stieb et al., 2019).

Key populations at higher risk from the increasing pollen exposure and allergenicity expected under climate change include those with asthma and allergic rhinitis, and recent evidence suggests that other populations, including those with heart disease, may also be affected.

Importantly, in Canada, Indigenous populations bear a disproportionately higher burden of respiratory diseases, including asthma and COPD, than the general population, increasing their susceptibility to outdoor air pollution, wildfire smoke, indoor air pollution, and aeroallergens. Multiple, compounding health inequities (see Chapter 9: Climate Change and Health Equity) may further contribute to higher vulnerability. Indigenous Peoples living in remote communities may also be more likely to experience high levels of wildfire smoke.

5.10.3 Adaptation

A key goal of air quality management in Canada is continuous improvement, through reductions in air pollutant emissions across multiple sectors (CCME, 2019). However, additional programs have been developed to address the health risks of air pollution by reducing exposure, and these programs will become increasingly important to counterbalance the expected negative impacts of climate change.

The AQHI serves as a health-protection tool designed to help Canadians make decisions to protect their health by limiting short-term exposure to outdoor air pollution. The AQHI reports current and forecast conditions daily for communities across Canada and provides specific advice related to air quality levels associated with low, moderate, high, and very high health risks, including for susceptible individuals. In addition, local authorities use air quality alerts or advisories under high-risk conditions. The AQHI does not measure effects from heat, and there is currently only limited integration of heat and air quality messages for the public in Canada. The Government of Canada also provides forecasts of wildfire $PM_{2.5}$ levels for the next 48 hours, which include mapping of predicted smoke paths, and fire smoke air quality alerts are issued when necessary. The British Columbia Centre for Disease Control has implemented an alternative version of the

AQHI during the wildfire season to better reflect risks during wildfire smoke events, and multiple provinces and territories have information for protecting community health from wildfire smoke.

Enhancing urban green space can have multiple co-benefits for health, including direct positive health impacts as well as a role in attenuating exposure to air pollution and contributing to the reduction of the urban heat island effect.

Adaptation strategies to address indoor air quality in Canada under a changing climate will require a multi-faceted risk management approach that incorporates control of indoor sources of air pollutants, adequate ventilation under increasing home airtightness, and air filtration. Flood-prevention strategies would help to mitigate mould caused by water damage, and increased use of CO detection would help to prevent deaths from CO poisoning during power outages. In addition, targeting actions to rural, geographically affected, or low-income communities can help to protect populations at higher risk.

Daily aeroallergen forecasts, which can aid in reducing exposure to aeroallergens and optimization of pharmacotherapy for allergy sufferers, are currently provided in Canada by ARL through the Weather Network. Community-based adaptation strategies to reduce pollen levels could include urban greening with low-allergenicity species. A project in Quebec has shown that municipal-level partnerships may be effective in coordinating multiple control strategies to address ragweed, a common allergen species.

5.10.4 Knowledge Gaps

Several important knowledge gaps remain in understanding of how the health of Canadians will be affected by air quality under a changing climate. Integrated modelling of climate change and air quality, including the effects of climate parameters on $PM_{2.5}$ levels, is needed to improve understanding of both the population health impacts associated with the climate penalty and the potentially large air quality health co-benefits of GHG mitigation measures. The impact of changing climatic conditions on biogenic emissions needs to be better understood and incorporated into air quality models. In addition, an overall synthesis and comparison of the potential air quality co-benefits of multiple IPCC climate mitigation pathways remain difficult because studies to date have used different approaches, assumptions, and modelling methodologies. Aligning future study methodologies would provide improved information for pursuing climate change mitigation policies.

Improved capacity to model wildfire smoke exposure and to understand interactions between climate and wildfire risk is required to inform projections of wildfire smoke health impacts under climate change. Improved understanding of the range of adverse health effects associated with air pollution exposure, including whether the health effects of wildfire smoke are different from those of ambient air pollution, would provide a more comprehensive assessment of the population health impacts and identify populations at higher risk.

Although it is well known that Canadians spend 90% of their time indoors, characterizing pollutant exposures indoors and the associated health risks is challenging. Changing climate conditions, as well as mitigation and adaptation measures, increase the complexity of this problem. There is a need for research that supports the assessment of the health implications of changing environmental conditions and which can guide healthy building design, energy saving, ventilation, and material selection.

Recent research suggests that the spectrum of health impacts associated with airborne allergen exposure may go beyond respiratory outcomes, which may help to identify new susceptible groups. A better understanding of aeroallergen distribution and interactions with air pollutants and green space would help to inform urban greening initiatives and adaptation measures to protect populations at higher risk.

Finally, further research is required to inform the development of effective adaptation and risk mitigation strategies for wildfire smoke, indoor air quality, and aeroallergens under a changing climate to better protect the health of Canadians.

5.11 References

Abelsohn, A., & Stieb, D. M. (2011). Health effects of outdoor air pollution: approach to counseling patients using the Air Quality Health Index. *Canadian family physician, 57*(8), 881–e287.

Adelson, N. (2005). The embodiment of inequity: health disparities in aboriginal Canada. *Canadian journal of public health, 96*(2), S45–S61. <https://doi.org/10.1007/BF03403702>

Adetona, O., Reinhardt, T.E., Domitrovich, J., Broyles, G., Adetona, A. M., Kleinman, M.T., Ottmar, R. D., & Naeher, L. P. (2016). Review of the health effects of wildland fire smoke on wildland firefighters and the public. *Inhalation Toxicology, 28*(3), 95-139. doi:10.3109/08958378.2016.1145771

Aerobiology Research Laboratories. (2019a). Retrieved from <https://www.pollenexperts.ca/what-we-do/>

Aerobiology Research Laboratories. (2019b). *Personalized pollen reports.* Retrieved from <https://www.pollenexperts.ca/get-involved/#gettheapps>

Alam, S., Lang, J. J., Drucker, A.M., Gotay, C., Kozloff, N., Mate, K., Patten, S.B., Orpana, H. M., Afshin, A., & Cahill, L. E. (2019). Assessment of the burden of diseases and injuries attributable to risk factors in Canada from 1990 to 2016: an analysis of the Global Burden of Disease Study. *Canadian Medical Association Journal Open*, *7*(1), E140-E148. doi:10.9778/cmajo.20180137

Albert-Green, A., Dean, C. B., Martell, D. L., & Woolford, D. G. (2013). A methodology for investigating trends in changes in the timing of the fire season with applications to lightning-caused forest fires in Alberta and Ontario, Canada. *Canadian Journal of Forest Research, 43*(1), 39-45. doi:10.1139/cjfr-2011-0432

Alberta Health Services. (2019). *Frequently Asked Questions: Wildfires / Air Quality due to Wildfire Smoke.* Government of Alberta. Retrieved from <https://www.albertahealthservices.ca/assets/wf/eph/wf-eph-wildfire-smoke-health.pdf>

Amann, M., Klimont, Z., & Wagner F. (2013). Regional and global emissions of air pollutants: Recent trends and future scenarios. *Annual Review of Environment and Resources, 38,* 31-55. doi:10.1146/annurev-environ-052912-173303

Amiro, B. D., Cantin, A., Flannigan, M. D., & de Groot, W. (2009). Future Emissions from Canadian Boreal Forest Fires. *Canadian Journal of Forest Research, 39*, 383-395. doi:10.1139/X08-154

Anderson, V. (2016). A Harmonized Heat Warning and Information System for Ontario (HWIS) Standard Operating Practice. Toronto, ON: Ontario Ministry of Health and Long-term Care. Retrieved from <http://www.health.gov.on.ca/en/common/ministry/publications/reports/heat_warning_information_system/heat_warning_information_system.aspx>

Ariano, R., Berra, D., Chiodini, E., Ortolani, V., Cremonte, L. G., Mazzarello, M. G., Galdi E., Calosso C., & Ciprandi, G. (2015). Ragweed allergy: Pollen count and sensitization and allergy prevalence in two Italian allergy centers. *Allergy & Rhinology (Providence, R.I.), 6*(3), 177-183. doi:10.2500/ar.2015.6.0141

Ariano, R., Canonica, G. W., & Passalacqua, G. (2010). Possible role of climate changes in variations in pollen seasons and allergic sensitizations during 27 years. *Annals of Allergy, Asthma & Immunology: Official Publication of the American College of Allergy, Asthma, & Immunology, 104*(3), 215-222. doi:10.1016/j.anai.2009.12.005

Asher, M. I., Montefort, S., Bjorksten, B., Lai, C. K., Strachan, D. P., Weiland, S. K., Williams, H., & ISAAC Phase Three Study Group. (2006). Worldwide time trends in the prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and eczema in childhood: ISAAC phases one and three repeat multicountry cross-sectional surveys. *Lancet (London, England), 368*(9537), 733-743. <https://doi.org/10.1016/S0140-6736(06)69283-0>

Baldauf, R. (2016): Recommendations for Constructing Roadside Vegetation Barriers to Improve Near-Road Air Quality, U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/072. <https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NRMRL&dirEntryId=321772&simpleSearch=1&searchAll=Recommendations+for+constructing+roadside+vegetation+barriers+to+improve+near+road+air+quality> [November 2020]

Barn, P. (2014). *Evidence review: Home and community clean air shelters to protect public health during wildfire smoke events (C. Elliott, & K. Rideout, Eds).* BC Centre for Disease Control. Retrieved from <http://www.bccdc.ca/resourcegallery/Documents/Guidelines%20and%20Forms/Guidelines%20and%20Manuals/Health-Environment/WFSG_EvidenceReview_CleanAirShelters_FINAL_v3_edstrs.pdf>

Barn, P., Larson, T., Noullett, M., Kennedy, S., Copes R., & Brauer, M. (2008). Infiltration of forest fire and residential wood smoke: an evaluation of air cleaner effectiveness. *Journal of Exposure Science and Environmental Epidemiology, 18*(5), 503-511. doi:10.1038/sj.jes.7500640

Barnes, E. A., Fiore, A. M., & Horowitz, L. W. (2016). Detection of trends in surface ozone in the presence of climate variability. *Journal of Geophysical Research: Atmospheres, 121*(10), 6112 – 6129, doi:10.1002/2015jd024397

BC Centre for Disease Control (BC CDC). (2014). Wildfire Smoke Response Planning. Retrieved from <http://www.bccdc.ca/health-professionals/professional-resources/wildfire-smoke-response-planning>

BC Centre for Disease Control (BC CDC). (2019). The burning reality of wildfire smoke and its public health impacts. Retrieved from <http://www.bccdc.ca/about/news-stories/stories/the-burning-reality-of-wildfire-smoke-and-its-public-health-impacts>

Beggs, C. B., Noakes, C. J., Sleigh, P. A., Fletcher, L. A., & Siddiqi, K. (2003). The transmission of tuberculosis in confined spaces: an analytical review of alternative epidemiological models. *The International Journal of Tuberculosis and Lung Disease, 7*(11), 1015-26.

Beggs, P. J. (2004). Impacts of climate change on aeroallergens: Past and future. Clinical and Experimental Allergy. *Journal of the British Society for Allergy and Clinical Immunology, 34*(10), 1507-1513. doi:10.1111/j.1365-2222.2004.02061.x

Bell M. L., Goldberg R., Hogrefe C., Kinney P. L., Knowlton K., Lynn B., Rosenthal J., Rosenzweig C., & Patz, J. A. (2007). Climate change, ambient ozone, and health in 50 US cities. *Climatic Change*, 82, 61–76. doi: 10.1007/s10584-006-9166-7

Benmarhnia, T., Mathlouthi, F., & Smargiassi, A. (2013). Health impacts of particles from forest fires. Institut National de Santé Publique du Québec. Retrieved from <https://www.inspq.qc.ca/pdf/publications/1793_Health_Impacts_Forest_Fires.pdf>

Berry, P., McBean, G., & Seguin, J. (2008). Vulnerabilities to natural hazards and extreme weather. In J. Seguin (Ed.), Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity (pp. 43-112). Ottawa, ON: Health Canada. <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Bjerg, A., Ekerljung, L., Eriksson, J., Näslund, J., Sjölander, S., Rönmark, E., Dahl, Å., Holmberg, K., Wennergren, G., Torén, K., Borres, M. P., Lötvall, J., & Lundbäck, B. (2016). Increase in pollen sensitization in Swedish adults and protective effect of keeping animals in childhood. *Clinical and Experimental Allergy: Journal of the British Society for Allergy and Clinical Immunology*, *46*(10), 1328–1336. <https://doi.org/10.1111/cea.12757>

Black, C., Tesfaigzi, Y., Bassein, J. A., & Miller, L. A. (2017). Wildfire smoke exposure and human health: significant gaps in research for a growing public health issue. *Environmental Toxicology and Pharmacology, 55,* 186-195. doi:10.1016/j.etap.2017.08.022

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N.,… Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres, 118,* 5380–5552, doi:10.1002/jgrd.50171.

Bone, A., Murray, V., Myers, I., Dengel, A., & Crump, D. (2010). Will drivers for home energy efficiency harm occupant health? *Perspectives in Public Health, 130*(5), 233-238. doi:10.1177/1757913910369092

Bonofiglio, T., Orlandi, F., Ruga, L., Romano, B., & Fornaciari, M. (2013). Climate change impact on the olive pollen season in Mediterranean areas of Italy: Air quality in late spring from an allergenic point of view. *Environmental Monitoring and Assessment, 185*(1), 877-890. doi:10.1007/s10661-012-2598-9

Boucher, O., Randall D., Artaxo P., Bretherton C., Feingold G., Forster P., Kerminen V.-M., Kondo Y., Liao H., Lohmann U., Rasch P., Satheesh S. K., Sherwood S., Stevens B., & Zhang X. Y. (2013). Clouds and Aerosols. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 571-658). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, doi:10.1017/CBO9781107415324.016

Boulanger, Y., Gauthier S., & Burton P. J. (2014). A refinement of models projecting future Canadian fire regimes using homogeneous fire regime zones. *Canadian Journal of Forest Research, 44*, 365 – 376, doi:/10.1139/cjfr-2013-0372.

Breton, M. C., Garneau, M., Fortier, I., Guay, F., & Louis, J. (2006). Relationship between climate, pollen concentrations of ambrosia and medical consultations for allergic rhinitis in Montreal, 1994-2002. *The Science of the Total Environment, 370*(1), 39-50. <https://doi.org/10.1016/j.scitotenv.2006.05.022>

Bush, E., & Lemmen, D. S. (Eds.). (2019). Canada's Changing Climate Report. Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019/>

Cakmak, S., Dales, R. E., Burnett, R. T., Judek, S., Coates, F., & Brook, J. R. (2002). Effect of airborne allergens on emergency visits by children for conjunctivitis and rhinitis. *Lancet (London, England), 359*(9310), 947-948. <https://doi.org/10.1016/S0140-6736(02)08045-5>

Camalier, L., Cox, W., & Dolwick P. (2007). The effects of meteorology on ozone in urban areas and their use in assessing ozone trends. *Atmospheric Environment, 41*(33), 7127–7137. doi:10.1016/j.atmosenv.2007.04.061.

Cames, M., & Helmers, E. (2013). Critical evaluation of the European diesel car boom – global comparison, environmental effects and various national strategies. *Environmental Sciences Europe, 25*, 15. doi:10.1186/2190-4715-25-15

Canadian Council of Ministers of the Environment (CCME). (2014). Resources: AQMS. Retrieved from <https://www.ccme.ca/en/resources/air/aqms.html>

Canadian Council of Ministers of the Environment (CCME). (2019). *Guidance Document on Air Zone Management*. Retrieved from <https://www.ccme.ca/files/Resources/air/Guidance%20Document%20on%20Air%20Zone%20Management.pdf>

Canadian Electricity Association (CEA). (2018). *Climate Change adaptation.* Retrieved from <https://electricity.ca/lead/protecting-our-environment/climate-change-adaptation/>

Canadian Mortgage and Housing Corporation (CMHC). (1998). Field Survey of Heat Recovery Ventilation Systems Final Report. Ottawa, ON: Canada Mortgage and Housing Corporation Research Division. Retrieved from <http://publications.gc.ca/collections/collection_2011/schl-cmhc/nh18-1/NH18-1-90-1998-eng.pdf>

Cariñanos, P., Casares-Porcel, M., Díaz de la Guardia, C., Aira, M. J., Belmonte, J., Boi, M., Elvira-Rendueles, B., De Linares, C., Fernández-Rodriguez, S., Maya-Manzano, J. M., Pérez-Badía, R., Rodriguez-de la Cruz, D., Rodríguez-Rajo, F. J., Rojo-Úbeda, J., Romero-Zarco, C., Sánchez-Reyes, E., Sánchez-Sánchez, J., Tormo-Molina, R., & Vega Maray, A. M. (2017). Assessing allergenicity in urban parks: A nature-based solution to reduce the impact on public health. *Environmental Research*, *155*, 219–227. <https://doi.org/10.1016/j.envres.2017.02.015>

Carrière, G. M., Garner, R., & Sanmartin, C. (2017). Housing conditions and respiratory hospitalizations among First Nations People in Canada. *Health Reports (Catalogue no. 82-003-X)*. Ottawa, ON: Statistics Canada. Retrieved from <https://www150.statcan.gc.ca/n1/pub/82-003-x/2017004/article/14789-eng.pdf>

Cascio, W. E. (2018). Wildland fire smoke and human health. *Science of the Total Environment, 624*, 586-595. doi:10.1007/s10393-004-0149-8

Chand, D., Wood, R., Anderson, T. L., Satheesh, S. K., & Charlson, R. J. (2009). Satellite-derived direct radiative effect of aerosols dependent on cloud cover. *Nature Geoscience, 2,* 181 -184. doi: 10.1038/NGEO437

Chen, H., Burnett, R. T., Kwong, J. C., Villeneuve, P. J., Goldberg, M. S., Brook, R. D., van Donkelaar, A., Jerrett, M., Martin, R. V., Brook, J. R., & Copes, R. (2013a). Risk of incident diabetes in relation to long-term exposure to fine particulate matter in Ontario, Canada. *Environmental Health Perspectives, 121*(7), 804-810. doi: 10.1289/ehp.1205958

Chen, H., Li, Q., Kaufman, J. S., Wang, J., Copes, R., Su, Y., & Benmarhnia, T. (2018). Effect of air quality alerts on human health: a regression discontinuity analysis in Toronto, Canada. *The Lancet Planetary Health, 2*(1), e19-e26. doi:10.1016/S2542-5196(17)30185-7

Chen, R., Wang, X., Meng, X., Hua, J., Zhou, Z., Chen, B., & Kan, H. (2013b). Communicating air pollution-related health risks to the public: An application of the Air Quality Health Index in Shanghai, China. *Environment international, 51*, 168-173. doi.org/10.1016/j.envint.2012.11.008

Clark, N. A., Allen, R. W., Hystad, P., Wallace, L., Dell, S.D., Foty, R., Dabek-Zlotorzynska, E., Evans, G., & Wheeler, A. J. (2010). Exploring variation and predictors of residential fine particulate matter infiltration. *International Journal of Environmental Research and Public Health, 7*(8), 3211-3224. doi: 10.3390/ijerph7083211

Climate and Clean Air Coalition (CCAC). (2020). Why we need to act now. Retrieved from <ccacoalition.org/en/content/why-we-need-act-now>

Cooper, O. R., Parrish D. D., Ziemke J., Balashov N. V., Cupeiro M., Galbally I. E., Gilge S., Horowitz L., Jensen N. R., Lamarque J.-F.,. Naik V, Oltmans S. J., Schwab J., Shindell D. T., Thompson A. M., Thouret V., Wang Y., & Zbinden R. M. (2014). Global distribution and trends of tropospheric ozone: An observation-based review. *Elementa: Science of the Anthropocene, 2,* 000029. doi:/10.12952/journal.elementa.000029.

Coumou, D., Di Capua G., Vavrus S., Wang L., & Wang S. (2018). The influence of Arctic amplification on mid-latitude summer circulation. *Nature Communications, 9*(1), 2959. doi: 10.1038/s41467-018-05256-8.

Crouse, D. L., Pinault, L., Balram, A., Brauer, M., Burnett, R. T., Martin, R. V., van Donkelaar, A., Villeneuve, P. J., & Weichenthal, S. (2019). Complex relationships between greenness, air pollution, and mortality in a population-based Canadian cohort. *Environment International, 128*, 292-300. doi.org/10.1016/j.envint.2019.04.047

Dales, R., Liu, L., Wheeler, A. J., & Gilbert, N. L. (2008a). Quality of indoor residential air and health. *Canadian Medical Association journal = Journal de l'Association Médicale Canadienne*, *179*(2), 147–152. <https://doi.org/10.1503/cmaj.070359>

Dales, R. E., Cakmak, S., Burnett, R. T., Judek, S., Coates, F., & Brook, J. R. (2000). Influence of ambient fungal spores on emergency visits for asthma to a regional children's hospital. *American Journal of Respiratory and Critical Care Medicine*, *162*(6), 2087–2090. <https://doi.org/10.1164/ajrccm.162.6.2001020>

Dales, R. E., Cakmak, S., Judek, S., & Coates, F. (2008b). Tree pollen and hospitalization for asthma in urban Canada. *International Archives of Allergy and Immunology, 146*(3), 241-247. doi:10.1159/000116360

Dales, R. E., Cakmak, S., Judek, S., Dann, T., Coates, F., Brook, J. R., & Burnett, R. T. (2004). Influence of outdoor aeroallergens on hospitalization for asthma in Canada. *The Journal of Allergy and Clinical Immunology, 113*(2), 303-306. doi:10.1016/j.jaci.2003.11.016

D'Amato, G., Bergmann, K. C., Cecchi, L., Annesi-Maesano, I., Sanduzzi, A., Liccardi, G., Vitale, C., Stanziola, A., & D'Amato, M. (2014). Climate change and air pollution: Effects on pollen allergy and other allergic respiratory diseases. *Allergo Journal International, 23*(1), 17-23. doi:10.1007/s40629-014-0003-7

D'Amato, G., Holgate, S. T., Pawankar, R., Ledford, D. K., Cecchi, L., Al-Ahmad, M., Al-Enezi, F., Al-Muhsen, S., Ansotegui, I., Baena-Cagnani, C. E., Baker, D. J., Bayram, H., Bergmann, K. C., Boulet, L.-P., buters, J. T. M., D'amato, M., dorsano, S., Douwes, J., Finlay, S. E., Garrasi, D., …. Annesi-Maesano, I. (2015). Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the world allergy organization. *The World Allergy Organization Journal, 8*(1), 25. doi:10.1186/s40413-015-0073-0

D'Amato, G., Vitale, C., Lanza, M., Molino, A., & D'Amato, M. (2016). Climate change, air pollution, and allergic respiratory diseases: An update. *Current Opinion in Allergy and Clinical Immunology, 16*(5), 434-440. doi:10.1097/ACI.0000000000000301

Das, L., & Kovesi, T. A. (2015). Bronchiectasis in children from Qikiqtani (Baffin) Region, Nunavut, Canada. *Annals of the American Thoracic Society*, *12*(1), 96–100. <https://doi.org/10.1513/AnnalsATS.201406-257OC>

Dawson, J. P., Adams P. J., & Pandis S. N. (2007). Sensitivity of $PM_{2.5}$ to climate in the Eastern US: a modeling case study. *Atmospheric Chemistry and Physics, 7*, 4295 – 4309. doi:10.5194/acp-7-4295-2007.

Day, M. C., & Pandis S. N. (2011). Predicted changes in summertime organic aerosol concentrations due to increased temperatures. *Atmospheric Environment, 45*(36), 6546 – 6556. doi:10.1016/j.atmosenv.2011.08.028

Demers, I., & Gosselin, P. (2019). At-a-glance -Pollens, climate and allergies: Quebec initiatives. *Health promotion and chronic disease prevention in Canada, 39*(4), 136-141. <https://doi.org/10.24095/hpcdp.39.4.05>

Deser, C., Knutti, R., Solomon S., & Phillips A. S. (2012). Communication of the role of natural variability in future North American climate. *Nature Climate Change, 2,* 775 – 779. doi: 10.1038/NCLIMATE1562.

Dodd, W., Howard, C., Rose, C., Scott, C., Scott, P., Cunsolo, A., & Orbinski, J. (2018a). The summer of smoke: Ecosocial and health impacts of a record wildfire season in the Northwest Territories, Canada. *The Lancet Global health, 6*(Suppl.2), S30. doi:10.1016/S2214-109X(18)30159-1

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018b). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health, 109*(3), 327-337. <https://doi.org/10.17269/s41997-018-0070-5>

Du, X., Chen, R., Meng, X., Liu, C., Niu, Y., Wang, W., Li, S., Kan, H., & Zhou, M. (2020). The establishment of National Air Quality Health Index in China. *Environment International*, *138*, 105594-105600. doi.org/10.1016/j.envint.2020.105594

Ebi, K. L., & McGregor, G. (2008). Climate change, tropospheric ozone and particulate matter, and health impacts. *Environment Health Perspectives, 116*(11), 1449-1455. doi:10.1289/ehp.11463

Elliott, C. T., Henderson, S. B., & Wan, V. (2013). Time series analysis of fine particulate matter and asthma reliever dispensations in populations affected by forest fires. *Environmental Health, 12,* 11. doi:10.1186/1476-069X-12-11.

Environment and Climate Change Canada (ECCC). (2020). A Healthy Environment and Healthy Economy: Canada's strengthened climate plan to create jobs and support people, communities and the planet. Gatineau, QC: Government of Canada. Retrieved from <https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf>

European Academies' Science Advisory Council. (2019). *T*he imperative of climate action to protect human health in Europe. German National Academy of Sciences. Retrieved from <https://easac.eu/publications/details/the-imperative-of-climate-action-to-protect-human-health-in-europe/>

European Collaborative Action (ECA). (2013). Harmonisation Framework for Health Based Evaluation of Indoor Emissions from Construction Products in the European Union Using the EU-LCI Concept. Luxembourg: Publications Office of the European Union. Retrieved from <http://publications.jrc.ec.europa.eu/repository/handle/JRC83683<

Fan, J., Wang Y., Rosenfeld D., & Liu, X. (2016). Review of aerosol-cloud interactions: mechanisms, significance and challenges. *Journal of the Atmospheric Sciences, 73*(11), 4221 – 4252. doi:10.1175/JAS-D-16-0037.1, 2016.

Fang, Y., Mauzerall, D. J., Liu, J., Fiore, A. M., & Horowitz, L. W. (2013). Impacts of 21st century climate change on global air pollution-related premature mortality. *Climatic Change, 121,* 239–253. doi: 10.1007/s10584-013-0847-8

Fann, N., Alman, B., Broome, R. A., Morgan, G. G., Johnston, F. H., Pouliot, G., & Rappold, A. G. (2018). The health impacts and economic value of wildland fire episodes in the U.S.: 2018-2012. *Science of the Total Environment, 610-611*, 802-809. doi:10.1016/j.scitotenv.2017.08.024

Fann, N., Brennan, T., Dolwick, P., Gamble, J. L., Ilacqua, V., Kolb, L., Notle, C.G., Spero, T. L., & Ziska, L. (2016). Air Quality Impacts. In Crimmins, A., J. Balbus, J. L. Gamble, C. B. Beard, J. E. Bell, D. Dodgen, R. J. Eisen, N. Fann, M. D. Hawkins, S. C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M. C. Sarofim, J. Trtanj, & L. Ziska (Eds.), *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (pp. 69-98). Washington, DC: US Global Change Research Program.

Fann, N., Kim, S.-Y., Olives, C., & Sheppard, L. (2017). Estimated changes in life expectancy and adult mortality resulting from declining $PM_{2.5}$ exposures in the contiguous United States: 1980–2010. *Environmental Health Perspectives, 125*(9), 097003. <https://doi.org/10.1289/EHP507>

Fann, N., Nolte, C.G., Dolwick, P., Spero, T.L., Brown, A. C., Phillips, S., & Anenberg, S. (2015). The geographic distribution and economic value of climate change-related ozone health impacts in the United States in 2030. *Journal of the Air & Waste Management Association, 65*(5), 570–580. doi:10.1080/10962247.2014.996270

Faustman, E. M., Silbernagel, S.M., Fenske, R. A., Burbacher, T. M., & Ponce, R. A. (2000). Mechanisms underlying Children's susceptibility to environmental toxicants. *Environmental Health Perspectives, 108*(Suppl.1), 13-21. doi:10.1289/ehp.00108s113

Fiore, A. M., Naik, V., & Leibensperger, E. M. (2015). Air quality and climate connections. *Journal of the Air & Waste Management Association, 65(*6), 645 – 685. doi:10.1080/10962247.2015.1040526

Flannigan, M. D., Cantin, A. S., de Groot, W. J., Wotton, M., Newbery, A., & Gowman, L. M. (2013). Global wildland fire season severity in the 21st century. *Forest Ecology and Management, 294*, 54 – 61. doi:10.1016/j.foreco.2012.10.022

Flannigan, M. D., Krawchuk, M. A., de Groot, W. J., Wotton, B. M., & Gowman, L. M. (2009). Implications of changing climate for global wildland fire. *International Journal of Wildland Fire, 18*(5), 483-507. doi: 10.1071/WF08187

Flannigan, M. D., Logan, K. A., Amiro, B. D., Skinner, W. R., & Stocks, B. J. (2005). Future area burned in Canada. *Climatic Change, 72*, 1-16. doi:10.1007/s10584-005-5935-y

Flannigan, M. D., Wotton, M., Marshall, G., de Groot, W. J., Johnston, J., Jurko, N., & Cantin, A. S. (2016). Fuel moisture sensitivity to temperature and precipitation: Climate change implications. *Climatic Change, 134*, 59-71. doi:10.1007/s10584-015-1521-0.

Fong, K. C., Hart, J. E., & James, P. (2018). A review of epidemiologic studies on greenness and health: Updated literature through 2017. *Current Environmental Health Reports, 5*(1), 77-87. doi:10.1007/s40572-018-0179-y

Ford, B., Val Martin, M., Zelasky, S. E., Fischer, E. V., Anenberg, S. C., Heald, C. L., & Pierce, J. R. (2018). Future fire implications of smoke concentrations, visibility, and health in the contiguous United States. *GeoHealth, 2*(8), 229-247. doi: 10.1029/2018GH000144.

Forster, P., & Shine, K. P. (1997). Radiative forcing and temperature trends from stratospheric ozone changes. *Journal of Geophysical Research Atmospheres, 102,* 10841–10855. doi:10.1029/96JD03510

Fu, P., Guo, X., Cheung, F. M. H., & Yung, K. K. L. (2019). The association between $PM_{2.5}$ exposure and neurological disorders: A systematic review and meta-analysis. *The Science of the Total Environment, 655*, 1240-1248. doi: 10.1016/j.scitotenv.2018.11.218

Fuertes, E., Markevych, I., Bowatte, G., Gruzieva, O., Gehring, U., Becker, A., Berdel, D., von Berg, A., Bergstrom, A., Brauer, M., Brunekreef, B., Bruske, I., Carlesten, C., Chan-Yeung, M., Dharmage, S.C., Hoffmann, B., Klumper, C., Koppelman, G. H., Kozyrskyi, A.,...Heinrich, J. (2016). Residential greenness is differentially associated with childhood allergic rhinitis and aeroallergen sensitization in seven birth cohorts. *Allergy, 71*(10), 1461-1471. doi:10.1111/all.12915

Gai, Y., Minet, L., Posen, I.D., Smargiassi, A., Tétrault, L.-F., & Hatzopoulou, M. (2020). Health and climate benefits of electric vehicle deployment in Greater Toronto and Hamilton Area. *Environmental Pollution, 265*, 114983. doi.org/10.1016/j.envpol.2020.114983

Gao, Y., Fu, J. S., Drake, J. B., Lamarque, J.-F., & Liu, Y. (2013). The impact of emission and climate change on ozone in the United States under representative concentration pathways (RCPs). *Atmospheric Chemistry and Physics, 13*(4), 9607-9621. doi:10.5194/acp-13-9607-2013

Garcia-Menendez, F., Saari, R. K., Monier, E., & Selin, N. E. (2015). U.S. Air quality and health benefits from avoided climate change under greenhouse gas mitigation. *Environmental Science & Technology, 49*(13), 7580-7588. doi: 10.1021/acs.est.5b01324

Gauderman, J. W., McConnell, R. O., Gilliland, F., London, S., Thomas, D., Avol, E., Vora, H., Berhane, K., Rappaport, E. B., Lurmann, F., Margolis, H. G. (2000). Association between air pollution and lung function growth in southern California children. *American journal of respiratory and critical care medicine. 162*(4), 1383-90. <https://doi.org/10.1164/ajrccm.162.4.9909096>

Gershon, A. S., Guan, J., Wang, C., & To, T. (2010). Trends in asthma prevalence and incidence in Ontario, Canada, 1996-2005: A population study. *American Journal of Epidemiology, 172*(6), 728-736. doi:10.1093/aje/kwq189

Gerson, A. S., Khan, S., Klein-Geltink, J., Wilton, D., To, T., Crighton, E. J., Pigeau, L., MacQuarrie, J., Allard, Y., Russell, S. J. & Henry, D. A. (2014). Asthma and chronic obstructive pulmonary disease (COPD) prevalence and health service use in Ontario Métis: A population-based cohort study. *PLoS One, 9*(4), e95899. doi: org/10.1371/journal.pone.0095899

Gillett, N. P., Weaver, A. J., Zwiers, F. W., & Flannigan, M. D. (2004). Detecting the effect of climate change on Canadian forest fires. *Geophysical Research Letters, 31*(18), L18211. doi:10.1029/2004GL020876

Giorgi, F., & Gutowski, W. J. (2015). Regional dynamical downscaling and the CORDEX initiative. *Annual Review of Environment and Resources, 40*(1), 467–490. doi: 10.1146/annurev-environ-102014-021217

Government of Canada. (2012). Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations (SOR/2012-167). *Canada Gazette Part II, 146(19). Retrieved from* <http://www.gazette.gc.ca/rp-pr/p2/2012/2012-09-12/html/sor-dors167-eng.html>

Government of Canada. (2015). *Understanding Air Quality Health Index messages.* Retrieved from <https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index/understanding-messages.html>

Government of Canada. (2018). Regulations Amending the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations (SOR/2018-263). *Canada Gazette Part II, 152*(25). Retrieved from <http://gazette.gc.ca/rp-pr/p2/2018/2018-12-12/html/sor-dors263-eng.html>

Government of Canada. (2019a). *Air Quality Health Index.* Retrieved from <https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index.html>

Government of Canada. (2019b). *How Info-Smog works.* Retrieved from <https://www.canada.ca/en/environment-climate-change/services/info-smog/how-it-works.html>

Government of Canada. (2019c). *Canada's Wildfire Smoke Prediction System (FireWork) Daily smoke forecast maps from early April to late October.* Retrieved from <https://weather.gc.ca/firework/index_e.html>

Government of Canada. (2019d). *Wildfire smoke and air quality.* Retrieved from <https://www.canada.ca/en/environment-climate-change/services/air-quality-health-index/wildfire-smoke.html>

Groot, E., Caturay, A., Khan, Y., & Copes, R. (2019). A systematic review of the health impacts of occupational exposure to wildland fires. *International Journal of Occupational Medicine and Environmental Health, 32*(2), 121-40. <https://doi.org/10.13075/ijomeh.1896.01326>

Haines, A. (2017). Health co-benefits of climate action. *The Lancet Planetary Health, 1*(1), e4-5. <https://doi.org/10.1016/S2542-5196(17)30003-7>

Hamlin, T., & Gusdorf, J. (1997). *Airtightness and energy efficiency of new conventional and R-2000 housing in Canada.* Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/site/eng/73407/publication.html>

Hanes, C., Wang, X., Jain, P., Parisien, M.-A., Little, J., & Flannigan, M. (2019). Fire-regime changes in Canada over the last half century. *Canadian Journal of Forest Research, 49,* 256–269. doi:10.1139/cjfr-2018-0293.

Hartling, L., Brison, R., & Pickett, W. (1998). Cluster of Unintentional Carbon Monoxide Poisonings Presenting to the Emergency Departments in Kingston, Ontario during 'Ice Storm 98'. *Canadian Journal of Public Health, 89*(6), 388-390. <https://doi.org/10.1007/BF03404080>

Haywood, J. M., & Shine, K.P. (1995). The effect of anthropogenic *sulfate and soot aerosol on the clear sky planetary radiation budget. Geophysical Research Letters, 22*(5), 603 – 606. doi:10.1029/95GL00075

Health Canada. (2007). *Residential Indoor Air Quality Guideline: Moulds.* Ottawa, ON: Government of Canada. Retrieved from <https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/mould-moisissure/alt/mould-moisissures-eng.pdf>

Health Canada. (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity (J. Seguin, Ed.).* Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Health Canada. (2013). *Canadian Smog Science Assessment - Volume 2: Health Effects.* Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/collections/collection_2014/sc-hc/En88-5-2-2013-eng.pdf>

Health Canada. (2014). *A Statistical Profile on the Health of First Nations in Canada: Determinants of Health, 2006 to 2010.* Ottawa, ON: Government of Canada. Retrieved from <https://www.sac-isc.gc.ca/eng/1585414580249/1585414609942>

Health Canada. (2016). *Human Health Risk Assessment for Ambient Nitrogen Dioxide.* Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/site/eng/9.816718/publication.html>

Health Canada. (2018). *Ventilation and the Indoor Environment.* Ottawa, ON: Government of Canada. Retrieved from <https://www.canada.ca/content/dam/hc-sc/documents/services/publications/healthy-living/ventilation-indoor-environment/ventilation-indoor-environment.pdf>

Health Canada. (2020). *Guidance for Cleaner Air Spaces during Wildfire Smoke Events.* Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/site/eng/9.891164/publication.html>

Health Canada. (2021). *Health Impacts of Air Pollution in Canada: Estimates of morbidity and premature mortality outcomes, 2021 Report.* Ottawa, ON: Government of Canada.

Heguy, L., Garneau, M., Goldberg, M. S., Raphoz, M., Guay, F., & Valois, M. F. (2008). Associations between grass and weed pollen and emergency department visits for asthma among children in Montreal. *Environmental Research, 106*(2), 203-211. doi:S0013-9351(07)00223-X

Henderson, S. B., Brauer, M., MacNab, Y. C., & Kennedy, S. M. (2011). Three measures of forest fire smoke exposure and their associations with respiratory and cardiovascular health outcomes in a population-based cohort. *Environmental Health Perspectives, 119*(9), 1266-1271. doi:10.1289/ehp.1002288

Hernberg, S., Sripaiboonkij, P., Quansah, R., Jaakkola, J.J., & Jaakkola, M. S. (2014). Indoor molds and lung function in healthy *adults. Respiratory medicine, 108*(5), 677-684. doi:10.1016/j.rmed.2014.03.004

Heroux, M.-E., Clark, N., Van Ryswyk, K., Mallick, R., Gilbert, N., Harrison, I., Rispler, K., Wang, D., Anastassopoulos, A., Guay, M., MacNeill, M., & Wheeler, A. (2010). Predictors of indoor air concentrations in smoking and non-Smoking residences. *International Journal of Environmental Research and Public Health, 7*(8), 3080-3099. doi:10.3390/ijerph7083080

Hogrefe, C., Lynn, B., Civerolo, K., Ku, J.-Y., Rosenthal, J., Rosenzweig, C., Goldberg, R., Gaffin, S., Knowlton, K. & Kinney, P. L. (2004). Simulating changes in regional air pollution over the eastern United States due to changes in global and regional climate and emissions. *Journal of Geophysical Research: Atmospheres, 109*(22), D22301, doi:10.1029/2004JD004690

Horton, D. E., Skinner, C. B., Singh, D. & Diffenbaugh, N. S. (2014). Occurrence and persistence of future atmospheric stagnation events. *Nature Climate Change, 4*, 698-703. doi:10.1038/NCLIMATE2272, 2014.

Huang, S., Xiong, J., Cai, C., Xu, W., & Zhang, Y. (2016). Influence of humidity on the initial emittable concentration of formaldehyde and hexaldehyde in building materials: experimental observation and correlation. *Scientific Reports, 6*, 23388. doi: 10.1038/srep23388

Hulin, M., Simoni, M., Veigi, G., & Annesi-Maesano, I. (2012). Respiratory health and indoor air pollutants based on quantitative exposure assessments. *The European Respiratory Journal, 40*(4), 1033-1045. doi: 10.1183/09031936.00159011

Hystad, P. U., Setton, E. M., Allen, R. W., Keller, P. C., & Brauer, M. (2009). Modeling residential fine particulate matter infiltration for exposure assessment. *Journal of Exposure Science & Environmental Epidemiology, 19*(6), 570-579. doi:10.1038/jes.2008.45

Indigenous Services Canada (ISC). (2018). *Preventing and Managing Chronic Disease in First Nations Communities: A guidance framework.* Ottawa, ON: Indigenous Services Canada. Retrieved from <http://publications.gc.ca/collections/collection_2018/aanc-inac/H34-313-1-2017-eng.pdf>

Institute for Health Metrics and Evaluation (IHME). (2019). *Global Burden of Disease Study 2017.* Retrieved from <http://www.healthdata.org/sites/default/files/files/policy_report/2019/GBD_2017_Booklet.pdf>

Institute of Medicine (IOM). (2011). *Climate Change, the Indoor Environment, and Health.* Washington, DC: The National Academies Press.

Insurance Bureau of Canada (IBC). (2013). *Canada inundated by severe weather in 2013: Insurance companies pay out record-breaking $3.2 billion to policyholders.* Retrieved from <http://www.ibc.ca/yt/resources/media-centre/media-releases/canada-inundated-by-severe-weather-in-2013-insurance-companies-pay-out-record-breaking-$3-2-billion-to-policyholders>

Intergovernmental Panel on Climate Change (IPCC). (2014). Synthesis Report. In C.B. Field, V.R. Barros, D.J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate Change 2014* (pp.151). Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C.* Cambridge, United Kingdom: Cambridge University Press. Retrieved from <https://www.ipcc.ch/sr15/chapter/spm/>

International Agency for Research on Cancer (IARC). (2016). *Outdoor Air Pollution: IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Lyon, France. Retrieved from* <https://monographs.iarc.fr/wp-content/uploads/2018/06/mono109.pdf>

Inuit Tapiriit Kanatami (ITK). (2014). *Social Determinants of Inuit Health in Canada. Retrieved from* <https://www.itk.ca/wp-content/uploads/2016/07/ITK_Social_Determinants_Report.pdf>

Ismaila, A. S., Sayani, A. P., Marin, M., & Su, Z. (2013). Clinical, economic, and humanistic burden of asthma in Canada: A systematic review. *BMC Pulmonary Medicine,* 13, 70. doi:10.1186/1471-2466-13-70

Jacobson, M. Z. (2001). Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature, 409*(6821), 695 – 697. doi: 10.1038/35055518

Jiang, Z., McDonald, B. C., Worden, H., Worden, J. R., Miyazaki, K., Qug, Z., Henze, D. K., Jones, D. B. A., Arellano, A. F., Fischer, E. V., Zhu, L., & Boersma, K. F. (2018). Unexpected slowdown of US pollutant emission reduction in the past decade. *Proceedings of the National Academy of Sciences of the United States of America, 115*(20), 5099 – 5104. doi:10.1073/pnas.1801191115, 2018.

Johnston, F. H., Henderson, S. B., Chen, Y., Randerson, J.T., Marlier, M., DeFries, R. S., Kinney, P., Bowman, D. M. J. S., & Brauer, M. (2012). Estimated global mortality attributable to smoke from landscape fires. *Environmental Health Perspectives, 120*(5), 695-701. <https://doi.org/10.1289/ehp.1104422>

Johnston, F. H., Wheeler, A. J., Williamson, G. J., Campbell, S. L., Jones, P. J., Koolhof, I. S., Lucani, C., Cooling, N.B., & Bowman, D.M.J.S. (2018). Using smartphone technology to reduce health impacts from atmospheric environmental hazards. *Environmental Research Letters, 13*(4), 044019. doi:10.1088/1748-9326/aab1e6

Kasoar, M., Voulgarakis, A., Lamarque, J.-F., Shindell, D. T., Bellouin, N., Collins, W. J., Faluvegi, G., & Tsigaridis, K. (2016). Regional and global temperature response to anthropogenic SO_2 emissions from China in three climate models. *Atmospheric Chemistry and Physics, 16*(15), 9785 – 9804. doi:10.5194/acp-16-9785-2016

Kearney, J., Wallace, L., MacNeill, M., Héroux, M.-E., Kindzierski, W., & Wheeler, A. (2014). Residential infiltration of fine and ultrafine particles in Edmonton. *Atmospheric Environment, 94*, 793-805. doi:10.1016/j.atmosenv.2014.05.020

Keefe, A. (2014). *Evidence review: Filtration in institutional settings during wildfire smoke events (C. Elliott, & K. Rideout, Eds).* BC Centre for Disease Control. Retrieved from <http://www.bccdc.ca/resourcegallery/Documents/Guidelines%20and%20Forms/Guidelines%20and%20Manuals/Health-Environment/WFSG_EvidenceReview_FiltrationinInstitutions_FINAL_v3_edstrs.pdf>

Keith, P. K., Desrosiers, M., Laister, T., Schellenberg, R. R., & Waserman, S. (2012). The burden of allergic rhinitis (AR) in Canada: Perspectives of physicians and patients. *Allergy, Asthma, and Clinical Immunology : Official Journal of the Canadian Society of Allergy and Clinical Immunology, 8*(1), 7-1492-8-7. doi:10.1186/1710-1492-8-7

Kelly, J., Makar, P. A., & Plummer, D. A. (2012). Projections of mid-century summer air-quality for North America: effects of changes in climate and precursor emissions. *Atmospheric Chemistry and Physics, 12*(12), 5367 – 5390. doi:10.5194/acp-12-5367-2012

Kim, H., Bouchard, J., & Renzi, P. M. (2008). The link between allergic rhinitis and asthma: A role for antileukotrienes? *Canadian Respiratory Journal, 15*(2), 91-98. doi:10.1155/2008/416095

Kirchmeier-Young, M. C., Gillett, N. P., Zwiers, F. W., Cannon, A. J., & Anslow, F. S. (2019). Attribution of the influence of human-induced climate change on an extreme fire season. *Earth's Future, 7*, 2-10. <https://doi.org/10.1029/2018EF001050>

Kirchmeier-Young, M. C., Zwiers, F. W., Gillett, N. P., & Cannon, A. J. (2017). Attributing extreme fire risk in Western Canada to human emissions. *Climatic Change, 144*, 365-379. doi:10.1007/s10584-017-2030-0

Kondo, M. C., De Roos, A. J., White, L. S., Heilman, W. E., Mockrin, M. H., Gross-Davis, C. A., & Burstyn, I. (2019). Meta-analysis of heterogeneity in the effects of wildfire smoke exposure on respiratory health in North America. *International Journal of Environmental Research and Public Health, 16*(6), 960. <https://doi.org/10.3390/ijerph16060960>

Korpi, A., Pasanen, A.-L. & Pasanen, P. (1998). Volatile Compounds Originating from Mixed Microbial cultures on building materials under various humidity conditions. *Applied and Environmental Microbiology, 64*(8), 2914-2919. <https://doi.org/10.1128/AEM.64.8.2914-2919.1998>

Kovesi, T., Zaloum, C., Stocco, C., Fugler, D., Dales, R.E., Ni, A., Barrowman, N., Gilbert, N. L., & Miler, J. D. (2009). Heat recovery ventilators prevent respiratory disorders in Inuit children. *Indoor Air, 19*(6), 489-499. doi:10.1111/j.1600-0668.2009.00615.x

Kovesi, T. (2012). Respiratory disease in Canadian First Nations and Inuit children. *Paediatrics & Child Health, 17*(7), 376-380. doi:10.1093/pch/17.7.376

Lafeuille, M. H., Gravel, J., Figliomeni, M., Zhang, J., & Lefebvre, P. (2013). Burden of illness of patients with allergic asthma versus non-allergic asthma. *The Journal of Asthma : Official Journal of the Association for the Care of Asthma, 50*(8), 900-907. doi:10.3109/02770903.2013.810244

Lam, Y. F., Fu, J. S., Wu, S., & Mickley, L. J. (2011). Impacts of future climate change and effects of biogenic emissions on surface ozone and particulate matter concentrations in the United States. *Atmospheric Chemistry and Physics, 11*(10), 4789 – 4806. doi:10.5194/acp-11-4789-2011

Lavigne, E., Gasparrini, A., Stieb, D. M., Chen, H., Yasseen, A. S., 3rd, Crighton, E., To, T., Weichenthal, S., Villeneuve, P. J., Cakmak, S., Coates, F., & Walker, M. (2017). Maternal Exposure to Aeroallergens and the Risk of Early Delivery. *Epidemiology (Cambridge, Mass.)*, *28*(1), 107–115. <https://doi.org/10.1097/EDE.0000000000000573>

Lavigne, É., Burnett, R. T., Stieb, D. M., Evans, G. J., Godri Pollitt, K. J., Chen, H., van Rijswijk, D., & Weichenthal, S. (2018). Fine Particulate Air Pollution and Adverse Birth Outcomes: Effect Modification by Regional Nonvolatile Oxidative Potential. *Environmental Health Perspectives*, *126*(7), 077012. <https://doi.org/10.1289/EHP2535>

Leech, J. A., Nelson, W. C., Burnett, R. T., Aaron, S., & Raizenne, M. E. (2002). It's about time: a comparison of Canadian and American time-activity patterns. *Journal of Exposure Analysis and Environmental Epidemiology*, *12*(6), 427–432. <https://doi.org/10.1038/sj.jea.7500244>

Leech, J. A., Raizenne, M., & Gusdorf, J. (2004). Health in occupants of energy efficient new homes. *Indoor Air*, *14*(3), 169–173. <https://doi.org/10.1111/j.1600-0668.2004.00212.x>

Leibensperger, E. M., Mickley, L. J., & Jacob, D. J. (2008). Sensitivity of US air quality to mid-latitude cyclone frequency and implications of 1980–2006 climate change. *Atmospheric Chemistry and Physics, 8*(23), 7075–7086. doi: 10.5194/acp-8-7075-2008

Liu, D., Whitehead, J., Alfarra, M. R., Reyes-Villegas, E., Spracklen, D. V., Reddington, C. L., Kong, S., Williams, P. I., Ting, Y.-C., Haslett, S., Taylor, J. W., Flynn, M. J., Morgan, W. T., McFiggans, G., Coe *H., & Allan J. D. (2017)*. Black-carbon absorption enhancement in the atmosphere determined by particle mixing state. *Nature Geoscience, 10*, 184 – 191. doi:10.1038/NGEO2901

Liu, J. C., Mickely, L. J., Sulprizio, M. P., Yue, X., Peng, R. D., Dominici, F., & Bell, M. L. (2016). Future respiratory hospital admissions from wildfire smoke under climate change in the Western US. *Environmental Research Letters, 11*(12), 124018. doi:10.1088/1748-9326/11/12/124018.

Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A., & Bell, M. L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research*, *136*, 120–132. <https://doi.org/10.1016/j.envres.2014.10.015>

Liu, J. C., Zheng, Y., Li, Z., Flynn, C., & Cribb, M. (2012). Seasonal variations of aerosol optical properties, vertical distribution and associated radiative effects in the Yangtze Delta region of China. *Journal of Geophysical Research: Atmospheres, 117*(D16), D00K38. doi:10.1029/2011JD016490

Lougheed, M. D., Lemière, C., Dell, S. D., Ducharme, F. M., Fitzgerald, J. M., Leigh, R., Licskai, C., Rowe, B. H., Bowie, D., Becker, A., Boulet, L. P., & Canadian Thoracic Society Asthma Committee (2010). Canadian Thoracic Society Asthma Management Continuum--2010 Consensus Summary for children six years of age and over, and adults. *Canadian Respiratory Journal*, *17*(1), 15–24. <https://doi.org/10.1155/2010/827281>

Lowe, A. J., Olsson, D., Braback, L., & Forsberg, B. (2012). Pollen exposure in pregnancy and infancy and risk of asthma hospitalisation - a register based cohort study. *Allergy, Asthma, and Clinical Immunology : Official Journal of the Canadian Society of Allergy and Clinical Immunology, 8*(1), 17. doi:10.1186/1710-1492-8-17

MacNeill, M., Kearney, J., Wallace, L., Gibson, M., Héroux, M. E., Kuchta, J., Guernsey, J. R., & Wheeler, A. J. (2014). Quantifying the contribution of ambient and indoor-generated fine particles to indoor air in residential environments. *Indoor Air*, *24*(4), 362–375. <https://doi.org/10.1111/ina.12084>

MacNeill, M., Wallace, L., Kearney, J., Allen, R. W., Van Ryswyk, K., Judek, S., Xu, X., & Wheeler, A. (2012). Factors influencing variability in the infiltration of $PM_{2.5}$ mass and its components. *Atmospheric Environment, 61,* 518-532. doi: 10.1016/j.atmosenv.2012.07.005

Maguet, S. (2018). *Public Health Responses to Wildfire Smoke Events*. BC Centre for Disease Control and National Collaborating Centre for Environmental Health. Retrieved from <https://ncceh.ca/sites/default/files/Responding%20to%20Wildfire%20Smoke%20Events%20EN.pdf>

Maidment, C. D., Jones, C. R., Webb, T.L., Hathway, E. A., & Gilbertson, J. M. (2014). The impact of household energy efficiency measures on health: A meta-analysis. *Energy Policy, 65*, 583-593. doi: 10.1016/j.enpol.2013.10.054

Manitoba Health. (2019). *Health Effects of Smoke Exposure due to Wildland Fires. Government of Manitoba*. Retrieved from <https://www.gov.mb.ca/health/publichealth/environmentalhealth/smoke.html>

Markandya, A., Sampedro, J., Smith, S. J., Van Dingenen, R., Pizarro-Irizar, C., Arto, I., & González-Eguino, M. (2018). Health co-benefits from air pollution and mitigation costs of the Paris Agreement: a modelling study. *The Lancet Planet Health, 2*(3), e126-e133. doi: 10.1016/S2542-5196(18)30029-9

Matz, C. J., Stieb, D. M., Davis, K., Egyed, M., Rose, A., Chou, B., & Brion, O. (2014). Effects of age, season, gender and urban-rural status on time-activity: Canadian Human Activity Pattern Survey 2 (CHAPS 2). *International Journal of Environmental Research and Public Health*, *11*(2), 2108–2124. <https://doi.org/10.3390/ijerph110202108>

Matz, C. J., Egyed, M., Xi, G., Racine, J., Pavlovic, R., Rittmaster, R., Henderson, S. B., & Stieb, D. M. (2020). Health impact analysis of $PM_{2.5}$ from wildfire smoke in Canada (2013-2015, 2017-2018). *The Science of the Total Environment*, *725*, 138506. <https://doi.org/10.1016/j.scitotenv.2020.138506>

McCuskee, S., Kirlew, M., Kelly, L., Fewer, S., & Kovesi, T. (2014). Bronchiolitis and pneumonia requiring hospitalization in young first nations children in Northern Ontario, Canada. *The Pediatric Infectious Disease Journal*, *33*(10), 1023–1026. <https://doi.org/10.1097/INF.0000000000000361>

McLean, K. E., Yao, J., & Henderson, S. B. (2015). An Evaluation of the British Columbia Asthma Monitoring System (BCAMS) and $PM_{2.5}$ Exposure Metrics during the 2014 Forest Fire Season. *International journal of environmental research and public health*, *12*(6), 6710–6724. <https://doi.org/10.3390/ijerph120606710>

Mearns, L. O., Sain, S., Leung, L. R., Bukovsky, M. S., McGinnis, S., Biner, S., Caya, D., Arritt, R. W., Gutowski, W., Takle, E., Snyder, M., Jones, R. G., Nunes, A. M. B., Tucker, S., Herzmann, D., McDaniel, L., & Sloan, L. (2013). Climate change projections of the North American Regional Climate Change Assessment Program (NARCCAP). *Climate Change, 120*, 965 – 975. doi:10.1007/s10584-013-0831-3.

Mehiriz, K., & Gosselin, P. (2019). Evaluation of the Impacts of a Phone Warning and Advising System for Individuals Vulnerable to Smog. Evidence from a Randomized Controlled Trial Study in Canada. *International Journal of Environmental Research and Public Health*, *16*(10), 1817. <https://doi.org/10.3390/ijerph16101817>

MetroVancouver. (2018). *Climate 2050 Strategic Framework. Retrieved from* <http://www.metrovancouver.org/climate2050>

Mickley, L. J., Jacob, D. J., Field, B. D., & Rind, D. (2004). Effects of future climate change on regional air pollution episodes in the United States. *Geophysical Research Letters, 31*(24), L24103. doi:10.1029/2004GL021216

Mills, D., Jones, R., Wobus, C., Ekstrom, J., Jantarasami, L., St Juliana, A., & Crimmins, A. (2018). Projecting Age-Stratified Risk of Exposure to Inland Flooding and Wildfire Smoke in the United States under Two Climate Scenarios. *Environmental Health Perspectives*, *126*(4), 047007. <https://doi.org/10.1289/EHP2594>

Ministère de l'Environnement et de la Lutte contre les changements climatiques. (2012). *Pan d'action 2013-2020 sur les changements climatiques*. Gouvernement du Québec. Retrieved from <http://www.environnement.gouv.qc.ca/changements/plan_action/pacc2020.pdf>

Ministère de l'Environnement et de la Lutte contre les changements climatiques. (2019). *Feux de forêt.* Gouvernement du Québec. Retrieved from <https://www.environnement.gouv.qc.ca/air/feux-foret/index.htm>

Munioz-Alpizar, R., Pavlovic, R., Moran, M.D., Chen, J., Gravel, S., Henderson, S.B., Menard, S., Racine, J., Duhamel, A., Gilbert, S., Beaulieu, P.-A., Davignon, D., Cousineau, S., & Bouchet, V. (2017). Multi-year (2013-2016) $PM_{2.5}$ wildfire pollution exposure over North America as determined from operation air quality forecasts. *Atmosphere, 8*(9), 179. doi: 10.3390/atmos8090179

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, D., Nakajima, T., Robock, A., Stephens, G., Takemura, T., & Zhang, H. (2013). Anthropogenic and Natural Radiative Forcing. *In* T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley, Eds., *Climate Change 2013: The Physical Science Basis (pp. 659-740).* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. doi:10.1017/CBO9781107415324.018

Naeher, L. P., Brauer, M., Lipsett, M., Zelikoff, J. T., Simpson, C. D., Koenig, J. Q., & Smith, K. R. (2007). Woodsmoke health effects: a review. *Inhalation Toxicology*, *19*(1), 67–106. <https://doi.org/10.1080/08958370600985875>

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T.Y., Kram, T., La Rovere, E.L., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., & Dadi, Z. (2000). Special report on emissions scenarios. In N. Nakicenovic, & R. Swart, Eds., *Emissions Scenarios (pp. 599). Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

National Collaborating Centre for Aboriginal Health (NCCAH). *(2017). Housing as a Social Determinant of First Nations, Inuit, and Métis Health.* Prince George, BC. Retrieved from <https://www.ccnsa-nccah.ca/docs/determinants/FS-Housing-SDOH2017-EN.pdf>

Natural Resources Canada (NRCan). (2016). *Energy Efficiency Trends in Canada.* Ottawa, ON: Natural Resources Canada, Office of Energy Efficiency.

Natural Resources Canada (NRCan). (2018). *Energy and Greenhouse Gas Emissions (GHGs). Retrieved from* <https://www.nrcan.gc.ca/energy/facts/energy-ghgs/20063>

Nazaroff, W., & Weschler, C. (2004). Cleaning products and air fresheners: Exposure to primary and secondary air pollutants. *Atmospheric Environment, 38*(18), 2841-2865. doi:10.1016/j.atmosenv.2004.02.040

Nolte, C. G., Gilliland, A. B., Hogrefe, C., & Mickley, L. J. (2008). Linking global to regional models to assess future climate impacts on surface ozone levels in the United States. *Journal of Geophysical Research: Atmospheres, 113*(D14), D14307. doi:10.1029/2007JD008497

Northwest Territories Health and Social Services (NT HSS). (2016a). *Wildfire Smoke and Your Health Air quality Self-assessment Method. Government of Northwest Territories.* Retrieved from <https://www.hss.gov.nt.ca/sites/hss/files/wildfire-smoke-health.pdf>

Northwest Territories Health and Social Services (NT HSS). (2016b). *Smoke Exposure from Wildfire: Guidelines for Protecting Community Health and Wellbeing. Government of the Northwest Territories.* Retrieved from <https://www.hss.gov.nt.ca/sites/hss/files/smoke-exposure-wildfire-guidelines.pdf>

Northwest Territories Health and Social Services (NT HSS). (2018). *Wildfire smoke information in the Northwest Territories. Government of the Northwest Territories.* Retrieved from <https://www.hss.gov.nt.ca/sites/hss/files/resources/smoke-warning-aug2018.pdf>

Nova Scotia Department of Health and Wellness. (2018). *Emergencies and Extreme Weather Events – Wildfires. Province of Nova Scotia.* Retrieved from <https://novascotia.ca/dhw/environmental/wildfires.asp>

Oakes, M., Baxter, L., & Long, T. C. (2014). Evaluating the application of multipollutant exposure metrics in air pollution health studies. *Environment International*, *69*, 90–99. <https://doi.org/10.1016/j.envint.2014.03.030>

Ontario Ministry of Environment Conservation and Parks (OMECP). (2010). *AQHI categories and health messages. Government of Ontario*. Retrieved from <http://www.airqualityontario.com/aqhi/health_messages.php>

Ontario Ministry of Health and Long term Care (OHLTC). (n.d.). *Emergency Management Forest Fire Smoke and Your Health. Government of Ontario.* Retrieved from <http://www.health.gov.on.ca/en/public/programs/emu/fire_mn.aspx>

Parekh, A., Roux, L., & Gallant, P. (2007, July). *Thermal and air leakage characteristics of Canadian housing [Conference session]*. The 11th Canadian Conference on Building Science and Technology, Banff, Alberta, Canada.

Park, S., Allen, R.J., & Lim, C. H. (2020). A likely increase in fine particulate matter and premature mortality under future climate change. *Air Quality, Atmosphere & Health, 13*(7), 143-151. doi.org/10.1007/s11869-019-00785-7

Partanen, A.-I., Landry, J.-S., & Matthews, H. D. (2018). Climate and health implications of future aerosol emission scenarios. *Environmental Research Letters, 13(*2), 024028. doi:10.1088/1748-9326/aaa511

Pavlovic, R., Chen, J., Anderson, K., Moran, M. D., Beaulieu, P. A., Davignon, D., & Cousineau, S. (2016). The FireWork air quality forecast system with near-real-time biomass burning emissions: Recent developments and evaluation of performance for the 2015 North American wildfire season. *Journal of the Air & Waste Management Association, 66(*9), 819-41. doi:10.1080/10962247.2016.1158214

Peters, D. R., Schnell, J. L., Kinney, P. L., Naik, V., & Horton, D. E. (2020). Public health and climate benefits and trade-offs of U.S. vehicle electrification. *GeoHealth, 4*(10), e2020GH000275. <https://doi.org/10.1029/2020GH000275>

Pfister, G. G., Walters, S., Lamarque, J.-F., Fast, J., Barth, M. C., Wong, J., Done, J., Holland, G. & Bruyère, C. L. (2014). Projections of future summertime ozone over the U.S. *Journal of Geophysical Research: Atmospheres, 119*(9), 5559–5582. doi:10.1002/2013JD020932

Pinault, L., Crouse, D., Jerrett, M., Brauer, M., & Tjepkema, M. (2016a). Spatial associations between socioeconomic groups and NO_2 air pollution exposure within three large Canadian cities. *Environmental Research*, *147*, 373–382. <https://doi.org/10.1016/j.envres.2016.02.033>

Pinault, L., Crouse, D., Jerrett, M., Brauer, M., & Tjepkema, M. (2016b). Socioeconomic differences in nitrogen dioxide ambient air pollution exposure among children in the three largest Canadian cities. *Health Reports*, *27*(7), 3–9.

Pinault, L., van Donkelaar, A., & Martin, R. V. (2017). Exposure to fine particulate matter air pollution in Canada. *Health Reports*, *28*(3), 9–16.

Potera, C. (2011). Climate change impacts indoor environment. *Environmental health perspectives*, *119*(9), a382. <https://doi.org/10.1289/ehp.119-a382>

Poulin, P., Levasseur, M.-E., & Huppé, V. (2016). *Mesures d'adaptation pour une saine qualité de l'air intérieur dans un contexte de changements climatiques : revue de la littérature.* Institut National de Santé Publique du Québec. Retrieved from <https://www.inspq.qc.ca/publications/2194>

Prather, M. J., Holmes, C. D., & Hsu, J. (2012). Reactive greenhouse gas scenarios: Systematic exploration of uncertainties and the role of atmospheric chemistry. *Geophysical Research Letters, 39*(9), L09803. doi:10.1029/2012GL051440

Public Health Agency of Canada (PHAC). (2018). *Key Health Inequalities in Canada: A National Portrait.* Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/science-research/key-health-inequalities-canada-national-portrait-executive-summary/hir-full-report-eng.pdf>

Radisic, S., Newbold, K. B., Eyles, J., & Williams, A. (2016). Factors influencing health behaviours in response to the air quality health index: A cross-sectional study in Hamilton, Canada. *Environmental Health Review, 59*(1), 17-29. doi:10.5864/d2016-002

Ramanathan, R., Chung, C., Kim, D., Bettge, T., Buja, L., Kiehl, J. T., Washington, W. M., Fu, Q., Sikka, D. R., & Wild, M. (2005). Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle. *Proceedings of the National Academy of Sciences of the United States of America, 102*(15), 5326 – 5333. doi: 10.1073/pnas.0500656102

Ravishankara, A. R., Dawson, J. P., & Winner, D. A. (2012). New Directions: Adapting air quality management to climate change: A must for planning. *Atmospheric Environment, 50*, 387 – 389. doi:10.1016/j.atmosenv.2011.12.048

Reading, C., & Halseth, R. (2013). *Pathways to improving well-being for Indigenous peoples: how living conditions decide health.* Prince George, BC: National Collaborating Centre for Aboriginal Health. Retrieved from <https://www.ccnsa-nccah.ca/docs/determinants/RPT-PathwaysWellBeing-Reading-Halseth-EN.pdf>

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., & Elliott, C. T. (2016). Critical Review of Health Impacts of Wildfire Smoke Exposure. *Environmental Health Perspectives*, *124*(9), 1334–1343. <https://doi.org/10.1289/ehp.1409277>

Reid, C. E., & Gamble, J. L. (2009). Aeroallergens, allergic disease, and climate change: impacts and adaptation. *EcoHealth*, *6*(3), 458–470. <https://doi.org/10.1007/s10393-009-0261-x>

Reisen, F., Duran, S. M., Flannigan, M. D., Elliott, C., & Rideout, K. (2015). Wildfire smoke and public health risk. *International Journal of Wildland Fire, 24*(8), 1029-1044. doi: 10.1071/WF15034

Rice, M. B., Thurston, G. D., Balmes, J. R., & Pinkerton, K. E. (2014). Climate change. A global threat to cardiopulmonary health. *American Journal of Respiratory and Critical Care Medicine*, *189*(5), 512–519. <https://doi.org/10.1164/rccm.201310-1924PP>

Rittmaster, R., Adamowicz, W. L., Amiro, B., & Pelletier, R. T. (2006). Economic analysis of health effects from forest fires. *Canadian Journal of Forest Research, 36*(4), 868-877. doi: 10.1139/x05-293

Rittmaster, R., Adamowicz, W. L., Amiro, B., & Pelletier, R. T. (2008). Erratum: Economic analysis of health effects from forest fires. *Canadian Journal of Forest Research, 38*(4), 908. doi:10.1139/X08-905

Romero-Lankao, P., Smith, J. B., Davidson, D. J., Diffenbaugh, N. S., Kinney, P. L., Kirshen, P., Kovacs, P., & Villers Ruiz, L. (2014). North America. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L.White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment, Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Romps, D. M., Seeley, J. T., Vollaro, D., & Molinari, J. (2014). Projected increase in lightning strikes in the United States due to global warming. *Science, 346*(6211), 851–854. doi: 10.1126/science.1259100

Saari, R. K., Selin, N. E., Rausch, S., & Thompson, T. M. (2015). A self-consistent method to assess air quality co-benefits from U.S. climate policies. *Journal of the Air and Waste Management Association (1995)*, *65*(1), 74–89. <https://doi.org/10.1080/10962247.2014.959139>

Saari, R. K., Mei, Y., Monier, E., & Garcia-Menendez, F. (2019). Effect of health-related uncertainty and natural variability on health impacts and cobenefits of climate policy. *Environmental science and technology*, *53*(3), 1098–1108. <https://doi.org/10.1021/acs.est.8b05094>

Santé Montréal. (2017). *Info-smog.* City of Québec. Retrieved from <https://santemontreal.qc.ca/en/public/advice-and-prevention/info-smog/>

Saskatchewan Environment Public Health and Safety. (n.d.). *Wildfire Smoke and Air Quality.* Government of Saskatchewan. Retrieved from <https://www.saskatchewan.ca/residents/environment-public-health-and-safety/wildfire-in-saskatchewan/fire-smoke-and-air-quality>

Saunois, M., Bousquet, P., Poulter, B., Peregon, A., Ciais, P., Canadell, J. G., Dlugokencky, E. J., Etiope, G., Bastviken, D., Houweling, S., Janssens-Maenhout, G., Tubiello, F. N., Castaldi, S., Jackson, R. B., Alexe, M., Arora, V. K., Beerling, D. J., Bergamaschi, P., Blake, D. R., Brailsford, G., …Zhu, Q. (2016). The global methane budget 2000 – 2012. *Earth System Science Data Discussions, 8*(2), 697–751. doi:10.5194/essd-8-697-2016

Schnell, J. L., & Prather, M. (2017). Co-occurrence of extremes in surface ozone, particulate matter, and temperature over eastern North America. *Proceedings of the National Academy of Sciences of the United States of America, 114*(11), 2854 – 2859. doi:10.1073/pnas.1614453114, 2017.

Scout Environmental. (2019). Air Health Check. Retrieved from <https://scoutenvironmental.com/air-health-check/>

Seguel, J. M., Merrill, R., Seguel, D., & Campagna, A. C. (2016). Indoor Air Quality. *American journal of lifestyle medicine*, *11*(4), 284–295. <https://doi.org/10.1177/1559827616653343>

Seinfeld, J. H., Bretherton, C., Carslaw, K. S., Coe, H., DeMott, P. J., Dunlea, E. J., Feingold, G., Ghan, S., Guenther, A. B., Kahn, R., Kraucunas, I., Kreidenweis, S. M., Molina, M. J., Nenes, A., Penner, J. E., Prather, K. A., Ramanathan, V., …Wood, R. (2016). Improving our fundamental understanding of the role of aerosol−cloud interactions in the climate system. *Proceedings of the National Academy of Sciences of the United States of America, 113*(21), 5781 – 5790. doi:10.1073/pnas.1514043113

Selin, N. E., Wu, S., Nam, K. M., Reilly, J. M., Paltsev, S., Prinn, R. G., & Webster, M. D. (2009). Global health and economic impacts of future ozone pollution. *Environmental Research Letters, 4*(4), 044014. doi:10.1088/1748-9326/4/4/044014

Sharpe, R. A., Thornton, C. R., Nikolaou, V., & Osborne, N. J. (2015). Higher energy efficient homes are associated with increased risk of doctor diagnosed asthma in a UK subpopulation. *Environment International*, *75*, 234–244. <https://doi.org/10.1016/j.envint.2014.11.017>

Shea, K. M., Truckner, R. T., Weber, R. W., & Peden, D. B. (2008). Climate change and allergic disease. *The Journal of Allergy and Clinical Immunology*, *122*(3), 443–455. <https://doi.org/10.1016/j.jaci.2008.06.032>

Shindell, D. T., Faluvegi, G., Rotstayn, L., & Milly, G. (2015). Spatial patterns of radiative forcing and surface temperature response. *Journal of Geophysical Research: Atmospheres, 120(11),* 5385–5403. doi:10.1002/2014JD022752

Shindell, D. T., Faluvegi, G., Seltzer, K., & Shindell C. (2018). Quantified, localized health benefits of accelerated carbon dioxide emission reductions. *Nature Climate Change, 8*(4), 291-295. doi:10.1038/s41558-018-0108-y

Shindell, D. T., Kuylenstierna, J. C. I., Vignati, E., van Dingenen, R., Amann, M., Klimont, Z., Anenberg, S. C., Muller, N., Janssens-Maenhout, G., Raes, F., Schwartz, J., Faluvegi, G., Pozzoli, L., Kupiainen, K., Höglund-Isaksson, L., Emberson, L., Streets, D., Ramanathan, V., ….Fowler, D. (2012). Simultaneously mitigating near-term climate change and improving human health and food security. *Science, 335*(6065), 183-189. doi:10.1126/science.1210026

Shindell, D. T., Lee, Y., & Faluvegi, G. (2016). Climate and health impacts of US emissions reductions consistent with 2ºC. *Nature Climate Change, 6,* 503-507. doi: 10.1038/nclimate2935

Sierra-Heredia, C., North, M., Brook, J., Daly, C., Ellis, A. K., Henderson, D., Henderson, S. B., Lavigne, É., & Takaro, T. K. (2018). Aeroallergens in Canada: Distribution, Public Health Impacts, and Opportunities for Prevention. *International Journal of Environmental Research and Public Health*, *15*(8), 1577. <https://doi.org/10.3390/ijerph15081577>

Silva, R. A., West, J. J., Lamarque, J. F., Shindell, D. T., Collins, W. J., Dalsoren, S., Faluvegi, G., Folberth, G., Horowitz, L. W., Nagashima, T., Naik, V., Rumbold, S. T., Sudo, K., Takemura, T., Bergmann, D., Cameron-Smith, P., Cionni, I., Doherty, R. M., Eyring, V., Josse, B., … Zeng, G. (2016). The effect of future ambient air pollution on human premature mortality to 2100 using output from the ACCMIP model ensemble. *Atmospheric Chemistry and Physics*, *16*(15), 9847–9862. <https://doi.org/10.5194/acp-16-9847-2016>

Silva, R. A., West, J. J., Lamarque, J. F., Shindell, D. T., Collins, W. J., Faluvegi, G., Folberth, G. A., Horowitz, L. W., Nagashima, T., Naik, V., Rumbold, S. T., Sudo, K., Takemura, T., Bergmann, D., Cameron-Smith, P., Doherty, R. M., Josse, B., MacKenzie, I. A., Stevenson, D. S., & Zeng, G. (2017). FUTURE GLOBAL MORTALITY FROM CHANGES IN AIR POLLUTION ATTRIBUTABLE TO CLIMATE CHANGE. *Nature climate change*, *7*(9), 647–651. <https://doi.org/10.1038/nclimate3354>

Singh, R., Walsh, P., & Mazza, C. (2019). Sustainable Housing: Understanding the Barriers to Adopting Net Zero Energy Homes in Ontario, Canada. *Sustainability, 11*(22), 6236-6257. doi:10.3390/su11226236

Skiles, S. M., Flanner, M., Cook, J. M., Dumont, M., & Painter, T. H. (2018). Radiative forcing by light-absorbing particles in snow: *Nature Climate Change, 8*(11), 964 – 971. doi:10.1038/s41558-018-0296-5

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., Olwoch, J. M., Revich, B., & Sauerborn, R. (2014). Human health: impacts, adaptation, and co-benefits. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects (pp. 709-754). Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom: Cambridge University Press.

Solomon, G. M., Hjelmroos-Koski, M., Rotkin-Ellman, M., & Hammond, S. K. (2006). Airborne mold and endotoxin concentrations in New Orleans, Louisiana, after flooding, October through November 2005. *Environmental Health Perspectives*, *114*(9), 1381–1386. <https://doi.org/10.1289/ehp.9198>

Spurr, K., Pendergast, N., & MacDonald, S. (2014). Assessing the use of the Air Quality Health Index by vulnerable populations in a 'low-risk' region: A pilot study. *Canadian Journal of Respiratory Therapy : CJRT = Revue Canadienne de la Therapie Respiratoire : RCTR*, *50*(2), 45–49.

Stach, A., García-Mozo, H., Prieto-Baena, J. C., Czarnecka-Operacz, M., Jenerowicz, D., Silny, W., & Galán, C. (2007). Prevalence of Artemisia species pollinosis in western Poland: impact of climate change on aerobiological trends, 1995-2004. *Journal of Investigational Allergology & Clinical Immunology*, *17*(1), 39–47

Statistics Canada. (2015). *Aboriginal Peoples: Fact Sheet for Canada*. Retrieved from <https://www150.statcan.gc.ca/n1/pub/89-656-x/89-656-x2015001-eng.htm>

Statistics Canada. (2017). *The housing conditions of Aboriginal people in Canada Census of Population 2016.* Ottawa ON: Government of Canada. Retrieved from <https://www12.statcan.gc.ca/census-recensement/2016/as-sa/98-200-x/2016021/98-200-x2016021-eng.pdf>

Steiner, A. L., Tonse, S., Cohen, R. C., Goldstein, A. H., & Harley, R. A. (2006). Influence of future climate and emissions on regional air quality in California. *Journal of Geophysical Research: Atmospheres, 111*(D18), D18303. doi:10.1029/2005JD006935

Stevenson, D. S., Young, P. J., Naik, V., Lamarque, J.-F., Shindell, D. T., Voulgarakis, A., Skeie, R. B., Dalsoren, S. B., Myhre, G., Berntsen, T. K., Folberth, G. A., Rumbold, S. T., Collins, W. J., MacKenzie, I. A., Doherty, R. M., Zeng, G., van Noije, T. P. C., Strunk, A., Bergmann, D., Cameron-Smith, P., …Archibald, A. (2013). Tropospheric ozone changes, radiative forcing and attribution to emissions in the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP). *Atmospheric Chemistry and Physics, 13*(6), 3063-3085. doi:10.5194/acp-13-3063-2013

Stieb, D. M., Burnett, R. T., Smith-Doiron, M., Brion, O., Shin, H. H., & Economou, V. (2008). A new multipollutant, no-threshold air quality health index based on short-term associations observed in daily time-series analyses. *Journal of the Air & Waste Management Association (1995)*, *58*(3), 435–450. <https://doi.org/10.3155/1047-3289.58.3.435>

Stieb, D. M., Chen, L., Beckerman, B. S., Jerrett, M., Crouse, D. L., Omariba, D. W., Peters, P. A., van Donkelaar, A., Martin, R. V., Burnett, R. T., Gilbert, N. L., Tjepkema, M., Liu, S., & Dugandzic, R. M. (2016). Associations of Pregnancy Outcomes and $PM_{2.5}$ in a National Canadian Study. *Environmental Health Perspectives*, *124*(2), 243–249. <https://doi.org/10.1289/ehp.1408995>

Stieb, D. M., Judek, S., van Donkelaar, A., Martin, R. V., Brand, K., Shin, H. H., Burnett, R. T., & Smith-Doiron, M. H. (2015). Estimated public health impacts of changes in concentrations of fine particle air pollution in Canada, 2000 to 2011. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *106*(6), e362–e368. <https://doi.org/10.17269/cjph.106.4983>

Stieb, D. M., Yao, J., Henderson, S. B., Pinault, L., Smith-Doiron, M. H., Robichaud, A., van Donkelaar, A., Martin, R. V., Ménard, R., & Brook, J. R. (2019). Variability in ambient ozone and fine particle concentrations and population susceptibility among Canadian health regions. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *110*(2), 149–158. <https://doi.org/10.17269/s41997-018-0169-8>

Stohl, A., Aamaas, B., Amann, M., Baker, L.H., Bellouin, N., Berntsen, T.K., Boucher, O., Cherian, R., Collins, W., Daskalakis, N., Dusinska, M., Eckhardt, S., Fuglestvedt, J. S., Harju, M., Heyes, C., Hodnebrog, Ø., Hao, J., Im, U., Kanakidou, M., Klimont, Z., Kupiainen, K., …. Zhu, T. (2015). Evaluating the climate and air quality impacts of short-lived pollutants. *Atmospheric Chemistry and Physics, 15*(18), 10529 – 10566 doi:10.5194/acp-15-10529-2015, 2015.

Stowell, J. D., Kim, Y.-M., Gao, Y., Fu, J. S., Chang, H. H., & Liu, Y. (2017). The impact of climate change and emissions control on future ozone levels: Implications for human health. *Environmental International, 108*, p. 41-50. doi:10.1016/j.envint.2017.08.001

Tagaris, E., Liao, K.-J., DeLucia, A. J., Deck, L., Amar, P. & Russell, A. G. (2009). Potential impact of climate change on air pollution-related human health effects. *Environmental Science and Technology, 43*(13), 4979–4988. doi: 10.1021/es803650w

Tagaris, E., Manomaiphiboon, K., Liao, K.-J., Leung, L. R., Woo, J.-H., He, S., Amar, P., & Russell, A. G. (2007). Impacts of global climate change and emissions on regional ozone and fine particulate matter concentrations over the United States. *Journal Geophysical Research: Atmospheres, 112*(D14), D14312. doi:10.1029/2006JD008262.

Tai, A. P. K., Mickley, L. J., & Jacob, D. J. (2010). Correlations between fine particulate matter ($PM_{2.5}$) and meteorological *variables in the United States: Implications for the sensitivity of $PM_{2.5}$ to climate change. Atmospheric Environment, 44*(32), 3976-3984. doi:10.1016/j.atmosenv.2010.06.060

Tai, A. P. K., Mickley, L. J., & Jacob, D. J. (2012). Impact of 2000–2050 climate change on fine particulate matter ($PM_{2.5}$) air quality inferred from a multi-model analysis of meteorological modes. *Atmospheric Chemistry and Physics, 12*(23), 11329-11337. doi:10.5194/acp-12-11329-2012

Takaro, T. K., Knowlton, K., & Balmes, J. R. (2013). Climate change and respiratory health: current evidence and knowledge gaps. *Expert Review of Respiratory Medicine*, *7*(4), 349–361. <https://doi.org/10.1586/17476348.2013.814367>

Tan, X., Chen, S., Gan, T. Y., Liu, B., & Chen, X. (2019). Dynamic and thermodynamic changes conducive to the increased occurrence of extreme fire weather over western Canada under possible anthropogenic climate change. *Agricultural and Forest Meteorology, 265*, 269-279. doi:10.1016/j.agrformet.2018.11.026

Taylor, P. E., Jacobson, K. W., House, J. M., & Glovsky, M. M. (2007). Links between pollen, atopy and the asthma epidemic. *International Archives of Allergy and Immunology*, *144*(2), 162–170. <https://doi.org/10.1159/000103230>

The Weather Network. (2019). *Pollen report list. Retrieved from* <https://www.theweathernetwork.com/forecasts/pollen/list>

Thompson, T. M., Rausch, S., Saari, R. K., & Selin, N. E. (2014). A systems approach to evaluating the air quality co-benefits of US carbon policies. *Nature Climate Change, 4,* 917-923. doi: 10.1038/nclimate2342

Thompson, T. M., Rausch, S., Saari, R. K., & Selin, N. E. (2016). Air quality co-benefits of subnational carbon policies. *Journal of the Air & Waste Management Association (1995)*, *66*(10), 988–1002. <https://doi.org/10.1080/10962247.2016.1192071>

To, T., Dell, S., Tassoudji, M., & Wang, C. (2009). Health outcomes in low-income children with current asthma in Canada. *Chronic Diseases in Canada*, *29*(2), 49–55.

Traidl-Hoffmann, C., Kasche, A., Menzel, A., Jakob, T., Thiel, M., Ring, J., & Behrendt, H. (2003). Impact of pollen on human health: more than allergen carriers? *International Archives of Allergy and Immunology*, *131*(1), 1–13. <https://doi.org/10.1159/000070428>

Trail, M., Tsimpidi, A. P., Liu, P., Tsigaridis, K., Rudokas, J., Miller, P., Nenes, A., Hu, Y., & Russell, A. G. (2014). Sensitivity of air quality to potential future climate change and emissions in the United States and major cities. *Atmospheric Environment, 94,* 552 – 563, doi:10.1016/j.atmosenv.2014.05.079

Turner, M. C., Jerrett, M., Pope, C. A., 3rd, Krewski, D., Gapstur, S. M., Diver, W. R., Beckerman, B. S., Marshall, J. D., Su, J., Crouse, D. L., & Burnett, R. T. (2016). Long-Term Ozone Exposure and Mortality in a Large Prospective Study. *American Journal of Respiratory and Critical Care Medicine*, *193*(10), 1134–1142. <https://doi.org/10.1164/rccm.201508-1633OC>

Turnock, S. T., Smith, S., & O'Connor, F. M. (2019). The impact of climate mitigation measures on near term climate forcers. *Environmental Research Letters, 14*(10), 104013. doi: 10.1088/1748-9326/ab4222

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research*, *166*, 628–637. <https://doi.org/10.1016/j.envres.2018.06.030>

United National Framework Convention on Climate Change (UNFCCC). (2015). *The Paris Agreement.* Retrieved from <https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement>

United States Centers for Disease Control and Prevention (US CDC). (2020). *COVID-19 considerations for cleaner air shelters and cleaner air spaces to protect the public from wildfire Smoke.* Atlanta, GA. Retrieved from <https://www.cdc.gov/coronavirus/2019-ncov/php/cleaner-air-shelters.html>

United States Environmental Protection Agency (US EPA). (2016). *Wildfire Smoke: A guide for public health officials.* Retrieved from <https://www.airnow.gov/publications/wildfire-smoke-guide/wildfire-smoke-a-guide-for-public-health-officials/>

United States Environmental Protection Agency (US EPA). (2019). *Integrated Science Assessment for Particulate Matter.* Washington, DC. Retrieved from <https://epa.gov/isa/integrated-science-assessment-particulate-matter>

United States Environmental Protection Agency (US EPA). (2020a). *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*. Washington, DC. Retrieved from <https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=348522>

United States Environmental Protection Agency (US EPA). (2020b). *Integrated Science Assessments (ISAs)*. Retrieved from <www.epa.gov/isa>

Vachon, J., Gallant, V., & Siu, W. (2018). Tuberculosis in Canada, 2016. *Canada Communicable Disease Report = Releve des Maladies Transmissibles au Canada*, *44*(3-4), 75–81. <https://doi.org/10.14745/ccdr.v44i34a01>

Vaitla, P. M., & Drewe, E. (2011). Identifying the culprit allergen in seasonal allergic rhinitis. *The Practitioner*, *255*(1740), 27–2.

Val Martin, M., Heald, C. L., Lamarque, J.-F., Tilmes, S., Emmons, L. K., & Schichtel, B. A. (2015). How emissions, climate, and land use change will impact mid-century air quality over the United States: a focus on effects at national parks. *Atmospheric Chemistry and Physics, 15*(5), 2805–2823. doi:10.5194/acp-15-2805-2015

Vandyck, T., Keramidas, K., Kitous, A., Spadaro, J. V., Van Dingenen, R., Holland, M., & Saveyn, B. (2018). Air quality co-benefits for human health and agriculture counterbalance costs to meet Paris Agreement pledges. *Nature Communications*, *9*(1), 4939. <https://doi.org/10.1038/s41467-018-06885-9>

Van Vuuren, D. P., & Carter, T. R. (2014). Climate and socio-economic scenarios for climate change research and assessment: reconciling the new with the old. *Climate change, 122*(3), 415-429. doi:10.1007/s10584-013-0974-2

Van Vuuren, D.P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K. (2011). The representative concentration pathways: an overview. *Climatic Change, 109*(1), 5-31. doi:10.1007/s10584-011-0148-z

Viegi, G., Maio, S., Simoni, M., & Annesi-Maesano, I. (2009). The epidemiological link between ageing and respiratory diseases. In V. Bellia and R. Incalzi (Eds.), Respiratory Diseases in Elderly (p. 1–17).

Wallace, L. (1996). Indoor particles: a review. *Journal of the Air & Waste Management Association (1995), 46(*2), 98–126. <https://doi.org/10.1080/10473289.1996.10467451>

Wang, X., Parisien, M.-A., Taylor, S. W., Candau, J.-N., Stralberg, D., Marshall, G. A., Little, J. M., & Flannigan, M. D. (2017). Projected changes in daily fire spread across Canada over the next century. *Environmental Research Letters, 12*(2), 025005. doi:10.1088/1748-9326/aa5835

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

Weichenthal, S., Lavigne, E., Villeneuve, P. J., & Reeves, F. (2016). Airborne Pollen Concentrations and Emergency Room Visits for Myocardial Infarction: A Multicity Case-Crossover Study in Ontario, Canada. *American Journal of Epidemiology, 183*(7), 613–621. <https://doi.org/10.1093/aje/kwv252>

Wen, X. J., Balluz, L., & Mokdad, A. (2009). Association between media alerts of air quality index and change of outdoor activity among adult asthma in six states, BRFSS, 2005. *Journal of Community Health, 34*(1), 40–46. <https://doi.org/10.1007/s10900-008-9126-4>

Weschler, C. J. (2006). Ozone's impact on public health: contributions from indoor exposures to ozone and products of ozone-initiated chemistry. *Environmental Health Perspectives, 114*(10), 1489–1496. <https://doi.org/10.1289/ehp.9256>

Weschler, C.J. (2009). Changes in indoor pollutants since the 1950s. *Atmospheric Environment, 43*(1), 153–169. doi: 10.1016/j.atmosenv.2008.09.044

West, J. J., Fiore, A. M., & Horowitz, L. W. (2012). Scenarios of methane emission reductions to 2030: abatement costs and co-benefits to ozone air quality and human mortality. *Climatic Change, 114*(3-4), 441–461. doi:10.1007/s10584-012-0426-4

West, J. J., Smith, S. J., Silva, R. A., Naik, V., Zhang, Y., Adelan, Z., Fry, M. M., Anenberg, S., Horowitz, L. W., & Lamarque, J. F. (2013). Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change, 3*(10), 885-889. doi: 10.1038/nclimate2009

West, J. J., Szopa, S., & Hauglustaine, D. A. (2007). Human mortality effects of future concentrations of tropospheric ozone. Comptes Rendus Geoscience, 339(11), 775-783. doi:10.1016/j.crte.2007.08.005

Wheeler, A. J., Gibson, M. D., MacNeill, M., Ward, T. J., Wallace, L. A., Kuchta, J., Seaboyer, M., Dabek-Zlotorzynska, E., Guernsey, J. R., & Stieb, D. M. (2014). Impacts of air cleaners on indoor air quality in residences impacted by wood smoke. *Environmental Science & Technology, 48*(20), 12157–12163. <https://doi.org/10.1021/es503144h>

Wolkoff, P. (1998). Impact of air velocity, temperature, humidity, and air on long-term VOC emissions from building products. Atmospheric Environment, 32(14–15), 2659-2668. doi: 10.1016/S1352-2310(97)00402-0

World Health Organization (WHO). (2020). Ambient (outdoor) air pollution. Retrieved from <www.who.int/mediacentre/factsheets/fs313/en/>

Wotton, B. M., Flannigan, M. D., & Marshall, G. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. Environmental Research Letters, 12(9), 095003. doi:10.1088/1748-9326/aa7e6e

Wright, G. S., & Klingenberg, K. (2015). Climate-specific passive building standards. Golden, CO: National Renewable Energy Lab (NREL). doi:10.2172/1215274

Wu, S., Mickley, L. J., Jacob, D. J., Rind, D., & Streets, D. G. (2008a). Effects of 2000 – 2050 changes in climate and emissions on global tropospheric ozone and the policy-relevant background surface ozone in the United States. *Journal of Geophysical Research: Atmospheres, 113*(D18), D18312. doi:10.1029/2007JD009639

Wu, S., Mickley, L. J., Leibensperger, E. M., Jacob, D. J., Rind, D., & Streets, D. G. (2008b). Effects of 2000-2050 change on ozone air quality in the United States. *Journal of Geophysical Research: Atmospheres, 113*(D6), D06302. doi:10.1029/2007JD008917

Xiong, J., Wei, W., Huang, S., & Zhang, Y. (2013). Association between the emission rate and temperature for chemical pollutants in building materials: general correlation and understanding. *Environmental Science and Technology*, *47*(15), 8540–8547. <https://doi.org/10.1021/es401173d>

Yahya, K., Campbell, P., & Zhang Y. (2017). Decadal application of WRF/chem for regional air quality and climate modeling over the U.S. under the representative concentration pathways scenarios. Part 2: Current vs. future simulations. *Atmospheric Environment, 152*, 584 – 604. doi:10.1016/j.atmosenv.2016.12.028

Yao, J., Stieb, D. M., Taylor, E., & Henderson, S. B. (2020). Assessment of the Air Quality Health Index (AQHI) and four alternate AQHI-Plus amendments for wildfire seasons in British Columbia. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *111*(1), 96–106. <https://doi.org/10.17269/s41997-019-00237-w>

Youssouf, H., Liousse, C., Roblou, L., Assamoi, E. M., Salonen, R. O., Maesano, C., Banerjee, S., & Annesi-Maesano, I. (2014). Non-accidental health impacts of wildfire smoke. *International Journal of Environmental Research and Public Health*, *11*(11), 11772–11804. <https://doi.org/10.3390/ijerph111111772>

Yue, X., Mickley, L. J., Logan, J. A., & Kaplan, J. O. (2013). Ensemble projections of wildfire activity and carbonaceous aerosol concentrations over the western United States in the mid-21st century. *Atmospheric Environment, 77,* 767-780. doi:10.1016/j.atmosenv.2013.06.003

Yukon Health and Social Services. (2019). *Wildfire Smoke.* Government of Yukon. Retrieved from <http://www.hss.gov.yk.ca/wildfiresmoke.php>

Zhang, J., & Smith, K. R. (2003). Indoor air pollution: a global health concern. *British Medical Bulletin*, *68*, 209–225. <https://doi.org/10.1093/bmb/ldg029>

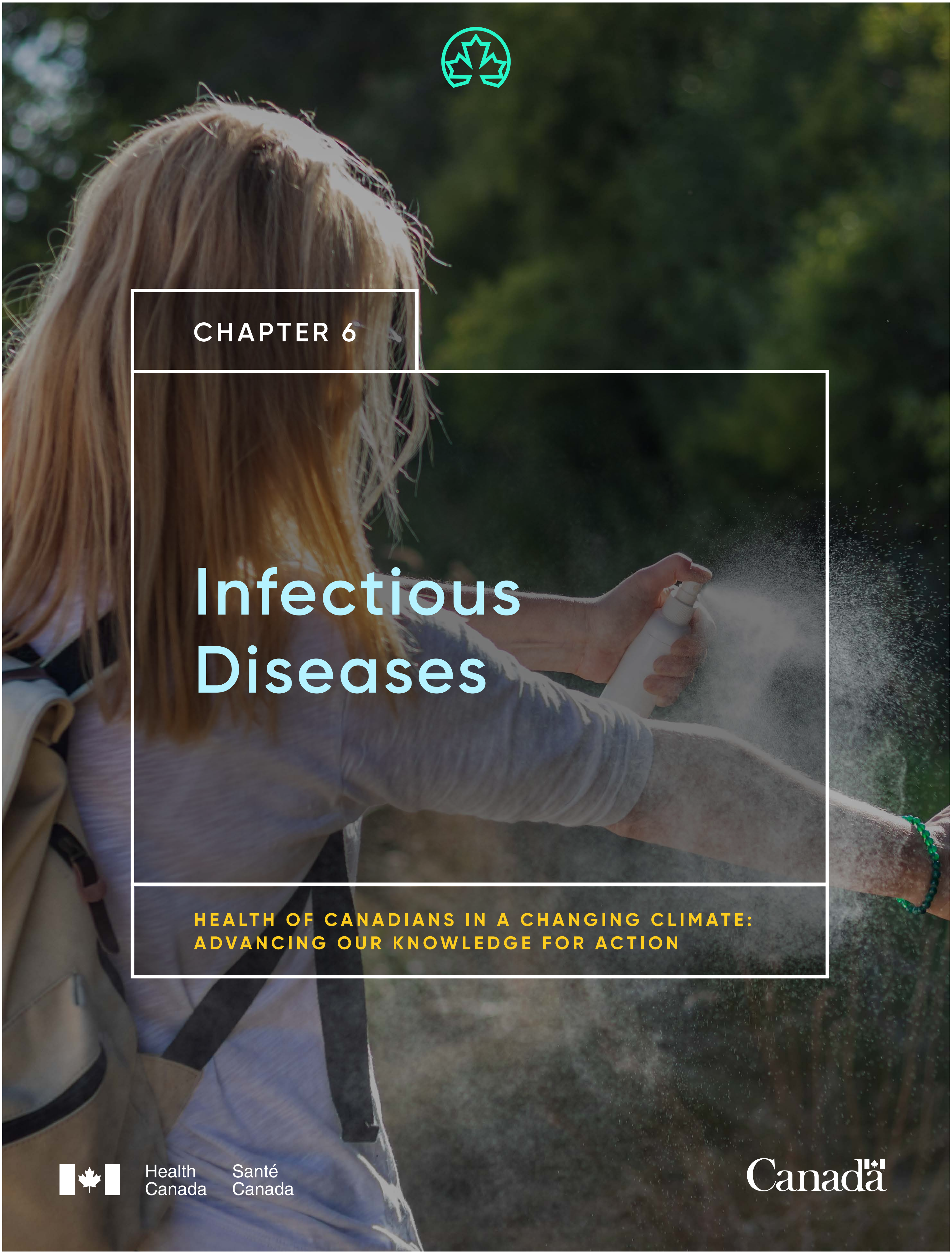
Zhang, Y., Smith, S. J., Bowden, J. H., Adelman, Z., & West, J. J. (2017). Co-benefits of global, domestic, and sectoral greenhouse gas mitigation for US air quality and human health in 2050. *Environmental Research Letters, 12*(11), 114033. <https://doi.org/10.1088/1748-9326/aa8f76>

Zhang, Y., West, J. J., Mathur, R., Xing, J., Hogrefe, C., Roselle, S. J., Bash, J. O., Pleim, J. E., Gan, C. M., & Wong, D. C. (2018). Long-term trends in the ambient $PM_{2.5}$- and O3-related mortality burdens in the United States under emission reductions from 1990 to 2010. *Atmospheric Chemistry and Physics*, *18*(20), 15003–15016. <https://doi.org/10.5194/acp-18-15003-2018>

Zickfeld, K., & Herrington, T. (2015). The time lag between a carbon dioxide emission and maximum warming increases with the size of the emission. *Environment Research Letters, 10*(3), 031001. doi:10.1088/1748-9326/10/3/031001

Ziska, L. H., & Beggs, P. J. (2012). Anthropogenic climate change and allergen exposure: The role of plant biology. *The Journal of Allergy and Clinical Immunology, 129*(1), 27-32. doi:10.1016/j.jaci.2011.10.032

Ziska, L. H., Makra, L., Harry, S. K., Bruffaerts, N., Hendrickx, M., Coates, F., Saarto, A., Thibaudon, M., Oliver, G., Damialis, A., Charalampopoulos, A., Vokou, D., Heidmarsson, S., Gudjohnsen, E., Vonini, M., Oh, J. W., Sullivan, K., Ford, L., Brooks, G. D., Myszkowska, D., …Crimmins, A. R. (2019). Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere: A retrospective data analysis. *The Lancet Planetary Health, 3*(3), e124-e131. doi:S2542-5196(19)30015-4



CHAPTER 6

Infectious Diseases

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Author

Nick H. Ogden, Public Health Agency of Canada

Contributing Authors

Catherine Bouchard, Public Health Agency of Canada

Gabrielle Brankston, University of Guelph

Elizabeth M. Brown, Public Health Ontario

Tricia Corrin, Public Health Agency of Canada

Antonia Dibernardo, Public Health Agency of Canada

Michael A. Drebot, Public Health Agency of Canada

David N. Fisman, University of Toronto

Eleni Galanis, BC Centre for Disease Control and University of British Columbia

Amy Greer, University of Guelph

Emily Jenkins, University of Saskatchewan

Julianne V. Kus, Public Health Ontario and University of Toronto

Patrick A. Leighton, Université de Montréal

L. Robbin Lindsay, Public Health Agency of Canada

Anne-Marie Lowe, Public Health Agency of Canada

Antoinette Ludwig, Public Health Agency of Canada

Shaun K. Morris, Hospital for Sick Children and University of Toronto

Victoria Ng, Public Health Agency of Canada

Linda Vrbova, Public Health Agency of Canada

Lisa Waddell, Public Health Agency of Canada

Heidi Wood, Public Health Agency of Canada

Suggested Citation

Ogden, N. H., Bouchard, C., Brankston, G., Brown, E. M., Corrin, T., Dibernardo, A., Drebot, M. A., Fisman, D. N., Galanis, E., Greer, A., Jenkins, E., Kus, J. V., Leighton, P. A., Lindsay, L. R., Lowe, A.-M., Ludwig, A., Morris, S. K., Ng, V., Vrbova, L., Waddell, L., & Wood, H. (2022). Infectious Diseases. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

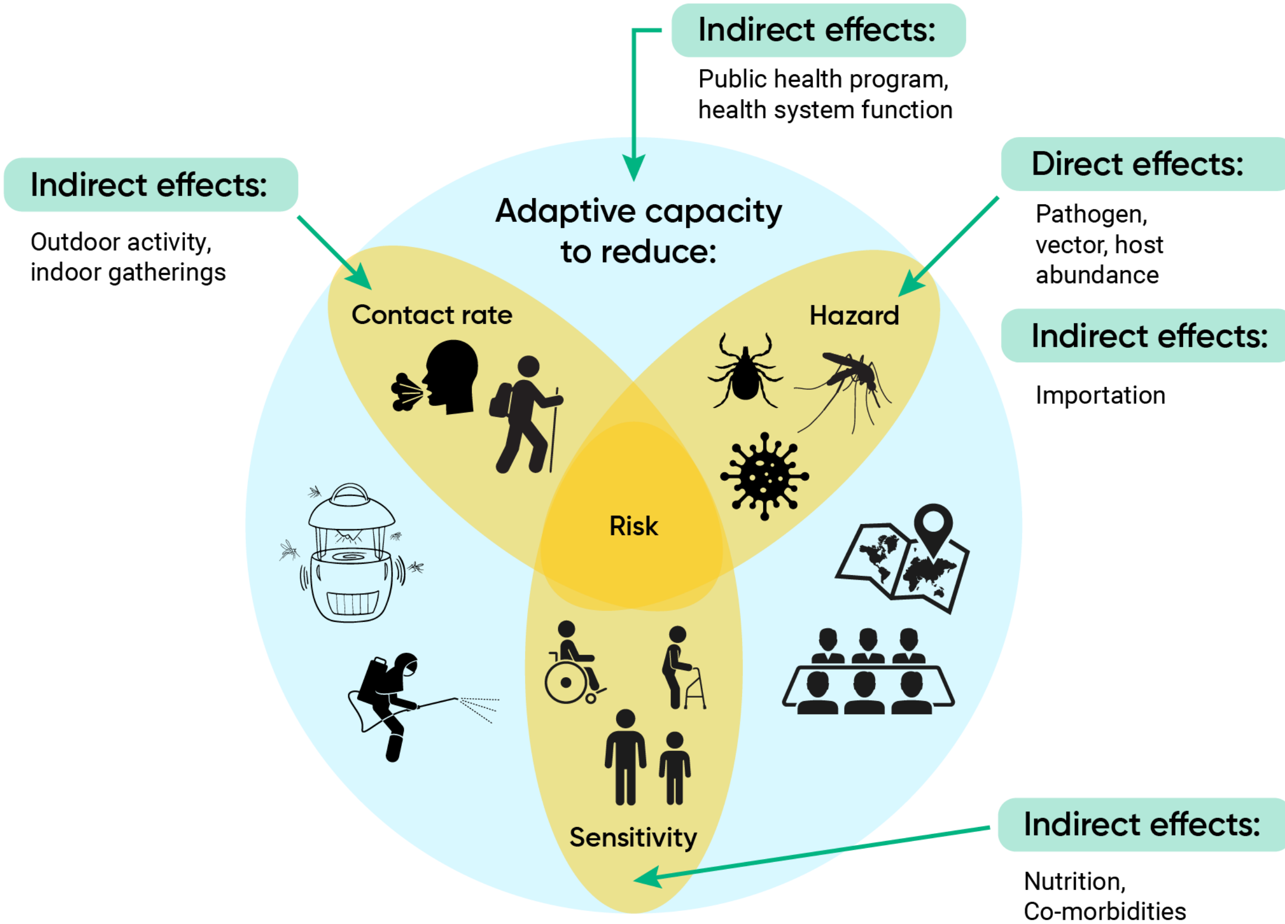
Summary

Climate change is affecting the risk from infectious diseases. There is evidence that the recent emergence of Lyme disease in Canada has been driven by climate warming, making more of Canada suitable for the ticks that carry the disease. Emergence of other insect-borne diseases, such as eastern equine encephalitis, could have been facilitated by a warming climate, and epidemics of West Nile virus infection have likely been driven by variability in weather and climate, which will increase with climate change. The risk from a very wide range of other infectious diseases is also known to be sensitive to weather and climate. Changes to geographic and seasonal patterns of these diseases in North America, and increased risk of importation of climate-sensitive diseases from further afield, are likely to pose increased risks to Canadians in coming decades. Adaptation measures include assessments of risk and vulnerability, integrated surveillance and early warning systems using emerging technologies, and a "One Health" approach that integrates human, animal, and environmental health.

Key Messages

- Under climate change, many diseases considered "climate-sensitive" are more likely to emerge or re-emerge globally and in Canada. These diseases include those transmitted by arthropod vectors (such as West Nile virus, Lyme disease), those directly transmitted from animals (zoonoses such as rabies, hantavirus pulmonary syndrome), those directly transmitted human-to-human (such as seasonal influenza, enterovirus infections), and those that can be acquired by inhalation from environmental sources (such as *Cryptococcus* infection, Legionnaires' disease).
- Infectious diseases new to Canada may spread northward from the United States, and from elsewhere in the world, carried by people and goods, or by wild animals. The indirect socio-economic effects of climate change may affect the capacity of nations to prevent and control infectious diseases globally, increasing the likelihood that new diseases will come into Canada through human travel and migration.
- Climate change is expected to make the Canadian environment more suitable for arthropod vectors (such as mosquitoes and ticks) and transmission of new infectious diseases. For example, mosquito-borne diseases already in Canada such as West Nile virus, which usually cause a limited number of infections each year, may produce epidemics under a more variable climate with more frequent extreme weather events.
- Potential effects of climate change on infectious diseases are identified by modelling studies, while disease surveillance has identified changes in occurrence of infectious diseases, and in some cases linked these changes to recent effects of climate change. These studies are largely restricted to diseases that humans acquire from arthropod vectors (insects and ticks) and directly from animals.

- Canada has high adaptive capacity to cope with infectious diseases given its robust national public health surveillance and response tied into national and international networks, a strong health system, and capacity for technological innovations. Canada is also a leader in “One Health” approaches that consider human, animal, and environmental factors together, using knowledge from many disciplines and sectors. Such approaches are essential to planning for emerging and re-emerging infectious diseases, including those related to climate change.
- Canada is also increasing its capacity to respond to effects of climate change on infectious diseases. This capacity will be enhanced by big data and modern genomic technologies, Earth observation from satellites, web crawling, and “citizen science” approaches to surveillance for climate change impacts on infectious diseases.



Components of vulnerability to infectious diseases in the context of climate change. The three intersecting components of risk are hazard, contact rate (which, with hazard, determines exposure), and sensitivity. Adaptation (represented by the blue background disc) depends on our capacity to minimize, and respond to changes in, each of these three components of risk. Green arrows show direct and indirect effects of climate change.

Overview of the Impacts of Climate Change on Infectious Diseases

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Infectious diseases transmitted by arthropod vectors	• Faster reproduction rates and greater survival, leading to increased abundance and geographic range of vectors found in Canada • Effects of weather variability and extreme weather events on reproduction rates and survival of mosquitoes that lead to rapid changes in populations • Faster reproduction rates and greater survival of exotic vectors once they are carried into Canada, making it more likely that exotic vectors and the diseases they carry (pathogens) can become established • Faster development of pathogens in mosquito vectors	• Increased incidence of Canada-endemic vector-borne diseases (e.g., Lyme disease, West Nile virus infection, eastern equine encephalitis) • Increased epidemics of Canada-endemic mosquito-borne diseases (West Nile virus infection, eastern equine encephalitis, California serogroup viruses) • Spread of US-endemic tick-borne (e.g., monocytic ehrlichiosis) and mosquito-borne (e.g., La Crosse virus infection) diseases into Canada • Increasing risk of autochthonous transmission of tropical/subtropical *Aedes* mosquito-borne diseases (dengue, chikungunya, Zika) • Impacts on health services
Infectious diseases directly transmitted by animals (zoonotic diseases)	• Changes to rates of reproduction and survival of wild animal reservoir hosts and other species resulting in changes in geographic ranges and levels of hazard for, and contact rates with, humans • Effects of weather on reproduction rates and survival of species such as rodents that can lead to rapid changes in their abundance	• Changes (increases in some locations, decreases in others) in geographic and temporal patterns of risk of directly transmitted zoonotic diseases (such as rabies, brucellosis) • Possible increasing frequency of outbreaks of some rodent-borne diseases (such as hantavirus pulmonary syndrome) • Impacts on health services

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Infectious diseases acquired by inhalation from environmental sources	• Possible increased survival and reproduction of fungi in soils and other land-based environments • Possible increase in multiplication of *Legionella* bacteria due to increased use of air conditioning	• Increased incidence, and changing geographic ranges of air-borne and aerosolized fungal infections (such as cryptococcosis) • Increased outbreaks of legionnellosis • Impacts on health services
Emerging infectious diseases	• Climate-change induced changes to the ecology of zoonotic diseases globally increases the possibility of emergence, spillover into humans and spread to Canada • Increased international travel, including human population migration, enhances global spread of zoonotic diseases that are also capable of human-to-human transmission	• Increased likelihood and frequency of epidemics and pandemics (such as SARS and COVID-19) including water-borne, food-borne, vector-borne, and zoonotic infectious diseases • Increased transmission of pathogens and infectious diseases, potentially leading to not only physical health impacts, but also impacts on mental, spiritual, and psychological health • Impacts on health services

List of Acronyms

CSGV	California serogroup viruses
CVV	Cache Valley virus
EEEV	eastern equine encephalitis virus
EIP	extrinsic incubation period
GCM	global climate models
GHG	greenhouse gas
GOARN	Global Outbreak Alert and Response Network
GPHIN	Global Public Health Intelligence Network
HFMD	hand-foot-and-mouth disease
IHR	International Health Regulations
JCV	Jamestown Canyon virus
JE	Japanese encephalitis
LACV	La Crosse encephalitis virus
MCDA	multi-criteria decision analysis
RCP	representative concentration pathways
RMSF	Rocky Mountain spotted fever
RRA	rapid risk assessment
RVFV	Rift Valley fever virus
SINV	Sindbis virus
SLEV	St. Louis encephalitis virus
SSHV	Snowshoe Hare virus
USUV	Usutu virus
VEE	Venezuelan equine encephalitis
WGS	whole genome sequencing
WHO	World Health Organization
WNV	West Nile virus
YF	yellow fever

6.1 Introduction

Infectious diseases continue to emerge and re-emerge globally, illustrated by epidemics and pandemics of new and existing diseases, such as coronavirus disease 2019 (COVID-19) caused by the SARS-CoV-2 coronavirus, Ebola in Africa, Middle East respiratory syndrome coronavirus infection in the Middle East, and Zika, chikungunya, yellow fever, and dengue virus infections in the Americas. Many infectious diseases are climate-sensitive; as a result, transmission of these diseases may be affected directly or indirectly by climate change. In Canada, it is expected that current infectious disease risks will increase and new diseases will emerge as the climate warms, causing concern for human health. This chapter considers the impacts of climate change on risks from infectious diseases of importance for public health in Canada. It expands on previous national climate change and health assessments to identify the state of knowledge of current and projected risks from infectious diseases, assesses vulnerability, and identifies where public health efforts may be required to protect the Canadian population. Infectious diseases related to the impacts of climate change on pathogen transmission in water and food are discussed in Chapter 7: Water Quality, Quantity, and Security, and Chapter 8: Food Safety and Security, respectively.

The demographic makeup of Canadians is changing, with an aging population (Statistics Canada, 2016), and more people affected by chronic illnesses, both of which can change the sensitivity of people to infectious disease hazards (Dye, 2014). In this chapter, risk is considered to have two main components: likelihood of exposure and sensitivity (i.e., severity of outcome), while the vulnerability of the population is considered to be the risk combined with the adaptive capacity (Figure 6.1). This is similar to other versions in the literature of the relationship between risk and vulnerability, where vulnerability is a component of risk that combines sensitivity, exposure, and adaptive capacity of the human population (IPCC, 2014). Exposure likelihood depends on the level of hazard, which is the number of infective organisms (i.e., infective humans, micro-organisms, arthropod vectors, animal reservoir hosts) in an individual's environment, and the rate of contact of uninfected humans with the hazard (Figure 6.1). In the context of infectious diseases, adaptive capacity is the capacity of public health systems to identify, prevent, and control disease, and of health systems to minimize the impact of disease through rapid and effective treatment. Climate change may affect each of the components of vulnerability through direct effects on the existence and level of hazard, indirect effects on rates of contact with the hazard, by increasing or decreasing population sensitivity, and by affecting adaptive capacity itself (Figure 6.1).

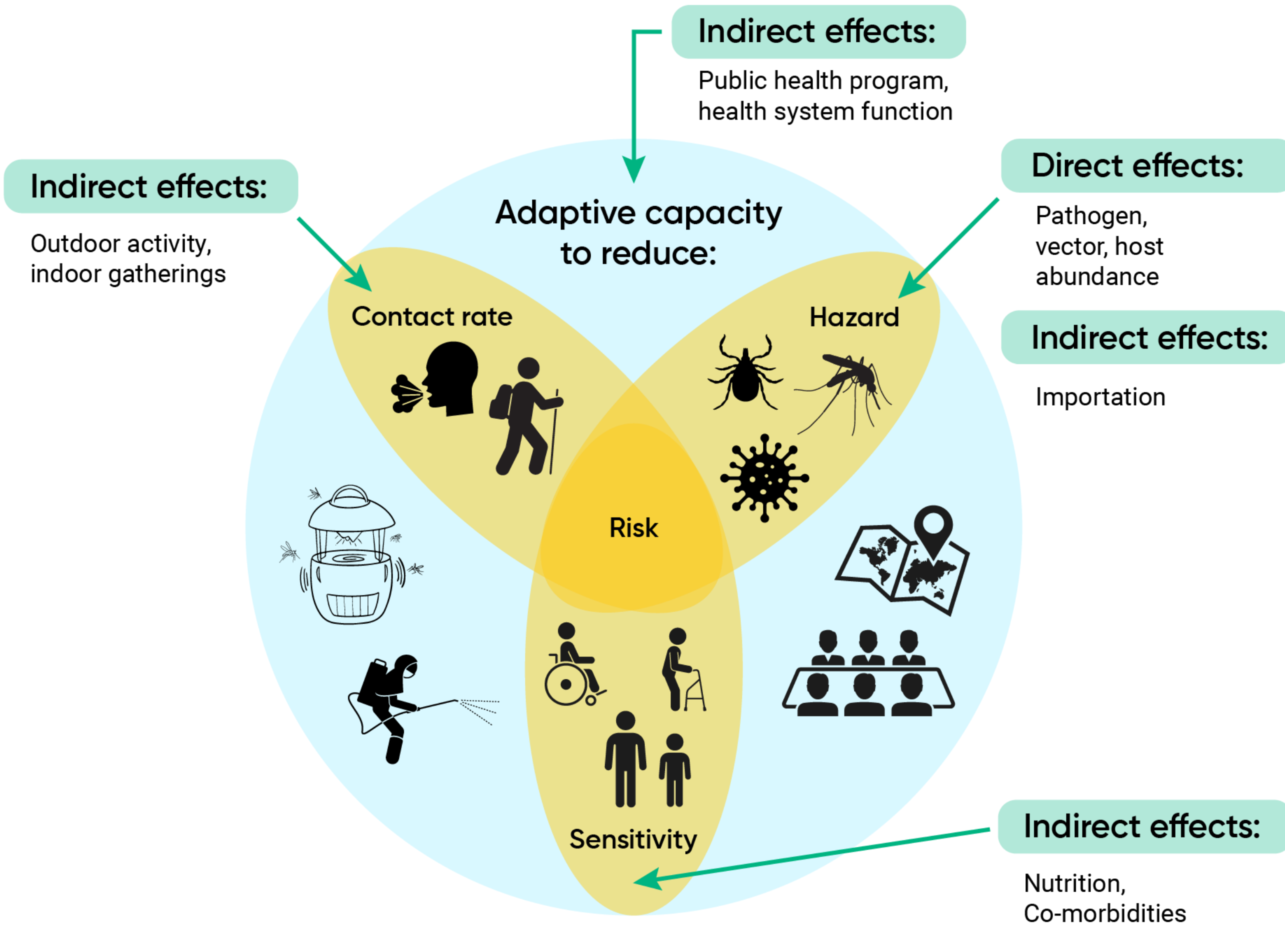


Figure 6.1 Components of vulnerability to infectious diseases in the context of climate change. The three intersecting components of risk are hazard, contact rate (which, with hazard, determines exposure), and sensitivity. Adaptation (represented by the blue background disc) depends on the capacity to minimize, and respond to changes in each of these three components of risk. Green arrows show direct and indirect effects of climate change.

6.1.1 Infectious Disease Emergence and Re-Emergence

Infectious diseases emerge through changes in their geographic ranges, "spillover," and "adaptive emergence." Spillover is when some environmental or socio-economic change allows an animal pathogen already transmissible to humans to come into contact with humans (e.g., Nipah virus). Adaptive emergence is due to genetic change in a micro-organism infecting animals, usually wildlife, that results in it becoming transmissible to humans from the animal (i.e., it becomes a zoonosis) and perhaps transmissible among humans (e.g., SARS-CoV) (Ogden et al., 2017).

There are multiple drivers of disease emergence, which include those associated with globalization and environment. These include climate change, social and demographic changes, and changes in public health systems and policies (Semenza et al., 2016). Endemic diseases can re-emerge (i.e., increase in incidence, or resurge as epidemics) through the same drivers. Climate change may directly affect infectious disease emergence and re-emergence through effects on the survival of pathogens, on survival and reproduction rates of arthropod vectors (e.g., mosquitoes, ticks, and fleas), and, in the case of zoonoses, on the abundance of animal reservoir hosts. These are factors that determine the potential for a pathogen to propagate among humans or, for zoonoses, animal hosts, which is described by the basic reproduction number R_0. If R_0 is one or higher (in which case one infection results in at least one more infection), the pathogen may persist and spread, but if R_0 is less than one, it will die out (Anderson & May, 1991). The direct effects of climate change that cause disease emergence in a particular location are effectively those that change R_0 from less than one to one or higher in that location.

Climate change may have indirect impacts on disease emergence and re-emergence by affecting other environmental and social changes, and by reducing the ability of public health systems to respond (e.g., extreme weather events may disrupt public health capacity to control disease outbreaks). The effects of climate change on ecosystems, including on biodiversity, may alter the hazards posed by zoonoses through complex effects on wildlife communities (Altizer et al., 2013; Cable et al., 2017). Other changes that can affect disease emergence and re-emergence may be related to public health adaptation initiatives to reduce broader health risks of climate change. For example, efforts to reduce heat islands in urban areas through the greening of cities (Beaudoin & Gosselin, 2016) and actions to manage floods (see Chapter 3: Natural Hazards) may increase zoonosis hazards from wildlife and vector-borne diseases (Medlock & Vaux, 2011; Millins et al., 2017). Increased use of air conditioning to combat urban heat could increase risks of legionellosis (Fitzhenry et al., 2017).

Climate change may have negative impacts on economies, particularly those of low- and middle-income countries, which could directly, or indirectly through an increase in conflicts, reduce infectious disease control and contribute to increasing densities of infectious agents (Ogden, 2017). Economic impacts and dislocation may simultaneously drive increased economic or refugee migration, increasing importation of infectious diseases to Canada from abroad (Ogden, 2017). In addition, if health systems are not climate-resilient (e.g., resilient to outages of power and communication systems associated with extreme weather events) (see Chapter 10: Adaptation and Health System Resilience), impacts may reduce the capacity to detect and respond to emerging or re-emerging infectious diseases (Mayhew & Hanefeld, 2014; Ebi et al., 2018; Global Commission on Adaptation, 2019). The range of projected climate change includes long-term changes in temperature and precipitation patterns, increased climate variability, and increased frequency of extreme weather events, which will vary among geographic regions in Canada (Bush & Lemmen, 2019). These changes will directly and indirectly affect different infectious disease risks idiosyncratically (Ogden & Lindsay, 2016).

6.1.2 Infectious Diseases in Previous Climate Change and Health Assessments

Since 2008, there have been six national, regional, or international assessments on the effects of climate change on infectious disease risks and vulnerability (Table 6.1). There were two assessments in Canada — one that focused on health in 2008 (Charron et al., 2008) and one that included health in a broader Government of Canada report on climate change impacts and adaptation in 2014 (Berry et al., 2014a). International assessments relevant to Canada included chapters on health and on North America from the Intergovernmental Panel on Climate Change (IPCC) (Romero-Lankao et al., 2014; Smith et al., 2014) and national assessments in the United States (Beard et al., 2016; Ebi et al., 2018).

All assessments identified arthropod-borne diseases (i.e., those transmitted by arthropods such as mosquitoes, ticks, and fleas) as most climate-sensitive, with climate determining the occurrence and abundance via effects on vector survival and reproduction, and on pathogen development in some vectors. The assessments suggest that climate warming is likely to increase risks from these diseases, but most assessments indicated moderate confidence in identifying which vector-borne diseases will be affected and the magnitude of the effects. This is due to the complexity of vector-borne disease transmission cycles. Multiple non-climatic determinants, including environmental and land-use changes, particularly for vector-borne zoonoses such as West Nile virus (WNV) and Lyme disease, and control efforts, particularly for exotic mosquito-borne diseases such as malaria and dengue, are important for determining the occurrence and abundance of vectors and pathogens. Previous assessments highlighted the climatic sensitivity of endemic hazard sensitivity in Canada and the United States, including plague and hantavirus infections that have a rodent reservoir; Lyme disease and other tick-borne diseases, such as Rocky Mountain spotted fever (RMSF); and endemic mosquito-borne diseases caused by WNV, eastern equine encephalitis virus (EEEV), and California serogroup viruses. The assessments identified that changes to geographic ranges and length of transmission seasons are particularly likely under climate change (Charron et al., 2008; Berry et al., 2014a; Smith et al., 2014; Beard et al., 2016; Ebi et al., 2018). Figure 6.2 illustrates the pathways through which climate change can affect infectious disease risks in Canada, according to previous assessments.

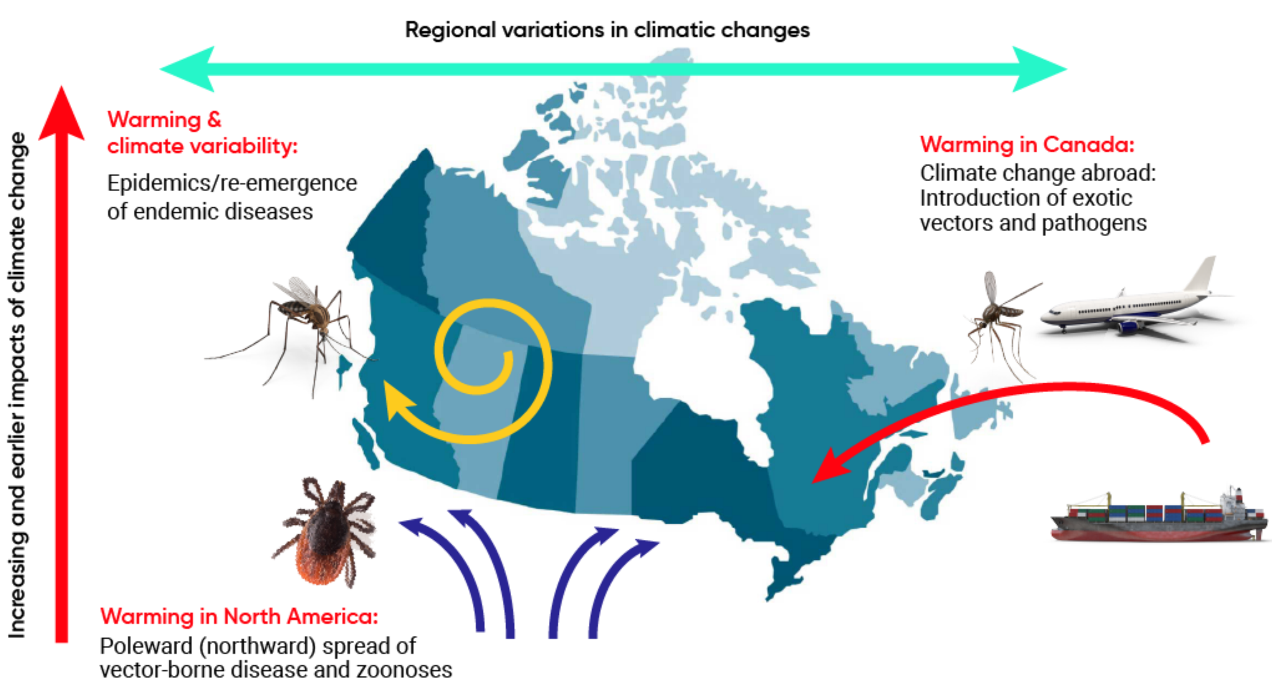


Figure 6.2 Climate change effects on infectious disease risks in Canada. Source: Ogden & Gachon, 2019.

The 2008 Canadian assessment provided model-based projections of the northward spread of Lyme disease from the United States into Canada associated with climate change–driven range expansion of the tick vector *Ixodes scapularis* (Charron et al., 2008). Subsequently, the spread of the tick along climate-determined trajectories and the emergence of Lyme disease in Canada were documented (Berry et al., 2014a; Smith et al., 2014; Beard et al., 2016; Ebi et al., 2018) (Table 6.1). These assessments also identified risks of the introduction of exotic vector-borne diseases, such as malaria, dengue, and chikungunya, with climate change. Increasing temperatures were anticipated to increase the geographical extent of North America suitable for transmission of exotic vector-borne pathogens and the survival of populations of the exotic mosquito vectors (e.g., *Aedes* species) that transmit them.

Table 6.1 Summary of assessment findings related to the effects of climate change on infectious diseases, excluding water- and food-borne diseases

ASSESSMENT	IDENTIFIED CLIMATE-SENSITIVE INFECTIOUS DISEASES	ANTICIPATED IMPACT OF CLIMATE CHANGE	EVIDENCE FOR IMPACTS OF CLIMATE CHANGE ON DISEASE RISKS	ADAPTATION AND ADAPTIVE CAPACITY AT THE TIME OF THE ASSESSMENT
Chapter 5 - The Impacts of Climate Change on Water-, Food-, Vector-, and Rodent-Borne Diseases in Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity (Charron et al., 2008)	• Tick-borne disease • Mosquito-borne disease • Hantavirus • Plague	• Northward geographic range spread of tick-borne and mosquito-borne diseases into Canada from the United States • Invasion of exotic mosquito-borne diseases (dengue, malaria) • Invasion of exotic directly transmitted infections (e.g., SARS)	None	Adaptive capacity in terms of risk assessment, surveillance, prevention, and control is robust in Canada, but gaps identified in knowledge of disease ecology, the effects of climate, expert capacity, surveillance, and warning systems

ASSESSMENT	IDENTIFIED CLIMATE-SENSITIVE INFECTIOUS DISEASES	ANTICIPATED IMPACT OF CLIMATE CHANGE	EVIDENCE FOR IMPACTS OF CLIMATE CHANGE ON DISEASE RISKS	ADAPTATION AND ADAPTIVE CAPACITY AT THE TIME OF THE ASSESSMENT
Chapter 7 - Human Health in Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation (Berry et al., 2014a)	As above	As above	Evidence for the emergence of Lyme disease via climate-determined trajectories, as well as increasing incidence of human cases	As above
Chapter 11 - Human Health: Impacts, Adaptation, and Co-Benefits in Intergovernmental Panel on Climate Change (IPCC) Assessment Report 5 (AR5) (Smith et al., 2014)	• Mosquito-borne diseases, such as malaria and dengue, in low- and middle-income countries • Tick-borne diseases in Europe and North America • Plague in Asia and North America • Hantavirus in North America	Possible increased incidence and range expansion of mosquito-borne and tick-borne diseases	None identified	Need to address risk and adaptive capacity in all countries by: • Reducing poverty • Improving nutrition, basic public health, and health services • Vulnerability mapping • Developing early warning systems linked to control programs

ASSESSMENT	IDENTIFIED CLIMATE-SENSITIVE INFECTIOUS DISEASES	ANTICIPATED IMPACT OF CLIMATE CHANGE	EVIDENCE FOR IMPACTS OF CLIMATE CHANGE ON DISEASE RISKS	ADAPTATION AND ADAPTIVE CAPACITY AT THE TIME OF THE ASSESSMENT
Chapter 26 - North America in IPCC AR5 North America Chapter (Romero-Lankao et al., 2014)	• Mosquito-borne diseases such as West Nile virus • Tick-borne diseases, particularly Lyme disease	• Possible increased incidence and range expansion of mosquito-borne and tick-borne diseases • Risk of invasion of exotic mosquito-borne diseases	Evidence for the emergence of Lyme disease via climate-determined trajectories in Canada	Need improved datasets and models to understand effects of environmental changes versus other determinants of vector-borne disease risk, and early warning systems
Chapter 5 - Vector-Borne Diseases in The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (Beard et al., 2016)	• Mosquito-borne disease such as West Nile virus and dengue • Tick-borne diseases such as Lyme disease • Plague	• Geographic range change, change in seasonality, and date of onset/duration of vector activity	None identified	Need improved models to understand and predict the effects of weather and climate changes versus other determinants of vector-borne disease risk, and field observations to support these

ASSESSMENT	IDENTIFIED CLIMATE-SENSITIVE INFECTIOUS DISEASES	ANTICIPATED IMPACT OF CLIMATE CHANGE	EVIDENCE FOR IMPACTS OF CLIMATE CHANGE ON DISEASE RISKS	ADAPTATION AND ADAPTIVE CAPACITY AT THE TIME OF THE ASSESSMENT
Chapter 14 - Human Health in Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment. (Ebi et al., 2018)	• Mosquito-borne disease such as West Nile virus and dengue • Tick-borne diseases such as Lyme disease	• Changes in geographic ranges, seasonal distribution, and abundance of disease vectors • Increased risks from mosquito-borne diseases abroad, which may spread into US territory	None identified	Need vulnerability and adaptation assessments and response plans, integrated surveillance for vector-borne diseases, and early warning systems such as disease forecasting

6.1.3 Managing Infectious Disease Risks

Adapting to climate-related infectious diseases first involves assessing risks to health and identifying populations at increased risk to the impacts. The capacity of public health systems to detect emerging and re-emerging infectious diseases by surveillance, and to prevent and control them by health promotion or more proactive measures such as vaccine development, as well as the capacity of health care systems to minimize consequences of infectious diseases, need to be assessed. Assessments provide information on vulnerability to infectious diseases and identify the most effective measures to reduce it (Berry, 2008). In general, previous assessments have suggested that, in North America, the ability of public health systems to assess risks from emerging and re-emerging infectious diseases, and to detect, prevent, and control them, is robust (see Table 6.1). The risk to most Canadians is low because of the relatively high socio-economic status of much of the population, which provides an environment that limits many disease risks, and because of the strong public health and health care infrastructures and systems. In addition, progress has been made in filling gaps in knowledge, surveillance, capacity, and early warning systems identified in previous assessments (see section 6.4 Adaptation to Reduce Health Risks).

6.2 Methods and Approach

This chapter includes analysis of the impacts of climate change on human risks from infectious diseases of importance for public health in Canada, with the exception of infectious diseases transmitted in drinking and recreational water and in food, which are addressed in separate chapters (see Chapter 7: Water Quality, Quantity, and Security, and Chapter 8: Food Safety and Security). This chapter is a narrative review authored by subject matter experts. However, to support the author team, a rapid review was conducted to identify the majority of the national and international literature on weather, climate, and climate change impacts on infectious diseases. The review focused on the five areas explored in the chapter:

- vector-borne diseases:
  - exotic mosquito-borne diseases, including those for which humans are the main reservoirs (e.g., malaria, dengue)
  - mosquito-borne diseases endemic in Canada (e.g., WNV disease)
  - non-mosquito, insect-borne diseases (e.g., plague)
  - tick-borne diseases (e.g., Lyme disease)
- directly transmitted zoonoses (e.g., rabies, hantavirus)
- infectious diseases directly transmitted human-to-human (e.g., influenza and enterovirus infections)
- infectious diseases transmitted by inhalation from environmental sources (e.g., cryptococcosis, legionellosis)
- Canadian capacity to adapt to changing risks from infectious diseases

The rapid review followed the general framework for scoping reviews first proposed by Arksey and O'Malley (2005) and further refined over the last 15 years (Levac et al., 2010; Peters et al., 2015; Tricco et al., 2016). It identified and characterized all of the available international research on climate change and infectious diseases using a systematic and reproducible methodology. A protocol was developed *a priori* and defines the scope of the rapid review, the comprehensive search strategy, and all tools used to screen citations and extract information from the literature (available upon request). The electronic search was conducted using Embase, PubMed, and Global Health in September 2018 to identify relevant literature in English and French on infectious diseases that also explored effects of weather, climate, and/or climate change. A grey literature search included targeted hand-searching of various government and scientific websites to identify reports that were not indexed in the electronic databases. Search results were de-duplicated in the reference management software Endnote (EndNote X7, Clarivate Analytics), and unique citations were uploaded into the web-based systematic review software Distiller SR (Distiller SR, Evidence Partners, Ottawa, Canada). Studies were screened for relevance by two reviewers, working independently, using a relevance screening tool developed *a priori*. All citations that were included after relevance screening were procured and confirmed to be relevant, and then the research was characterized using the developed data characterization tool. More recent publications were identified during the chapter review process.

Where sufficient information exists, in this chapter the confidence in direction and strength of the effects of climate change are identified. Identification of climate- or weather-sensitivity of diseases was considered to provide limited evidence for effects of climate change, evidence for climate- or weather-sensitivity combined with projections of effects of climate change provides medium evidence, while detected changes in infectious disease risks attributable to recent climate change was considered as providing robust evidence for effects of climate change.

6.3 Climate-Sensitive Health Risks, Projected Impacts of Climate Change, and Evidence of Impacts to Date

6.3.1 Vector-Borne Diseases

6.3.1.1 Effects of Climate Change on the Ecology and Epidemiology of Vectors and Vector-Borne Disease Transmission

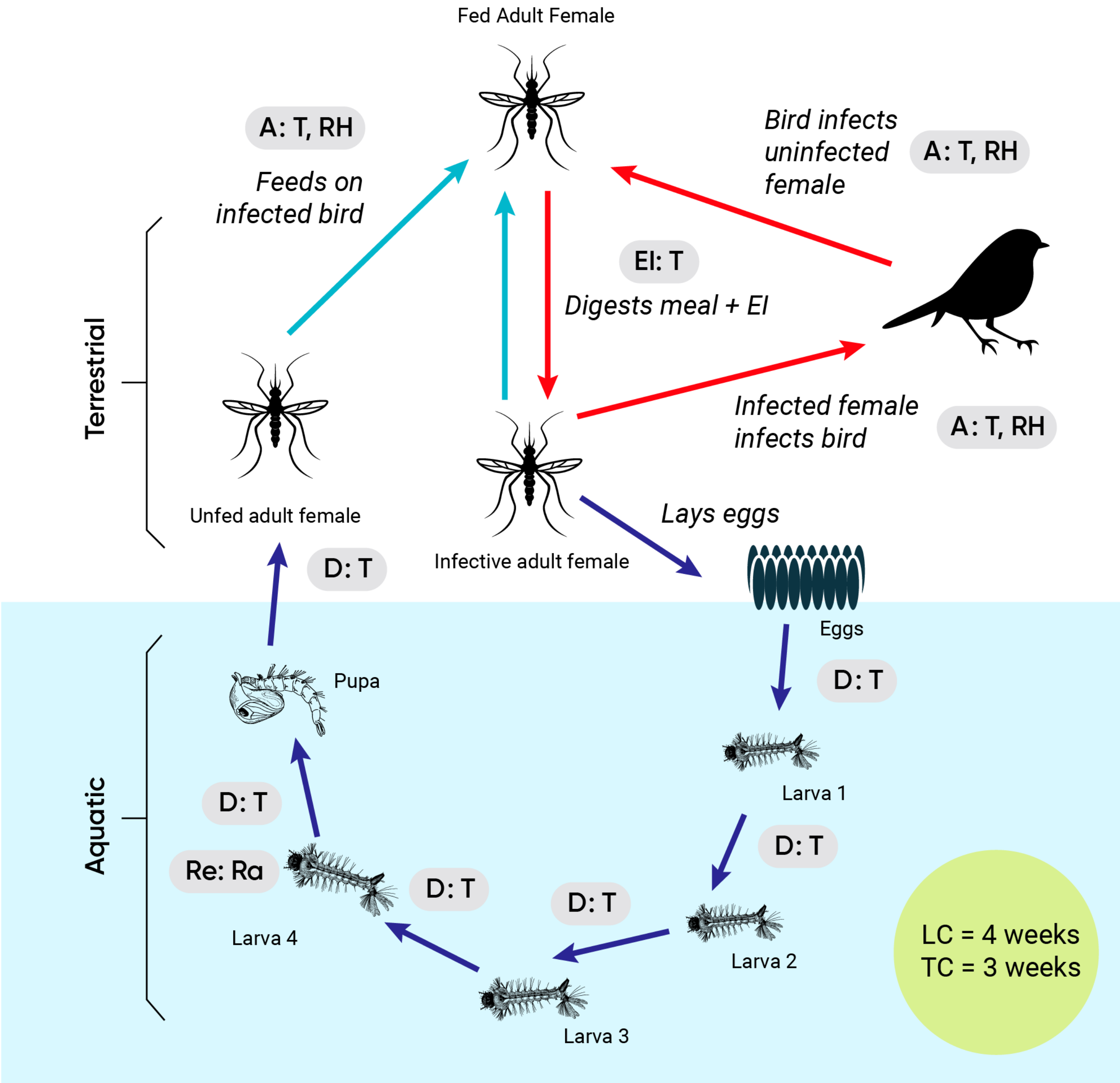
The life cycles of many arthropod vectors, and the impacts of weather and climate on these life cycles, have been intensely studied in the laboratory, field, and modelling studies, and reviewed elsewhere (Ogden & Lindsay, 2016). How changes in weather and climate may affect arthropod vectors and the transmission of vector-borne diseases is summarized in Box 6.1. While the effects of weather and climate are generic for arthropod vectors, how specifically they affect life cycles and transmission cycles is highly idiosyncratic among the different vectors and pathogens (Figure 6.3). Climate change may affect the risk of vector-borne diseases by altering human social-behavioural risk factors, such as perception of risk and adoption of preventive behaviours (Bouchard et al., 2018). Human population growth, movement, and social and economic factors (e.g., changing exposure to tick-borne encephalitis virus in eastern Europe due to changing population exposure following collapse of the Eastern Bloc) have also been associated with differential rates of human exposure to vectors and vector-borne diseases (Randolph, 2004). How climate change may affect risks indirectly through these factors requires further study.

Box 6.1 How weather and climate change can affect arthropod vectors and vector-borne diseases

Warming temperatures can have a number of effects on vectors and vector-borne diseases, including:

- increasing survival of vectors;
- accelerating development from one life stage to the next, resulting in shorter life cycles and greater vector abundance;
- increasing periods of the year when vectors can be active and therefore the likelihood they feed successfully (Monaghan et al., 2015);
- shortening the duration of the extrinsic incubation period (EIP) of mosquito-borne pathogens. The EIP is the time it takes for a pathogen ingested in a blood meal to get from the mosquito's gut to its salivary glands, from which it can be delivered to another host.

An optimal temperature range exists for most vectors and vector-borne diseases. Extreme high and low temperatures can reduce vector activity and survival. For example, for mosquito-borne diseases, if the temperature is too cold, most mosquitoes die before the EIP is complete, while at very high temperatures most mosquitoes die, whether or not the EIP is complete. This results in a temperature range specific for mosquito species–pathogen combinations, outside of which efficient pathogen transmission by mosquitoes is impossible. Optimal rainfall ranges are also required for vectors and vector-borne diseases. Increased rainfall generally increases mosquito abundance by increasing the habitat for immature (larval and pupal) mosquitoes, which are aquatic. Only adult females take blood meals that transmit pathogens. However, heavy rainfall can reduce vector activity, for example, by drowning ticks and washing out immature mosquitoes from their habitat. In some cases, droughts can limit arthropod vectors. For example, droughts generally decrease mosquito populations by reducing the habitat for immature mosquitoes, and may reduce tick numbers if severe enough to dry out the woodland in which they live. However, droughts can increase mosquitoes in some urban habitats by turning drains into standing water, which is habitat for mosquito larvae and pupae.


Fed Adult Female
A: T, RH
Feeds on infected bird
Bird infects uninfected female
A: T, RH
EI: T
Digests meal + EI
Terrestrial
Infected female infects bird
A: T, RH
Unfed adult female
Infective adult female
Lays eggs
D: T
Eggs
D: T
Pupa
Larva 1
D: T
Aquatic
D: T
Re: Ra
D: T
D: T
Larva 4
Larva 2
Larva 3
LC = 4 weeks
TC = 3 weeks

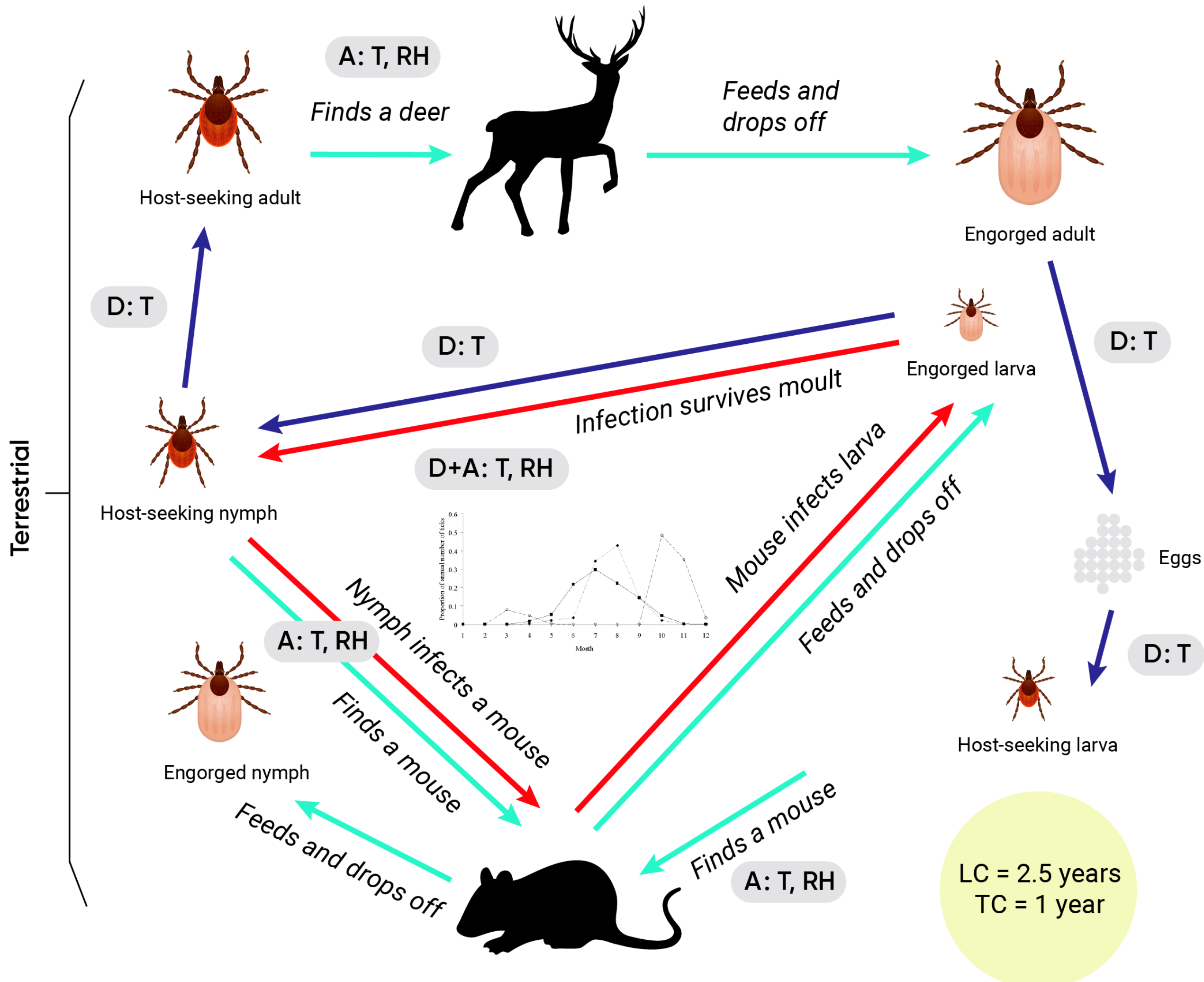


Figure 6.3 The impacts of weather and climate on the life cycles of dipteran and ixodid tick vectors. The impacts of climate change are illustrated using the life cycle of the mosquito *Culex pipiens* and its role in the transmission of West Nile virus (WNV) in A. The life cycle of the tick *Ixodes scapularis* and its role in the transmission of the Lyme disease agent *Borrelia burgdorferi* is illustrated in B. In both, dark and pale blue arrows indicate development, and host finding/detachment from hosts, respectively, while red arrows indicate pathogen transmission cycles. Points at which weather and climate (and potentially climate change) may affect the vector's life cycle (LC) and pathogen transmission cycle (TC) are indicated by the grey-filled boxes in which A = effects on activity, D = effects on inter-stadial development rates, EI = effects on the extrinsic incubation period, Re = effects on reproduction, T = effects of temperature, Ra = effects of rainfall, and RH = effects of humidity. In the centre of the *B. burgdorferi* transmission cycle (B) is an illustration of the seasonal activity of the tick vectors, which may be affected by climate and climate change through effects on both development and activity, as described in the text. Source: Ogden & Lindsay, 2016.

Box 6.2 Scenarios for introduction of exotic vector-borne diseases into Canada

Scenario 1 – Local spread of US-endemic pathogens into regions of Canada where the mosquito vectors are already present

Based on current knowledge, this scenario relates particularly to St. Louis encephalitis virus (SLEV, a flavivirus) and La Crosse encephalitis virus (LACV, a bunyavirus), which cause uncommon but severe and sometimes fatal disease in humans, and are endemic to central and eastern US states bordering Canada (Centers for Disease Control and Prevention, 2018a; Centers for Disease Control and Prevention, 2018b). The main vectors for SLEV (*Culex tarsalis* and *Cx. pipiens*) and LACV (*Aedes triseriatus*), as well as their wild animal reservoirs (wild birds for SLEV and chipmunks and squirrels for LACV), are established in parts of Canada (Centers for Disease Control and Prevention, 2018a; Centers for Disease Control and Prevention 2018b; Giordano et al., 2015). A short-lived epidemic of SLEV in Southern Ontario in 1975 suggests that endemicity may be possible if environmental conditions become suitable (Spence et al., 1977).

Scenario 2 – Spread of "exotic" diseases endemic to other countries to regions of Canada where mosquito vectors are already present

The possibility of autochthonous transmission of exotic diseases transmitted by *Aedes* species mosquitoes is a reality where the mosquitoes have become endemic, such as Southern Europe and the Southern United States (Rezza et al., 2007; Bouri et al., 2012; Delisle et al., 2015; Likos et al., 2016; Septfons et al., 2016; Venturi et al., 2017). West Nile virus emerged in the United States and Canada by this mechanism, most likely by importation of infected mosquitoes on an aircraft followed by endemic transmission due to the existence of competent mosquito vectors and avian reservoir hosts (Gubler, 2007; Artsob et al., 2009; Zheng et al., 2014; Giordano et al., 2017). Other diseases that may emerge in Canada under this scenario include Japanese encephalitis (JE), malaria, Sindbis virus (SINV) infection, Usutu virus (USUV) infection, and Venezuelan equine encephalitis (VEE) infection (Table 6.2). All of these diseases are transmitted by mosquito vectors that have long been established in some parts of Canada (Berrang-Ford et al., 2009; Giordano et al., 2015; Giordano et al., 2018). The reservoir hosts for many of these diseases also already exist in Canada. For example, swine, wild birds, rodents, and horses are reservoirs of JE, SINV, USUV, and VEE virus, respectively.

Scenario 3 – Spread of "exotic" diseases endemic to other countries to Canada where mosquito vectors are not currently present

This scenario is the same as scenario 2, except that it applies to exotic mosquito-borne diseases for which both pathogen and vector would have to be imported and become endemic. Therefore, this is the least likely scenario for the emergence of a new mosquito-borne disease in Canada. For most of Canada, mosquito-borne diseases in this group include chikungunya, dengue, yellow fever (YF), and Zika virus infection, as the *Aedes* species vectors *Ae. albopictus* and *Ae. aegypti* have been considered absent. However *Ae. albopictus* has recently emerged in one area of Southern Ontario (Windsor-Essex County Health Unit, 2019b), so for this region chikungunya, dengue, and Zika virus are pathogens that could emerge according to scenario 2. YF is transmitted by *Ae. aegypti* but not by *Ae. albopictus* (Cuoto-Lima et al., 2017), so YF remains a "scenario 3" pathogen. Rift Valley fever virus (RVFV) is endemic to East Africa; however, livestock and wildlife species, such as white-tailed deer in North America, are thought to be capable of acting as reservoirs for the virus (Golnar et al., 2014; Wilson et al., 2018). The African floodwater-breeding *Aedes* species vectors of RVFV are absent from North America, but mosquito species endemic to the United States and Canada have been observed to transmit the virus under laboratory conditions (Gargan et al., 1988; Turell et al., 2010; Iranpour et al., 2011; Turell et al., 2013a; Turell et al., 2013b; Turell et al., 2014). If these mosquitoes can transmit the virus under field conditions, RVFV should be considered a pathogen that could emerge according to scenario 2.

6.3.1.2 Exotic Mosquito-Borne Diseases

There is a wide range of mosquito-borne diseases of public health significance globally. Some, such as malaria, dengue, yellow fever, and chikungunya, which are transmitted from human to human by mosquitoes, are among the world's greatest public health threats, causing millions of cases and deaths annually (WHO, 2019a). Other diseases, many of which are mosquito-borne zoonoses, such as those caused by Sindbis and Venezuelan equine encephalitis viruses, occur more sporadically (Table 6.2). Exotic mosquito-borne diseases are absent from Canada due to multiple factors, including climate. For most exotic mosquito-borne diseases, Canada's climate is currently too cold for the vectors, and/or for development of the pathogens in the mosquito (Ng et al., 2019). Other barriers exist, including the lack of animal reservoir hosts for some diseases (such as primates for yellow fever virus) and standards of housing, including doors and windows, which prevent entry of vectors, and air conditioning systems, which inhibit human-to-human transmission by mosquitoes (Reiter, 2001). Physical barriers need to be surmounted for the pathogens and vectors to be transported to Canada from overseas.

The expansion of the geographic range of exotic vector-borne diseases into Canada requires movement of exotic vectors and pathogens from the countries where they are endemic. Increasing global trade and travel are expected to facilitate the global movement of mosquito vectors (infected or not) and infected travellers, thereby increasing the possibility of importation of vectors and pathogens into regions where they have not previously occurred (Tatem et al., 2006; Tatem et al., 2012; Semenza et al., 2016). There are three scenarios whereby vector-borne diseases currently exotic to Canada may emerge here (Box 6.2).

The public health impact of climate change on each emergence scenario will vary and could include increased likelihood of Canadians acquiring infection while travelling abroad, increased likelihood of short-lived autochthonous (i.e., local, within Canada) transmission where competent vectors are already established, and permanent endemicity of new diseases in Canada (Ng et al., 2019).

Mosquito vectors of exotic mosquito-borne diseases are sensitive to weather conditions, and climate change would be expected to affect them. Field and laboratory experiments demonstrate the temperature sensitivity of the *Aedes* and *Anopheles* species mosquitoes that are the main vectors of the most important exotic mosquito-borne diseases globally (Brady et al., 2013; Shapiro et al., 2017). In general, warmer temperatures, high humidity, and increased precipitation facilitate the life cycle of mosquitoes by supporting larval development and survival and by extending adult lifespan (Reeves et al., 1994; Jetten & Focks, 1997; Paaijmans et al., 2009; Yang et al., 2009). These climatic conditions will influence pathogen transmission by:

- reducing egg development time in adult female mosquitoes, thus reducing time between blood feeds and increasing feeding frequency (Reeves et al., 1994; Jetten & Focks, 1997; Paaijmans et al., 2013);
- shortening the EIP, thereby allowing mosquitoes to become infectious faster (Davis, 1932; Reeves et al., 1994; Jetten & Focks, 1997; Paaijmans et al., 2009; Paaijmans et al., 2013; Xiao et al., 2014); and
- increasing mosquito longevity, enabling infectious mosquitoes to bite more people (Yang et al., 2009).

However, many of these weather-dependent relationships are complex; relationships can be non-linear, can have opposite effects depending on circumstance, and can be influenced by non-climatic factors (Box 6.1).

The degree to which climate change will affect, or has already affected, the global distribution of many mosquitoes and mosquito-borne diseases is uncertain. This is because the relationship between climate and vector-borne diseases, particularly those transmitted human-to-human via mosquitoes, is complex, and the spatiotemporal distribution of vectors and the pathogens they carry depends on a range of factors that are not directly climatic. These factors include increased mobility and interconnectivity of people and goods (Junxiong & Yee-Sin, 2015; Semenza et al., 2016; Tabachnick, 2016; Lindsey et al., 2018; Romeo-Aznar et al., 2018), urbanization and other land-use changes (Junxiong & Yee-Sin, 2015; Jones & O'Neill, 2016; Semenza et al., 2016; Asad & Carpenter, 2018; Romeo-Aznar et al., 2018), socio-economic factors (KC & Lutz, 2017; Reina Ortiz et al., 2017; Lindsey et al., 2018; Moreno-Madriñán & Turell, 2018; Romeo-Aznar et al., 2018), demographic changes, including those due to immigration and population growth (Asad & Carpenter, 2018; Lindsey et al., 2018; Romeo-Aznar et al., 2018), population immunity (Anyamba et al., 2012; Larrieu et al., 2014; Semenza et al., 2016), genetic evolution and adaptation (Gubler, 2007; Tsetsarkin et al., 2007; Tabachnick, 2016), access to health care (Reiter, 2008; Ooi & Gubler, 2009; Semenza et al., 2016), and vector control and intervention programs (Githeko et al., 2000; Junxiong & Yee-Sin, 2015; Tasanee et al., 2015). Some of these factors are independent of climate change, but some may be influenced by climate change, and climate change may affect mosquito-borne diseases indirectly via these factors.

Despite the uncertainty, effects of climate change on the spread of mosquitoes and mosquito-borne diseases are likely (high confidence), with regional variation across the globe (Smith et al., 2014). By shortening the length of the life cycle, increasing mosquito survival, and enhancing pathogen transmission, climate change will drive the expansion of mosquito and mosquito-borne pathogen populations in some locations and increase the geographic scope, mostly poleward and toward higher altitudes, of their ecological niches in many cases (Campbell et al., 2015; Kraemer et al., 2015; Samy et al., 2016; Hertig, 2019; Kamal et al., 2019; Kraemer et al., 2019). While mosquito populations may expand into new geographic areas, they may disappear from others (Machado-Machado, 2012; Escobar et al., 2016; Williams et al., 2016).

A warming climate is expected to enhance populations of Canada-endemic mosquito species (Hongoh et al., 2012) and conditions for pathogen transmission, making Southern Canada, in particular, more suitable for the emergence of new mosquito-borne diseases by scenarios 1 and 2 (Box 6.2). Temperature conditions in parts of Southern Canada are also expected to become increasingly suitable for populations of the yellow fever mosquito *Ae. aegypti* and the Asian tiger mosquito *Ae. albopictus* that are vectors of dengue, chikungunya, Zika, and yellow fever. Climate change is also expected to increase temperature suitability for virus transmission (Ng et al., 2017), rendering mosquito-borne disease emergence by scenario 3 (Box 6.2) increasingly possible in Southern Canada. Southern Coastal British Columbia, Southern Ontario, Quebec, New Brunswick, and Nova Scotia are anticipated to become climatically suitable for *Ae. albopictus* (Ogden et al., 2014a), while Southern Coastal British Columbia may also become suitable for *Ae. aegypti* (Campbell et al., 2015; Kamal et al., 2019). In 2016, an adult *Ae. aegypti* was collected in Southern Ontario. A very small number of adults and larvae were found in the subsequent year under enhanced mosquito trapping and field surveillance in the area, suggesting this species has not become established in Canada (Windsor-Essex County Health Unit, 2019a). However, *Ae. albopictus* has been found sporadically in multiple, but restricted, locations in Southern Ontario since 2005. There is one small area of Canada where *Ae. albopictus* became established between 2017 and 2018, although, to date, there is no evidence that these mosquitoes carry pathogens that have caused illness in humans (Windsor-Essex County Health Unit, 2019b).

Particularly for scenarios 2 and 3, the likelihood that new vector-borne diseases emerge in Canada will depend on the number of pathogen and/or vector introduction events, as well as the degree to which climate change makes Canada a more suitable environment for them to become established. Some forms of global movement may be driven by climate change, for example, climate refugees (McMichael et al., 2012) and changes in travel patterns (World Tourism Organization & United Nations Environment Programme, 2008). Climate change may therefore have three impacts that increase the likelihood of emergence by scenarios 2 and 3:

- increased climatic suitability in Canada;
- increased abundance of exotic pathogens and their vectors in countries outside Canada; and
- increased introduction of pathogens and vectors.

Even without the effects of climate change, global interconnectivity is increasing (Findlater & Bogoch, 2018), and Canadians are enthusiastic travellers (Statistics Canada, 2019), so local and global movement will continue to pose a growing risk for the introduction of exotic pathogens via imported vectors and infected humans into Canada. Pathways of introduction may be predictable, however. For Japanese encephalitis (JE), the most probable scenario for introduction into the United States would be by JE-infected female mosquitoes arriving on aircraft from eastern China (Oliveira et al., 2018). JE incursion would likely follow a similar pathway into Canada, with coastal British Columbia being the most likely entry location because of its many travel and trade connections with Asia. It also has a temperate climate and endemic mosquito vectors and reservoirs that might support local JEV transmission, should it arrive.

In addition to a suitable climate, other factors such as poverty and a lack of access to infrastructure, health care, and disease control measures are also important for endemic transmission of exotic pathogens transmitted human-to-human by mosquitoes (Ebi et al., 2006a; Halstead, 2008). Social conditions for most of the Canadian population (particularly population density and housing) are expected to limit mosquito biting rates, and health services remove infected people from transmission, making it difficult for efficient, sustained transmission cycles of such exotic pathogens to become established (Berrang-Ford et al., 2009; Ng et al., 2019). It is more likely that the public health impact will be occasional autochthonous cases in Canadians who have not travelled. These people may have severe health consequences because, in the absence of a history of travel, diagnosis may be delayed (Berrang-Ford et al., 2009; Ng et al., 2019). Delayed diagnosis of "unexpected" cases of exotic mosquito-borne disease in Canadians could lead to some chains of transmission and limited outbreaks. Examples from outside Canada include the introduction of chikungunya virus into Mediterranean Europe in 2007 and dengue in France, Croatia, and Madeira between 2010 and 2013. These events may have been driven by particularly warm weather conditions (Rezza et al., 2007; Tomasello & Schlagenhauf, 2013).

In contrast, if exotic mosquito-borne zoonoses invade, they may be more likely to become endemic if environmental conditions, including climate, are suitable, as pathogen transmission among wildlife and/or livestock reservoir hosts would be mainly unrestricted, as has been the case for WNV. The range expansion of Sindbis virus (SINV) and Usutu virus (USUV), out of Africa and into Europe, have strongly paralleled that of WNV in North America (Weissenböck et al., 2002; Ashraf et al., 2015). Given that the mosquito vectors and reservoirs for USUV and SINV are already present in Canada, and the climate in invaded parts of Europe is very similar to that of southern regions of Canada, the emergence of SINV or USUV in this country as disease-causing endemic viruses is possible. Infections with SINV and USUV produce unpleasant but relatively mild infections in immunocompetent humans.

Another exotic mosquito-borne zoonosis, Rift Valley fever virus (RVFV), can cause infections that are serious and can be fatal (WHO, 2019b), so the possibility of emergence of this virus in Canada is a more concerning threat. Canada-endemic mosquito species have been shown to be competent vectors for RVFV, while a wide range of wildlife and domesticated livestock are animal reservoirs (Box 6.2, Table 6.2). The most likely mechanism of introduction into North America is considered to be RVFV-infected humans arriving on aircraft from endemic areas where there is an outbreak (Golnar et al., 2014; Golnar et al., 2018). Should the traveller come into contact with endemic mosquito vectors, transmission to wildlife and/or livestock may result in endemicity.

Table 6.2 Key global mosquito-borne diseases and features of their transmission (vectors and hosts), geographic occurrence, and the presence of vectors and hosts in Canada and the United States

DISEASE	PATHOGEN(S)	GEOGRAPHIC DISTRIBUTION OF HUMAN CASES	ENDEMICITY IN THE US	PRIMARY VECTORS	VECTORS ESTABLISHED IN CANADA?	IF ABSENT FROM CANADA, ARE VECTORS ESTABLISHED IN THE UNITED STATES?	PRIMARY RESERVOIRS	PRIMARY RESERVOIR(S) IN CANADA?	EVIDENCE OF SENSITIVITY TO CLIMATE	INTRODUCTION SCENARIO
Chikungunya	Chikungunya virus	Africa, Southeast Asia, Philippines, Pacific Islands, Middle East, Caribbean, Americas	Not endemic but locally acquired cases reported in 2014–2015 in Florida and Texas	*Aedes aegypti* and *Ae. albopictus*	Emerging population of *Ae. albopictus* in a very limited area of Southern Ontario	*Aedes aegypti* southern states to Southern New York state, *Ae. albopictus* in southern and northeast states, including those bordering Central and Eastern Canada	Humans, wild primates (in Africa)	Yes (humans), no wild primates	Yes	2
Dengue	Dengue virus serotypes 1 to 4	Asia, the Pacific, Americas, Africa, Caribbean	Endemic in Puerto Rico	*Ae. aegypti* and *Ae. albopictus*	Emerging population of *Ae. albopictus* in a very limited area of Southern Ontario	*Aedes aegypti* southern states to Southern New York state, *Ae. albopictus* in southern and northeast states, including those bordering Central and Eastern Canada	Humans, wild primates in Southeast Asia and Western Africa	Yes (humans), no wild primates	Yes	2
Japanese encephalitis	Japanese encephalitis virus	Asia, Pacific Islands, Torres Strait of Australia, Papua New Guinea	Not endemic	*Culex* spp. mosquitoes	*Cx. tarsalis* in Western and Central Canada		Domestic pigs and wild birds	Yes	Yes	2
La Crosse encephalitis	La Crosse virus	United States (upper mid-western and mid-Atlantic and southeast states)	Endemic to most of the eastern states, including states that border Canada	*Aedes triseriatus*	*Aedes triseriatus* in Eastern Canada		Small mammals (chipmunks and squirrels	Yes	Yes	1

DISEASE	PATHOGEN(S)	GEOGRAPHIC DISTRIBUTION OF HUMAN CASES	ENDEMICITY IN THE US	PRIMARY VECTORS	VECTORS ESTABLISHED IN CANADA?	IF ABSENT FROM CANADA, ARE VECTORS ESTABLISHED IN THE UNITED STATES?	PRIMARY RESERVOIRS	PRIMARY RESERVOIR(S) IN CANADA?	EVIDENCE OF SENSITIVITY TO CLIMATE	INTRODUCTION SCENARIO
Malaria	*Plasmodium* spp.	Central America, South America, Africa, Southeast Asia, Middle East, Southwest Pacific	Not endemic	*Anopheles* spp. mosquitoes, particularly *An. gambiae* and *An. arabiensis*	*Anopheles quadrimaculatus* in Eastern Ontario and Quebec, *Anopheles freeborni* in British Columbia		Humans	Yes	Yes	2
Rift Valley fever	Rift Valley fever virus	Eastern and Southern Africa, Saudi Arabia, Indian Ocean	Not endemic	African floodwater *Aedes* spp. mosquitoes	Some *Aedes* species in Canada are capable of transmitting the virus in the laboratory		Unknown, possibly livestock, equines, and wild ungulates	Yes	Yes	3
Sindbis fever	Sindbis virus	Northern Europe, Australia, China, South Africa	Not endemic	Ornithophilic *Culex*, *Culiseta*, *Ochlerotatus*. and *Aedes* spp. mosquitoes	*Culex pipiens* and some *Ochlerotatus* and *Aedes* spp.		Birds	Yes	Yes	2
St. Louis encephalitis	St. Louis encephalitis virus	Central, Western, and Southern United States	Endemic in northern, eastern, and central states including states bordering Canada	*Culex tarsalis*, *C. pipiens*, *C. quinquefasciatus*, *C. nigripalpus*	*Culex tarsalis* in Western and Central Canada and *Culex pipiens* along the US-Canada border		Birds	Yes	Yes	1

DISEASE	PATHOGEN(S)	GEOGRAPHIC DISTRIBUTION OF HUMAN CASES	ENDEMICITY IN THE US	PRIMARY VECTORS	VECTORS ESTABLISHED IN CANADA?	IF ABSENT FROM CANADA, ARE VECTORS ESTABLISHED IN THE UNITED STATES?	PRIMARY RESERVOIRS	PRIMARY RESERVOIR(S) IN CANADA?	EVIDENCE OF SENSITIVITY TO CLIMATE	INTRODUCTION SCENARIO
Usutu virus	Usutu virus	Africa, Europe	Not endemic	*Culex pipiens*, *Cx. neavei*	*Culex pipiens* along the US-Canada border		Birds	Yes	Yes	2
Venezuelan equine encephalitis	Venezuelan encephalitis virus	South and Central Americas, Mexico and cases as far as Southern United States	Not endemic	*Culex*, *Aedes*, *Mansonia*, *Psorophora*, *Deincerites*, and *Ochlerotatus* spp. mosquitoes	*Oc. sollicitans* in Eastern Canada	*Oc. taeniorhynchus* along most of US coast and *Culex melanoconion* in Florida	Rodents, equines	Yes	Yes	2
Yellow fever	Yellow fever virus	Tropical and subtropical Africa, South America	Not endemic	*Ae. aegypti*		*Aedes aegypti* southern states to Southern New York state	Humans, wild primates	Yes (humans), no wild primates	Yes	3
Zika	Zika virus	Africa, Southeast Asia, South America	Not endemic but locally acquired cases in Puerto Rico, Florida, and Texas from 2015–2016	*Ae. aegypti*, *Ae. albopictus*	Emerging population of *Ae. albopictus* in a very limited area of Southern Ontario	*Aedes aegypti* southern states to southern New York state, *Ae. albopictus* in southern and northeastern states, including those bordering Central and Eastern Canada	Humans, wild primates	Yes (humans), no wild primates	Yes	2

6.3.1.3 Canada-Endemic Mosquito-Borne Diseases

All four of the most medically important arboviruses endemic to Canada — WNV, EEEV, snowshoe hare virus (SSHV), and Jamestown Canyon virus (JCV) — are transmitted through bites of infected female mosquitoes. Mosquitoes acquire infections from specific mammalian or avian reservoir hosts. The main mosquito vectors for WNV are *Cx. pipiens* and *Cx. restuans* in Eastern Canada and *Cx. tarsalis* in Western Canada (Kramer et al., 2008), while for EEEV, *Culiseta melanura* is the main vector (Armstrong & Andreadis, 2010). Non-*Culex* mosquito species (e.g., *Aedes*, *Culiseta*, and *Anopheles* spp.) are the primary vectors of the California serogroup viruses (CSGV), such as SSHV and JCV (Drebot, 2015; Pastula et al., 2015; Webster et al., 2017). For WNV and EEEV, a wide range of bird species serve as reservoirs, including corvids and passerines (Kilpatrick et al., 2006; Kramer et al., 2008; Ludwig et al., 2010; Reisen, 2013). The main reservoir of JCV is the white-tailed deer (Andreadis et al., 2008), while squirrels, chipmunks, and hares are the reservoir hosts for SSHV (Drebot, 2015). A number of these viruses are also maintained by transovarial transmission, which allows for less dependence on mammalian reservoirs (Griot et al., 1993).

Additional viral and bacterial agents transmitted by insects are also endemic in Canada but are less active, or their occurrence is under-studied. Western equine encephalitis virus appears to have decreased in prevalence in Canada in recent decades, while Cache Valley virus (CVV) has been responsible for a number of livestock (i.e., sheep) outbreaks in Ontario, Quebec, and other provinces, but human infection is most likely under-reported (Drebot, 2015). Arboviruses can also be transmitted occasionally by blood transfusion or tissue transplants (Fonseca et al., 2005; Pathogen Regulation Directorate, 2010). Apart from this possibility, humans are incidental/dead-end hosts for these mosquito-transmitted diseases; while they can be infected, they cannot subsequently transmit viruses to feeding mosquitoes with any efficiency because viremia is transient and viral loads are low (Kramer et al., 2008; Kulkarni et al., 2015).

Approximately 20% of individuals who are exposed to mosquito-borne viruses, such as WNV, EEEV, JCV, or SSHV, will develop acute clinical illness, including fever, headache, skin rash, nausea, and muscle aches. Most affected people recover fully, but approximately 1% develop severe illness (e.g., meningitis, encephalitis, acute flaccid paralysis, and poliomyelitis), in which case neurologic and cognitive deficits may be prolonged or permanent. Approximately 10% of severe cases are fatal. Individuals over 70 years of age and those with underlying medical conditions, such as obesity, diabetes, hypertension, and heart disease, are at greater risk of severe illness. However, SSHV causes neurological illness in children as well. People who are immunocompromised are also at greater risk (Petersen et al., 2013a; Petersen et al., 2013b; Sejvar, 2014; Badawi et al., 2018). The severity of illness varies and depends upon the virus; for example, EEEV is one of the most severe mosquito-transmitted diseases in the United States, with approximately 33% mortality in those developing neurological illness and significant brain damage in most survivors who developed symptomatic disease (Centers for Disease Control and Prevention, 2018c). Western equine encephalitis virus and CVV give rise to a similar range of symptoms; while the majority of cases are asymptomatic, a varying percentage develop encephalitis, meningoencephalitis, encephalomyelitis, high fever, altered consciousness, neurologic dysfunction, aseptic meningitis, stiff neck, headache, myalgia, tremors, nausea, vomiting, and urinary tract infection. The mortality rate is between 5% to 20% for St. Louis encephalitis virus, but is believed to be much lower for western equine encephalitis virus and CVV infection (Centers for Disease Control and Prevention, 2018d).

The expected effects of climate change on Canada-endemic mosquito-borne diseases are northward range expansion associated with long-term warming and more epidemic behaviour associated with climate variability and extreme weather events, via effects on vector survival and reproductive rates (together affecting vector abundance), biting rates, the length of the activity season, and the duration of the EIP. Canada-endemic mosquito-borne diseases are zoonoses transmitted from wild animals (birds and mammals). The effects of climate change on the populations of these animals are expected to affect the pathogen transmission cycles. These effects may simply result in northward range expansion of hosts, but there may be more complex effects on reservoir host biodiversity. For example, changes in host abundance and geographic range may be limited by physical conditions (e.g., barriers to movement) and/or biological processes (e.g., reduced access to food at critical times in the life cycle, such as breeding and rearing periods). Resulting changes in species composition can have varying consequences, such as disruptions in predator–prey and host–parasite relationships. Therefore, although host biodiversity will likely change in response to new climate conditions, uncertainties remain regarding how such changes will affect exposure risk of Canadians to vector-borne diseases (Varrin et al., 2007). In all likelihood, the impact will be specific to the ecosystem or habitat, resulting in a patchwork of increasing and decreasing biodiversity of host communities, changing with time across the country. Climate change may have more rapid effects on host communities via extreme weather events, such as droughts and heat events, which can bring reservoir hosts searching for water sources to mosquito breeding grounds (Shaman et al., 2005; Wang et al., 2010; Harrigan et al., 2014).

Many modelling studies have examined the relationship between climatic variables (mainly temperature and precipitation) and WNV infection (infected humans, birds, or mosquitoes) in Canada (Wang et al., 2011; Chen et al., 2013; Tam et al., 2014; Paz, 2015; Yoo et al., 2016; DeFelice et al., 2018). However, the ecology of EEEV and CSGV remains under-studied, likely due to perceptions that these viruses are not as important for public health, as well as a lack of detailed surveillance data. However, land cover, including proximity and size of coniferous forested area and wetlands, has been found to influence EEEV and JCV occurrence (Vander Kelen et al., 2014; Rocheleau et al., 2018) and could also be affected by climate change.

The impact of climate change on WNV transmission in Canada has been investigated in two studies with similar conclusions. Chen et al. (2013) examined WNV transmission in the Prairies, where *Cx. tarsalis* is the main vector, and projected an extension of seasonal activity of WNV-infected *Cx. tarsalis* from three months (June to August) to five months (May to September) by the 2080s. The authors also projected a northward range expansion for *Cx. tarsalis* and WNV. Since this vector is also capable of transmitting CVV, the range and prevalence of this disease may also be influenced by this *Cx. tarsalis* expansion (Ayers et al., 2018). Hongoh et al. (2012) modelled the potential distribution of *Cx. pipiens* populations in Eastern Canada under current and future projected climate change and projected a similar northward range expansion for this eastern vector of WNV.

A greater understanding of how climate change may alter communities of avian and mammalian reservoir host species would enable more robust evaluation of climate change effects, but few studies have conducted these evaluations, due to limited data and methodological constraints. Current evidence indicates that climatically suitable ranges (or climate envelopes) for many species will likely shift northwards in response to warming temperatures. For example, ecological niche models for 765 species suggest that climate change may increase biodiversity in Southern Quebec during this century, as species move northward (Berteaux et al., 2010; Chambers et al., 2013). Similarly, many bird species that currently breed in the northern portion of the Eastern United States are likely to move northward into Canada, increasing the richness of bird species in Eastern Canada (DesGranges & Morneau, 2010). Habitat loss and disturbance, induced by climate change or other factors, that may result in habitat fragmentation (Warren & Lemmen, 2014) can affect avian and mammalian reservoir host communities (Berteaux & Stenseth, 2006). To what extent these positive and negative effects on host populations will cause increased or decreased risks from mosquito-borne diseases is not yet clear and needs further study (Salkeld et al., 2013).

Mosquito-borne infections have been identified in Canada for many decades; however, recently the number of cases of arbovirus infection appears to be increasing (Ludwig et al., 2019). Since 2002, the annual reported incidence of human cases of WNV, the only Canada-endemic mosquito-borne disease that is nationally reportable, has fluctuated significantly over time at a national level. Reported cases have ranged from five cases in 2010 to highs of 1481 in 2003 (during initial invasion across Canada) and 2215 cases in 2007, associated with an unprecedented abundance of *Cx. tarsalis* mosquitoes in the Prairie provinces (Figure 6.4). This may be consistent with the effects of weather and climate variability on WNV dynamics (Ludwig et al., 2019).

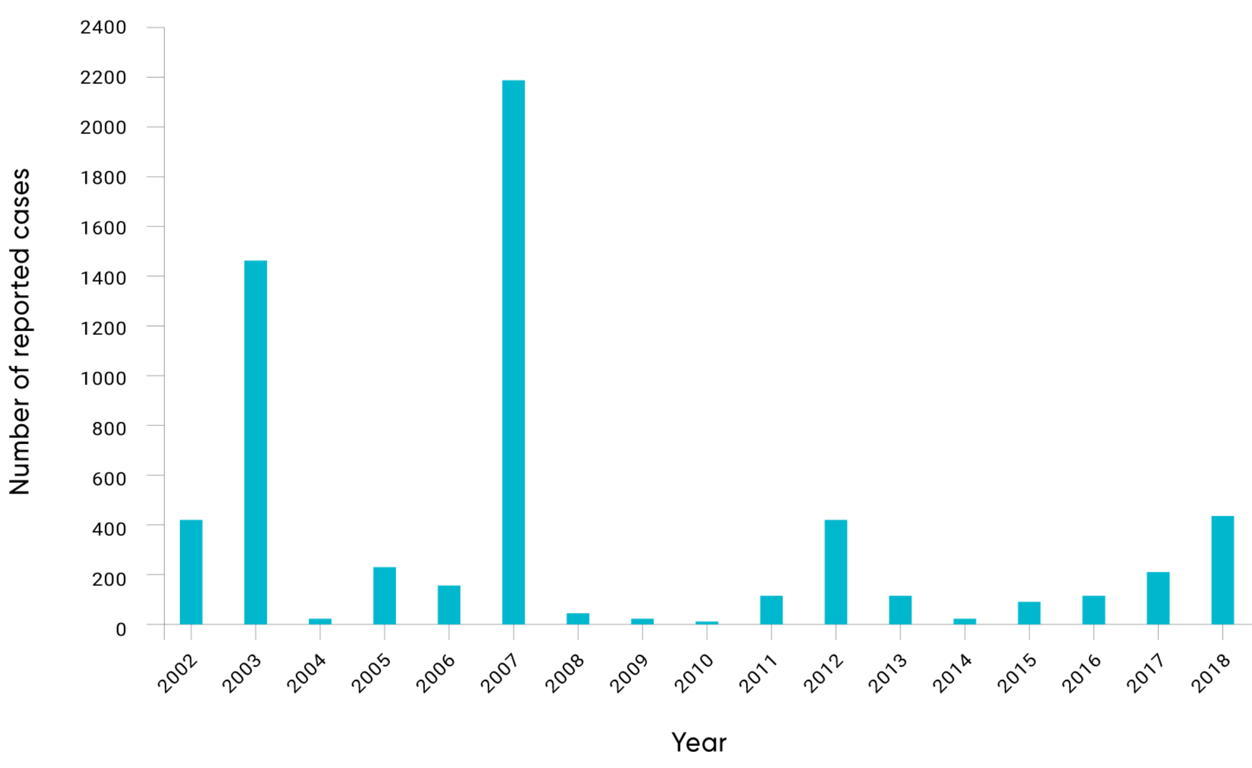


Figure 6.4 The number of reported human cases of WNV each year in Canada. Source: Government of Canada, 2019a.

Geographical variation over time has been dramatic as well. In 2003 and 2007, most human cases of WNV were reported in the Prairies (Alberta, Saskatchewan, and Manitoba), but in 2002, 2012, and 2018 most reported cases were detected in Ontario and Quebec. This variability is at least in part consistent with the effects of local weather variability on the abundance of *Cx. tarsalis*, *Cx. pipiens*, and *Cx. restuans* mosquitoes during outbreak years, and an indication that greater weather variability under climate change may result in more epidemic behaviour of endemic mosquito-borne diseases (Ludwig et al., 2019). Human CSGV cases have been detected across Canada, and a single human EEEV case was reported in 2016 in Ontario (M. Drebot, personal communication, 2019).

Increased awareness of CSGVs, enhanced field surveillance in reservoir hosts, and greater diagnostic capacity in humans and animals, may have contributed to their "emergence" as a public health concern during the mosquito season. Routine diagnostic testing for CSGVs was conducted during the late 1970s and 1980s but discontinued until new testing methods were introduced in 2005, when human cases were once again documented in Canada. Over 200 probable and confirmed cases of CSGV infections and/or exposures have been identified by laboratory-based surveillance from 2005 to 2014, with illness from JCV being more frequently detected than illness caused by SSHV (Drebot, 2015; Lau et al., 2017; Webster et al., 2017; M. Drebot, personal communication, 2019). Although CSGV infections are not nationally notifiable, the numbers of CSGV infections have been summarized in the Public Health Agency of Canada's (PHAC) arbovirus annual reports (Government of Canada, 2019a) and have ranged from 34 to 122 cases per year. To date, there have been no direct associations observed between the effects of weather variability or recent climate change and the incidence of these mosquito-borne viruses in Canada, although such associations may exist.

In Canada, changes have been observed in the geographic distributions and densities of mosquito vectors. The mosquito fauna of Canada, which includes 74 mosquito species from 10 different genera, was described in the 1970s (Wood et al., 1979). Since then, six species (*Ochlerotatus ventrovittis*, *Oc. japonicus*, *Culex salinarius*, *Culex erraticus*, *Anopheles perplexens*, and *An. crucians*) have been reported as possibly newly established in Canada (Thielman & Hunter, 2007; Giordano et al., 2015; Iranpour et al., 2017). In addition, the geographic range of 10 species (*Uranotaenia sapphirina*, *Culiseta melanura*, *Cs. minnesotae*, *Culex tarsalis*, *Ochlerotatus sticticus*, *Oc. spencerii*, *Oc. dorsalis*, *Oc. nigromaculis*, *Oc. campestris*, and *Oc. cataphylla*) has expanded in Canada (Iranpour et al., 2009). Some of these range expansions, which may affect public health, could have been facilitated by changes in climate, but lack of systematic surveillance precludes any conclusion.

There is strong observational evidence of range shifts for mammal and bird species in North America. Over the past 40 years, about 180 of 305 bird species wintering in North America expanded their range northward, at an average rate of 1.4 km per year. Similarly, the breeding ranges of birds in Southern North America have shifted by an average of 2.4 km per year (Federal, Provincial, & Territorial Governments of Canada, 2010). Within the northeastern forests of North America, 27 of 38 species for which historical ranges are documented have expanded their ranges, predominantly northward (Rodenhouse et al., 2009). Published accounts of range shifts in Canada are available for a number of species (Hitch & Leberg, 2007; Blancher et al., 2008;), with detailed analyses for some species, including the hooded warbler (*Setophaga citrina*) (Melles et al., 2011), and the southern flying squirrel (*Glaucomys volans*) (Garroway et al., 2010; Garroway et al., 2011). It is very possible that geographic range shifts of these species have been driven, in part, by recent climate warming. Such range changes could affect endemic mosquito-borne pathogen transmission by changing ranges of reservoir species, while species that are not reservoirs may act to "dilute" arbovirus transmission cycles (Levine et al., 2017). However, further study is required to understand precisely how, where, and when this may have an impact on risk to humans.

6.3.1.4 Other Insect-Borne Zoonotic Diseases

Other insect-borne zoonotic diseases may also be affected by climate change. Plague, caused by the bacterium *Yersinia pestis*, has been documented sporadically in Western Canada. *Yersinia pestis* is transmitted by the bite of an infected flea or by direct contact with infectious tissues or fluids while handling an animal or human that is sick with, or has died from, plague. Droplet-transmission via coughing or sneezing is also possible, due to infection of the lungs of an animal or human with pneumonic plague (Centers for Disease Control and Prevention, 2019a). People infected with plague usually develop flu-like symptoms. After this flu-like phase, they develop varying symptoms, depending on the form of plague — bubonic, septicemic (this form typically develops as a complication of bubonic plague), or pneumonic. Plague is an infection that requires urgent medical care, as mortality rates are high in the absence of treatment (Centers for Disease Control and Prevention, 2019a). The natural reservoirs of *Y. pestis* are wild rodents, particularly ground squirrels in North America and gerbils in Asia.

There is a well recognized association of climatic patterns (generally warmer and wetter periods) with spillover of plague from gerbil–flea transmission cycles to humans in central Asia, due to effects on vegetation that promote gerbil and then flea populations (Kausrud et al., 2010; Samia et al., 2011). These spillover events in Asia are thought to have been the source of the great plague pandemics (the Justinian plague and the Black Death) that decimated human populations in Europe (Kausrud et al., 2010). The impact of climate was studied on plague outbreaks in pre-industrial Europe (1347 to 1760 CE). In contrast to spillover in the Asian steppes, the results suggested that plague in Europe was associated with drier and colder climates (Yue & Lee, 2018). This difference is likely due to the transmission in Europe being driven by a combination of direct human-to-human transmission (causing pneumonic type of plague in humans) and flea-borne transmission from peri-domestic rat reservoirs (producing the bubonic type of plague), both of which may be influenced by effects of climate on human population density and behaviour (Earn et al., 2020). A 56-year time series of human plague cases in the Western United States was used to explore the effects of climatic patterns on plague incidence. As in central Asia, warmer and wetter climate was associated with increased numbers of human cases (Ben Ari et al., 2008). In a consecutive study, the same group found that El Niño–Southern Oscillation and Pacific Decadal Oscillation, in combination, affect the dynamics of plague over the Western United States by enhancing dry-to-wet changes in the climate. The underlying mechanism could involve changes in precipitation and temperatures that affect both hosts and vectors as in Asia. Snow may play a key role, possibly via effects on summer soil moisture, which affects flea survival and development and growth of vegetation for rodents (Ben Ari et al., 2010). A study of the relationships between climatic variables and the frequency of human plague cases (from 1960 to 1997) in Northeastern Arizona and Northwestern New Mexico suggested that plague risk can be estimated by monitoring key climatic variables, most notably maximum daily summer temperature values and time-lagged (one- and two-year) amounts of late winter (February–March) precipitation (Enscore et al., 2002).

Modelling studies have been conducted on the impact of climate change on plague distribution in North America. Using an ecological niche-modelling approach, models by Holt et al. (2009) suggest that, by 2050, climate conditions may reduce plague risk in the southern parts of California and increase risk along the northern coast and the Sierras. A study by Nakazawa et al. (2007) suggested that the disease shifts in accordance with patterns of climatic shift, but that overall geographic shifts will likely be subtle, with some northward movement of southern limits and possibly northward movement of northern limits as well.

Studies of flea species vectors of *Y. pestis* in Canadian prairie dog populations suggested that flea counts per individual varied inversely with the number of days in the prior growing season with more than 10 mm of precipitation; an index of the number of precipitation events that might have caused a substantial, prolonged increase in soil moisture and vegetative production (Eads & Hoogland, 2017). Beyond these studies there have been no attempts to assess how precisely climate change may impact plague dynamics and geographic range in Canada, and there are no field surveillance data available to explore any climatic impacts on the environmental hazard of plague in Canada. Plague is nationally notifiable, but only one human case has been recorded, which occurred in 1939 (Government of Canada, 2018a).

Chagas disease is caused by the protozoal parasite *Trypanosoma cruzi* and is an infection most commonly acquired through contact with the feces of an infected triatomine bug (or "kissing bug"), a blood-sucking insect that feeds on humans and animals. Chagas disease has an acute and a chronic phase and, if untreated, infection is lifelong. Infection may be mild or asymptomatic. There may be fever and/or swelling around the site of inoculation. Many people may remain asymptomatic for life, but 20% to 30% of infected people develop debilitating and sometimes life-threatening medical problems over the course of their lives (Centers for Disease Control and Prevention, 2018e). It is absent from Canada and, while most of the estimated 300,000 cases of Chagas disease in persons living in the United States were likely acquired in Latin American countries, transmission cycles of *T. cruzi* involving animal hosts and humans, and autochthonous vector-borne human infections, have been reported in Texas, California, Tennessee, Louisiana, and Mississippi in the United States (Steverding, 2014).

Chagas disease is likely under-recognized and having an impact on the health care system and economy globally because of limited screening and treatment and a lack of awareness among health care professionals (Click Lambert et al., 2008; Bern & Montgomery, 2009). The possible impact of climate change on Chagas disease vectors in North America has been explored using ecological niche-modelling methods; while northward range expansions of some species were predicted, increasing risks for Canada were not found (Carmona-Castro et al., 2018).

6.3.1.5 Tick-Borne Zoonotic Diseases

Ticks transmit a wide range of bacterial, viral, and protozoan pathogens globally (Sonenshine, 2018). While it is generally acknowledged that increases in temperature associated with climate change will likely contribute to a general increase in the number, type, activity level, and geographical distribution of ticks in North America (Eisen et al., 2016; Sonenshine, 2018), the magnitude of impact climate change will have on risks from tick-borne diseases is uncertain and will likely vary regionally. In Canada, evidence suggests that the emergence of Lyme disease, associated with the northward range spread of the tick *Ixodes scapularis*, has been driven, at least in part, by recent climate warming (Ebi et al., 2017; Hoegh-Guldberg et al., 2019).

Tick-borne diseases of public health significance are zoonoses, and in North America the natural reservoir hosts are wild animals, particularly rodents. There are two types of ticks, hard-bodied (Ixodid) ticks and soft-bodied (Argasid) ticks (Lindquist et al., 2016). In Northern North America, including Canada, the soft-bodied tick of most public health importance is *Ornithodorus hermsi*, which transmits the bacterium that causes relapsing fever, *Borrelia hermsii*. Other soft-bodied ticks and relapsing fever *Borrelia* species occur in the

United States; *Borrelia turicatae* and *Borrelia parkeri* are transmitted by *Ornithodoros turicata* and *Ornithodoros parkeri*, respectively, but are not currently endemic to Canada (Sage et al., 2017). Both *O. hermsi* and *B. hermsii* are naturally cave-dwelling species, and the natural hosts for blood meals by the ticks, and reservoir hosts for *B. hermsii*, are wild rodents. While *Ornithodorus hermsi* and *B. hermsii* most commonly occur in caves in the mountainous regions of the Western United States and have limited distribution in Southern British Columbia, they invade cabins in these regions, which is where most human infections are acquired (Dworkin et al., 2008).

Tick-borne relapsing fever is a febrile, septicemic disease with a sudden onset followed by numerous relapses with afebrile intervals (Artsob, 2000; Murray, 2003). Persistence of the bacterium and relapses are associated with bacteria evading the immune response (Cutler, 2010). There is a very wide range of symptoms, including rashes, ocular lesions, jaundice, and vomiting (Ogden et al., 2014b). However, it is uncommon in humans in Canada, due to the low frequency with which people come into contact with infected ticks.

An ecological niche-modelling approach identified elevation (higher elevations being more favourable) and specific ranges of temperature and precipitation as key determinants of the presence of *O. hermsi* ticks and *B. hermsii* (Sage et al., 2017). In this same study, wider northward and westward range expansion into mountainous regions of British Columbia were projected using three global climate models (GCM) (GCMs: ACCESS1-0, HadGEM2-ES, and CCSM4) and two estimates of greenhouse gas concentration trajectories denoted by representative concentration pathways (RCP) 4.5 and 8.5. Greater range expansion was projected in Canada with the higher greenhouse gas emission scenario, RCP8.5. For both RCP4.5 and RCP8.5, all models projected a range contraction in the United States.

Diseases transmitted by hard-bodied ticks pose the greatest tick-borne disease challenges for public health in North America, and, among these, the most important is Lyme disease, caused by the bacterium *Borrelia burgdorferi*. Lyme disease is a disease affecting multiple body systems that begins with mild non-specific illness and, in most cases, a typical skin rash known as erythema migrans. If untreated, the disease progresses to disseminated Lyme disease with neurological or cardiac manifestations and, in late stages, arthritis (Wormser et al., 2006). This bacterium is transmitted by *Ixodes scapularis* (the black-legged tick) in Northeastern and Upper Midwest United States, and in Southern Central and Eastern Canada, and *I. pacificus* (the western black-legged tick) in the Pacific states of the United States and Southern British Columbia (Bouchard et al., 2015; Eisen et al., 2016). In Southern British Columbia, the geographic range of *I. pacificus*, and the risk of *B. burgdorferi* infection the tick poses, is thought to be quite wide (Mak et al., 2010). However, the risk of acquiring Lyme disease is much lower where *I. pacificus* is the vector, compared to most regions where *I. scapularis* is the vector, due to characteristics of the ecology of *I. pacificus* that result in generally low infection prevalence in this tick and less likelihood that it bites humans (Eisen et al., 2016). There have been no studies to date to assess possible impacts of climate change on future *I. pacificus* and *B. burgdorferi* distributions in British Columbia. Modelling of current *I. pacificus* and *B. burgdorferi* distributions in British Columbia has identified temperature — specifically, mean daily temperatures in January and July — as an important determinant of the ecological niche of these species, and climate change is expected to have an impact on northward and possibly altitudinal distributions (Mak et al., 2010).

For *I. scapularis*, a range of field and laboratory studies (Ogden, 2014) suggested that the main impact of temperature on this species is on development rates and activity; woodland habitats in Canada provide refuges for the ticks, in which they are protected from the direct effects of very low winter temperatures that would otherwise kill them. Model-based assessments of the risk of occurrence of *I. scapularis* used effects of temperature on development rates, and thus life cycle length, to identify lower temperature limits for persistence of self-sustaining tick populations (Ogden et al., 2005). These limits have now been extensively validated by field studies, which, in concert with analysis of passive tick surveillance data, have identified a spatiotemporal pattern of south-to-north range spread into Canada from the United States (and now within Canada) that is consistent with recent climate warming having been a key driver (Ogden et al., 2010; Leighton et al., 2012; Clow et al., 2017; Ebi et al., 2017).

The rapidly increasing incidence of Lyme disease in Canada, identified by national surveillance (Gasmi et al., 2017), is consistent with the observed range expansion of *I. scapularis*, as well as increasing infection prevalence in recently established tick populations (Ogden et al., 2013; Clow et al., 2017) (see Figure 6.5). Due to the high level of agreement among studies, and the evidence of climate change impacts, there is high confidence that the emergence of Lyme disease in Eastern and Central Canada has been associated with recent climate warming. The observed emergence of Lyme disease in Canada is consistent with effects of climate change acting on the tick vector itself. However, there is also evidence that a warming climate may be influencing the risk of Lyme disease via effects on other parts of the transmission cycle, particularly the abundance and geographic range of key rodent reservoir hosts (Simon et al., 2014).

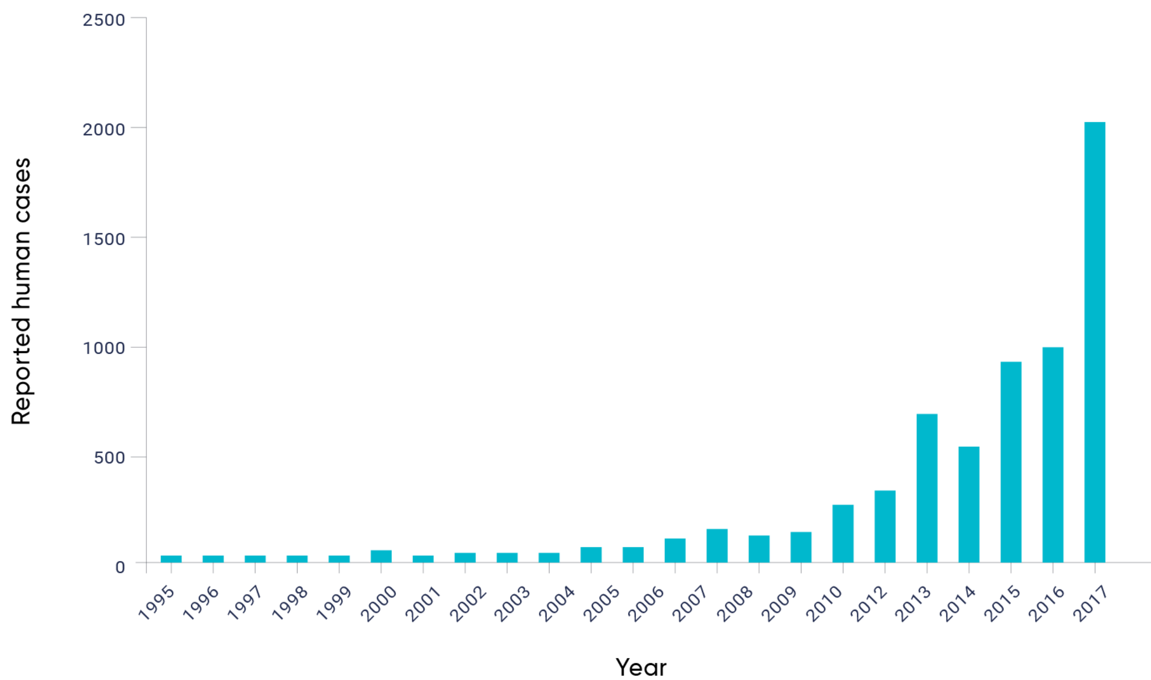


Figure 6.5 The evolution of Lyme disease risk in Canada and human cases. Bar chart shows the evolution of human Lyme disease cases. Note that Lyme disease became nationally notifiable in December 2009. Data from 2009 and earlier are based on voluntary submission of information from provinces and territories in which Lyme disease was notifiable. Source: Gasmi et al., 2018.

Other *Ixodes scapularis*-transmitted pathogens, additional to *B. burgdorferi*, are now emerging in Canada from the United States as the ticks spread north (Table 6.3), but none of the diseases they cause are currently nationally notifiable. Details of these are presented in Box 6.3.

Box 6.3 Diseases and pathogens transmitted by *Ixodes scapularis* ticks that are emerging with Lyme disease

Anaplasmosis, caused by the bacterium *Anaplasma phagocytophilum*, has non-specific symptoms (e.g., fever, headache, and muscle aches) and a case-fatality rate less than 1% (Biggs et al., 2016). Human or animal cases have been identified in most provinces where the ticks occur (Edginton et al., 2018).

Babesiosis, caused by the protozoan *Babesia microti*, causes a Lyme-like disease, with a case-fatality rate of 2%–5% (Biggs et al., 2016). The pathogen has been detected in *I. scapularis* ticks in Manitoba, Ontario, Quebec, and New Brunswick (O'Brien et al., 2016), although human cases have been identified only in Manitoba (Bullard et al., 2014).

Powassan virus, which was first detected in Powassan, Ontario, is transmitted by a number of different tick species. Presentation can vary greatly, from asymptomatic infections to fatal encephalitis cases, and the case-fatality rate is 10% (Artsob, 1988). Two lineages have been identified in vector ticks, with Lineage I identified in *I. cookei*, the nest-living groundhog tick, in Ontario, Quebec, and New Brunswick, while Lineage II, also known as deer tick virus, is transmitted by *I. scapularis* in Manitoba, Ontario, and Nova Scotia (Corrin et al., 2018).

Borrelia miyamotoi was first identified in 2013 in Canada, and this pathogen has been found in *I. scapularis* and *I. pacificus* ticks (Dibernardo et al., 2014). *Borrelia miyamotoi* is more closely related to the *Borrelia* species that cause relapsing fever, which are transmitted by soft-bodied ticks. The disease has generally non-specific symptoms of fever, fatigue, headache, myalgia, chills, nausea, and arthralgia, which may relapse, as do other relapsing fever infections.

A model-based assessment of the possible effects of climate change on the geographic range of the tick *Dermacentor variabilis*, a vector of RMSF and tularemia, which is already endemic to much of Southern Canada, suggested that the range of this tick will expand northward in Canada (Minigan et al., 2018). Prolonged extreme values of temperature (i.e., high or low), low humidity, and intense rainfall could adversely affect tick survival by reducing their activity and increasing their mortality rate (Ogden & Lindsay, 2016). However, this is expected to have less of an effect on ticks than on mosquitoes, because of the tick's ability to find refuge in their woodland habitats (Ogden & Lindsay, 2016). Model-based studies have suggested that, while the northern limit of the geographic range of *I. scapularis* and *D. variabilis* ticks will move northward with climate change, there will also be a northward contraction of the southern limit of the ticks' range as the climate becomes too hot for them (Brownstein et al., 2005a; Minigan et al., 2018). If so, this may affect exposure to the ticks for those living in southern US states, but is unlikely to affect risk in Canada. Studies of

I. scapularis suggest that ticks in the Southeastern United States may adapt to a hot climate (Ogden et al., 2018), so this effect may be minimal.

Non-climate factors also determine where tick populations and pathogen transmission cycles can become established. These include microhabitat features, such as soil characteristics, which are critical for tick survival and the successful establishment of new tick populations (Lindsay et al., 1998; Guerra et al., 2002). Modifications in habitat characteristics, in parallel with climate change, such as habitat fragmentation, loss of biodiversity, resource availability, and land use, affect the dynamics of ticks, their animal hosts, and the exposure of ticks to humans (Brownstein et al., 2005b; Simon et al., 2014). In some parts of Canada, the emergence of *I. scapularis* and *B. burgdorferi* is patchy and uneven, likely because of the suitability of different woodlands for tick survival and because of variations in tick host abundance (Gabriele-Rivet et al., 2015). Changes in non-climate factors can drive emergence of tick-borne diseases. For example, Lyme disease emerged in the United States in the 20th century, likely as a consequence of the reforestation of farmland and the increase in the deer populations, which allowed the expansion of the tick populations (Kilpatrick et al., 2017).

While Lyme disease and other tick-borne diseases transmitted by *I. scapularis* and *I. pacificus* ticks are the tick-borne diseases of greatest concern for public health in Canada at present, other Canada-endemic tick-borne diseases (Table 6.3) are possibly being affected by a warming climate or may be affected in the future. Currently, there is no evidence of the impact of recent warming on these diseases; however, there is evidence from surveillance showing recent increases in the abundance and range of tick vectors of these other diseases. These include increased abundance of *I. cookei* (a vector of Lineage I Powassan virus), *Dermacentor variabilis* (a vector of RMSF, tularaemia, and Colorado tick fever), and *Rhipicephalus sanguineus* (a vector of RMSF) in Eastern Canada (Gasmi et al., 2018), and range expansion of *D. variabilis* in the Prairie provinces (Dergousoff et al., 2013) (Table 6.3).

The northward range expansion of Lyme disease into Canada provides proof of concept of the following:

- The geographic range of ticks and tick-borne diseases in North America may be limited by climate.
- A warming climate may permit northward range expansion of these species.
- Migratory birds and, perhaps, other mammalian tick host species act as a route of introduction of ticks and tick-borne pathogens each year from the United States into parts of Canada that are becoming climatically suitable for their endemicity (Ogden et al., 2008; Nelder et al., 2019).

Therefore, other US-endemic ticks and tick-borne pathogens that are not currently endemic to Canada may spread north. Northward expansion of the range of *Amblyomma americanum*, a vector of tularemia, *Heartland virus*, and the bacterial pathogens *Ehrlichia ewingii* and *E. chaffeensis*, as well as the suspected cause of red meat allergies (Reynolds & Elston, 2017), has been detected in the United States (Stafford et al., 2018). Multiple model-based assessments suggest that areas of Southern Canada will become climatically suitable for this tick with a warming climate (Raghavan et al., 2019; Sagurova et al., 2019). This tick, and the infectious disease and other public health issues it brings, are likely to spread into Canada in the coming decades, likely introduced by migratory birds (Gasmi et al., 2018; Nelder et al., 2019).

Table 6.3 Tick-borne pathogens affecting humans and their associated vector tick species that occur in Canada or may spread into Canada

PATHOGEN (DISEASE IN HUMANS)	YEAR OF IDENTIFICATION	PRINCIPAL TICK VECTOR(S)	PRINCIPAL RESERVOIR HOST SPECIES	GEOGRAPHIC DISTRIBUTION[a]		NATIONALLY NOTIFIABLE	EVIDENCE OF ENDEMICITY IN CANADA		
				CANADA	US		TICKS	HUMANS	ANIMALS
Anaplasma phagocytophilum (human anaplasmosis)	1994	*Ixodes scapularis*, *Ixodes pacificus*	Rodents	BC, AB, SK, MB, ON, QC, NB, NL, NS, PEI	Upper MW and NE states	No	Yes	Yes	Yes
Babesia microti (human babesiosis)	1970	*Ixodes scapularis*	Mice	MB, ON, QC, NB, NS	NE and upper MW states	No	Yes	Yes	Yes
Borrelia burgdorferi (Lyme disease)	1982	*Ixodes scapularis*, *Ixodes pacificus*	Rodents	BC, AB, SK, MB, ON, QC, NB, NS, NL, PEI	NE and upper MW states	Yes	Yes	Yes	Yes
Borrelia hermsii (tick-borne relapsing fever)	1935	*Ornithodoros hermsi*	Rodents and rabbits	BC	Western states	No	–	Yes	–
Borrelia mayonii/ *Borrelia mayonii*-like? (no specific name*)	2014	*Ixodes scapularis*, *Ixodes angustus*	Rodents	ON, BC	Upper MW states: Minnesota and Wisconsin	No	Yes	–	Yes
Borrelia miyamotoi (no specific name)	2013	*Ixodes scapularis*, *Ixodes pacificus*	Mice	BC, AB, MB, ON, QC, NB, NS, NL, PEI	Upper MW, NE, and the mid-Atlantic states	No	Yes	No	–
Colorado tick fever virus (Colorado tick fever)	1946	*Dermacentor andersoni*	Golden mantled squirrels, deer mice, and rabbits	SK, AB	Western states: Colorado, Utah, Montana, Wyoming	No	No	Yes	–

PATHOGEN (DISEASE IN HUMANS)	YEAR OF IDENTIFICATION	PRINCIPAL TICK VECTOR(S)	PRINCIPAL RESERVOIR HOST SPECIES	GEOGRAPHIC DISTRIBUTION[a]		NATIONALLY NOTIFIABLE	EVIDENCE OF ENDEMICITY IN CANADA		
				CANADA	US		TICKS	HUMANS	ANIMALS
Ehrlichia chaffeensis (human monocytic ehrlichiosis)	1987	*Amblyomma americanum*	White-tailed deer	-	Southeastern and south-central states	No	No	No	–
Ehrlichia ewingii (generically named Ehrlichiosis)	1999	*Amblyomma americanum*	White-tailed deer	-	Southeastern and south-central states	No	–	–	–
Ehrlichia muris-like agent (no specific name)	2011	*Ixodes scapularis*, *Ixodes muris*	Mice	MB	Upper MW states	No	Yes	–	–
Francisella tularensis[c] (tularemia)	1924	*Dermacentor variabilis*, *Dermacentor andersoni*, *Haemaphysalis leporispalustris*, *Amblyomma americanum*	Rabbits, hares, and rodents	Canada-wide	All states	Yes	Yes	Yes	Yes
Heartland virus (no specific name)	2012	*Amblyomma americanum*	White-tailed deer	–	MW and south states	No	No	–	–
Lineage I Powassan virus (no specific name)	1963	*Ixodes cookei*, *Ixodes marxi*, *Ixodes spinipalpis*	Small and medium-sized woodland mammals (woodchucks)	ON, QC, NB, PEI	NE states and Great Lakes region	No	Yes	Yes	Yes

PATHOGEN (DISEASE IN HUMANS)	YEAR OF IDENTIFICATION	PRINCIPAL TICK VECTOR(S)	PRINCIPAL RESERVOIR HOST SPECIES	GEOGRAPHIC DISTRIBUTION[a]		NATIONALLY NOTIFIABLE	EVIDENCE OF ENDEMICITY IN CANADA		
				CANADA	US		TICKS	HUMANS	ANIMALS
Lineage II Powassan virus (no specific name)	2001	*Ixodes scapularis*, *Dermacentor andersoni*	Mice	<u>MB</u>, <u>ON</u>, <u>NS</u>	NE and upper MW states	No	Yes	–	–
Rickettsia rickettsii (Rocky Mountain spotted fever)	1909	*Dermacentor variabilis*, *Dermacentor andersoni*, *Rhipicephalus sanguineus*	Variety of wild mammals, including rodents	<u>BC</u>, <u>AB</u>, <u>SK</u>, <u>ON</u>, NS	Eastern, central, western, and southwestern states	No	Yes[b]	Yes	Yes

Source: Bouchard et al., 2019

Note: * Where there is no specific disease name, diseases are named after the pathogen (e.g., Powassan virus disease)

(–) indicates no data available and/or no studies have been performed

a. Canada: Provinces where endemic transmission is known to occur are underlined. For provinces that are not underlined, pathogen transmission cycles are unknown, and infections were detected in adventitious ticks, and/or in humans or animals most likely infected by adventitious ticks.

US: States where highest incidence rate of human cases were found.

b. Based on historical surveys in ticks in Canada, rather than recent surveys.

c. Francisella tularensis may be mechanically transmitted by a range of biting flies, but only ticks act as biological vectors.

Abbreviations: AB, Alberta; BC, British Columbia; MB, Manitoba; NB, New Brunswick; NL, Newfoundland and Labrador; NS, Nova Scotia; ON, Ontario; PEI, Prince Edward Island; QC, Quebec; SK, Saskatchewan; US, United States; NE, Northeast; MW, Midwest.

6.3.2 Zoonoses Directly Transmitted from Animals to Humans

In this section, zoonoses that can be transmitted directly from animals to humans are considered (Figure 6.6). Zoonoses transmitted in food and water are considered in Chapters 7: Water Quality, Quantity, and Security, and Chapter 8: Food Safety and Security. The risk of infection by directly transmitted zoonoses may be influenced by direct effects of climate change and weather on the survival of the pathogens, indirect effects on their host species and communities, and/or effects on contact rates between the pathogens and humans. Together, these determine the frequency of "spillover" events, that is, when pathogens are successfully transmitted from animals to humans (Altizer et al., 2013; Brierley et al., 2016), as well as the possibility of adaptive emergence of zoonoses, which then result in epidemics or pandemics affecting human populations (Ogden et al., 2017). Climate change may, therefore, drive global emergence of zoonotic infectious diseases. Directly transmitted zoonoses, mostly from wildlife, are the zoonoses that emerge and re-emerge most frequently on a global scale (Jones et al., 2008).

Climate change impacts on zoonoses in the North are expected to be greater than elsewhere in Canada, including effects on vector-, food-, and water-borne zoonoses, as well as directly transmitted zoonoses (Parkinson et al., 2014). Greater climatic impact, coupled with, in many cases, higher consumption of traditional and country foods,[1] suggest that Northern communities, particularly Northern Indigenous communities, are at greater risk of health effects (Brook et al., 2009). A further concern is that, as permafrost melts with a warming climate, pathogens that have remained dormant but viable in animal carcasses or soil, may be released into the environment and cause disease outbreaks (Revich et al., 2012). For most of the directly transmitted zoonoses discussed in this section, there is evidence of sensitivity to climate and/or weather, which raises the possibility of current and future impacts of climate change. In very few cases have there been attempts to assess such impacts. Also, for very few directly transmitted zoonoses is there evidence of changing patterns of disease or risk, but that may be due, in part, to the lack of systematic surveillance of these diseases in Canada.

1 Traditional Inuit food, also known as country food, is an integral part of Inuit identity and culture, a significant source of nutrients, and contributes to individual and community health and well-being. It includes marine animals (e.g., walrus, seals, etc.), caribou, birds, fish, and foraged foods.

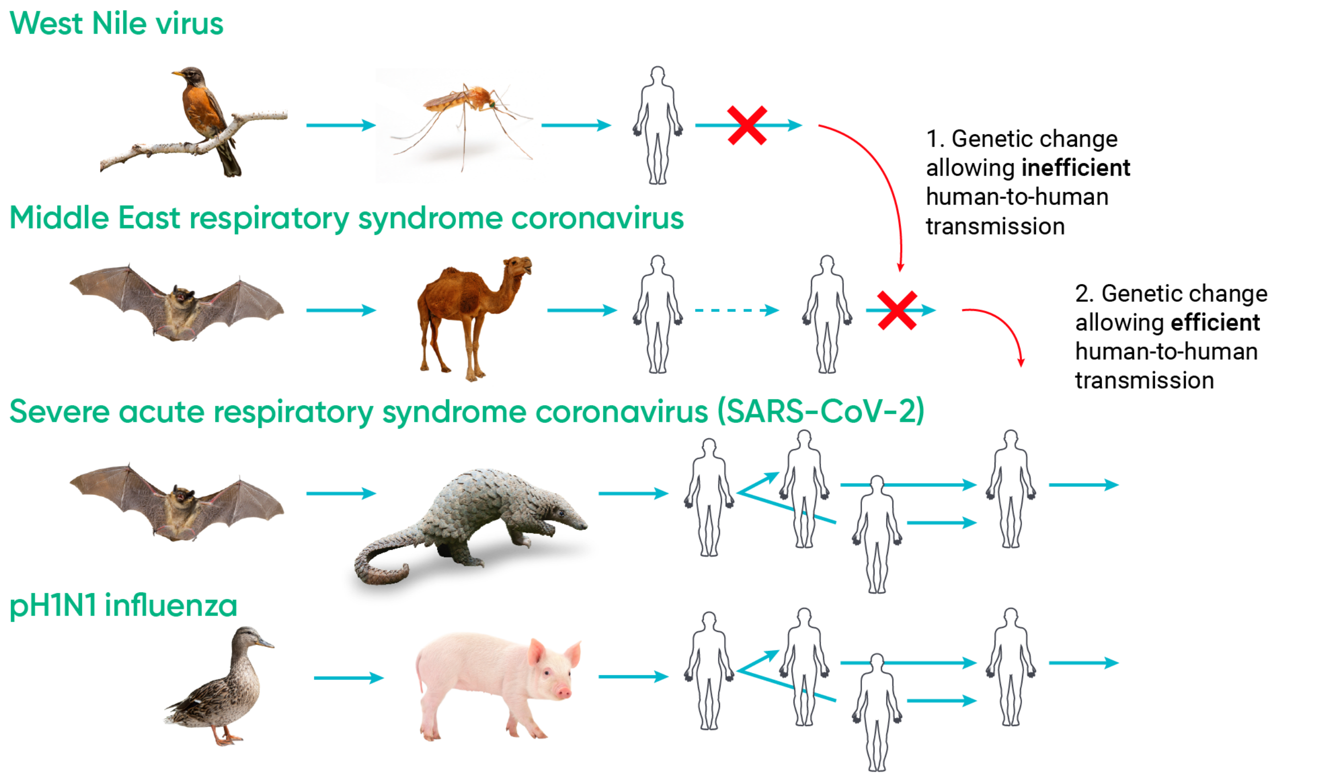


Figure 6.6 Zoonoses and emergence by genetic change and/or evolution.

6.3.2.1 Viral Zoonoses

Globally, one of the most highly pathogenic and high-impact groups of directly transmitted viral zoonoses are avian influenza A viruses. Global epidemics of highly pathogenic (for humans) avian influenza viruses have occurred in recent decades (Goneau et al., 2018), and outbreaks have occurred in domesticated poultry in Canada, sparking fears of human cases (Skowronski et al., 2007). Disease in humans varies from mild illness to severe illness, with high case-fatality rates (Neumann, 2015). The main reservoirs of avian influenza viruses are wild birds, particularly waterfowl (i.e., swans, geese, and ducks). Influenza viruses of swine are also of great public health concern, although these viruses are now maintained mostly by domesticated swine, and effects of climate change are relatively unlikely (Schultz-Cherry et al., 2011). Pandemic influenza viruses, such as the 1918 and 2009 H1N1 viruses, emerge following recombination (a molecular process) of avian, swine, and human influenza viruses (Neumann et al., 2009). Due to the high level of threat from zoonotic and pandemic influenza viruses, there is extensive surveillance for them in wild and domesticated animals and humans, both globally and in Canada (Government of Canada, 2017; Government of Canada, 2018b), and a program of preparedness for pandemics (Government of Canada, 2019b).

Box 6.4 Climate change and coronavirus disease (COVID-19)

The coronavirus disease (COVID-19) pandemic is a paradigm of a zoonotic infectious disease that spills over into humans and then becomes a pandemic, due to characteristics of the virus that permit efficient human-to-human transmission, and due to globalization that allows rapid international spread (Ogden et al., 2017). The causal virus, SARS-CoV-2, is likely a coronavirus of bat origin (Lau et al., 2020) that may have spilled over into humans from an intermediary animal reservoir such as pangolins (Han, 2020; Zhang et al., 2020). Contact with infected animals or animal products at a "wet market" in the city of Wuhan, Hubei province, China, some time during late 2019 has been implicated as the original spillover event (Zhang et al., 2020), although uncertainty around the origins of the virus remains. After that time, the virus likely evolved more efficient human-to-human transmissibility (Andersen et al., 2020). Despite intensive control within China (Wang et al., 2020), and travel restrictions to and from China, global spread occurred (Wu et al., 2020), and COVID-19 was declared a pandemic (WHO, 2020).

Recent climate change may have affected transmission of SARS-CoV-2 via impacts on the ecology of natural transmission cycles (see section 6.1.1 Infectious Disease Emergence and Re-Emergence) that resulted in a particularly high prevalence of infection in the wildlife captured for food or medicinal products and that facilitated spillover in the Wuhan wet market. However, there is no evidence for this at the time of writing (O'Reilly et al., 2020). There is some limited evidence of reduced transmission of SARS-CoV-2 at high temperatures (Pequeno et al., 2020), and there is speculation that climate change may result in seasonally varying transmission of SARS-CoV-2 if, and when, it becomes endemic (Kanzawa et al., 2020; Kissler et al., 2020). However, at this point in the pandemic, it appears that non-pharmaceutical health interventions are more important than physical environment in influencing viral transmission (Jüni et al., 2020).

Indirect effects of climate change on COVID-19 transmission via effects on contact rates between people and on air quality, as for other human-to-human transmitted respiratory viruses (see section 6.3.3.1 Respiratory Infections) could be expected. While the transmission of COVID-19 via the fecal–oral route is thought to be possible (Gupta et al., 2020) and viral RNA has been detected in wastewater from communities with ongoing COVID-19 transmission (Randazzo et al., 2020), there is no evidence to date that SARS-CoV-2 is a water-borne pathogen.

Despite limited evidence for direct or indirect impacts of climate change on COVID-19 transmission, further studies are needed. These studies should also take into account that impacts of COVID-19 are likely greatest among socio-economically disadvantaged individuals and communities via effects on transmission and disease severity (Ji et al., 2020; Nash & Geng, 2020).

Emergence and re-emergence of avian influenza risks to humans could be driven by a number of climate change effects on the ecology of the viruses, including bird migration patterns and changes in land use and livestock production patterns (Morin et al., 2018). Transmission of avian influenza viruses among wild birds, which often involves fecal–oral transmission via water, may be inhibited by climate warming, as the survival of the viruses is greater in cool compared to warm water (Morin et al., 2018). Consistent with this, the prevalence of infected birds in a Canadian study was higher if sampling was preceded by cold weather (Papp et al., 2017), and phylogenetic data suggest that influenza A viruses actually emerged following the Little Ice Age (Gatherer, 2010). However, complexity associated with the global transmission of avian influenza viruses means that, while avian influenza viruses are inherently climate-sensitive, the effects of climate change could be positive, with reduced disease transmission because of effects on environmental survival of the viruses, or negative, with increasing transmission through indirect effects of other factors (Gilbert et al., 2008; Gatherer, 2010; Morin et al., 2018).

Rabies is a zoonotic disease that represents a major worldwide health concern with more than 55,000 human deaths annually (Knobel et al., 2005). Rabies virus is capable of infecting cerebral and nervous tissues of all mammals, usually leading to behavioural changes followed by death (WHO, 2013). In Canada, rabies is associated with several wildlife species, including bats, skunks, raccoons, and foxes, that each maintain distinct viral variants circulating endemically within their populations (Rosatte, 1988; Tinline & Gregory, 2020). Human cases of rabies are rare in Canada, with only three domestically acquired cases since 2000 (Filejski, 2016), but human exposures to rabid animals followed by administration of post-exposure prophylactic treatment occur annually across the country.

While climate-driven ecological change is likely to affect the circulation of rabies in each of its respective host populations to some extent, such impacts are likely to be felt first and most significantly in the Arctic. Rabies occurs across the Arctic and is regarded as enzootic, or prevalent, in Northern Canada (north of 60 degrees north latitude) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). The main reservoir host of Arctic rabies is the Arctic fox (*Vulpes lagopus*).

Arctic rabies is caused by a unique strain of rabies virus, referred to as the Arctic rabies virus variant, which circulates within the Arctic and sub-Arctic regions, with sporadic incursions toward more southern regions, occasionally leading to establishment of enzootic rabies in these areas (Rosatte, 1988). In the Canadian Arctic, rabies cases in domestic animals and wildlife are reported every year, and Arctic residents receive more rabies post-exposure prophylactic treatments per capita than any other population in Canada (Rosatte, 1988; Mitchell & Kandola, 2005; Aenishaenslin et al., 2014; CFIA, 2019).

Northern Canada is experiencing climate change at rates faster and greater than the global and Canadian averages (Larsen et al., 2014; Bush & Lemmen, 2019). While the long-term impacts of rapid climate warming on Arctic rabies have yet to be documented, rabies ecology and epidemiology are likely to be altered by ongoing climate-driven perturbations to Arctic ecosystems. These include fading population cycles of lemmings, a key source of food for Arctic foxes (Fuglei & Ims, 2008; Kausrud et al., 2008), reduced extent and duration of sea ice used by foxes for winter foraging and movement (Kim et al., 2016), and the northward range expansion of red foxes (*Vulpes vulpes*). Red foxes are both a resource competitor for Arctic foxes and competent reservoir host for the Arctic rabies variant (Rosatte, 1988; Hersteinsson & MacDonald, 1992; Gallant et al., 2012). A recent modelling study (Simon et al., 2019) suggested that rabies incidence may initially stabilize due to reduced variation in prey dynamics, with interactions between Arctic and red foxes intensifying outbreaks where these species overlap. However, in the long term, displacement of Arctic foxes by red foxes and restricted winter movements due to reduced sea ice extent may limit rabies transmission in warmer areas. Similarly, Huettmann et al. (2017) predicted a reduction of the current ecological niche of rabies virus in Alaska with climate warming.

Hantaviruses cause infections of wild rodent and insectivorous mammal populations and can cause hantavirus pulmonary syndrome, a fever followed by acute pulmonary edema and shock. There is no specific treatment for hantavirus pulmonary syndrome; the case-fatality rate is 38% in Canada (Drebot et al., 2000), where, on average, four cases are reported a year (Government of Canada, 2015). Humans become infected by contact with infected rodents or their excretions, particularly aerosolized urine or feces (Weir, 2005). In a previous report (Charron et al., 2008), the climate sensitivity of hantavirus incidence, associated with effects on rodent populations, was identified. There have been no further studies of hantavirus in Canada, and potential impacts of climate change are unexplored.

6.3.2.2 Parasitic Zoonoses

In Canada, the zoonotic protozoans *Cryptosporidium*, *Giardia*, and *Toxoplasma* are the most important parasites for public health, according to expert opinion, and the first two are nationally notifiable (FAO & WHO, 2014). Transmission of *Cryptosporidium* and *Giardia* spp. can be directly from animals, for example, from neonatal farm animals or in petting zoo environments. It can also occur from human to human through close contact and outbreaks in communal, caregiving environments, and through food or water. The effects of climate change on infections by these parasites will most likely occur through food- or water-borne transmission (see Chapter 7: Water Quality, Quantity, and Security, and Chapter 8: Food Safety and Security).

Currently, the human burden of disease, including neural and ocular lesions associated with visceral larval migrans (i.e., the migration of larvae through the body) due to the zoonotic ascarids (i.e., roundworms) *Baylisascaris procyonis* and *Toxocara canis* is not known in Canada, and only isolated cases and serosurveys are reported (Embil et al., 1988; Sapp et al., 2016). The reservoir hosts for these ascarids are, respectively, raccoons and domestic dogs. In Southern Canada, dogs are also competent hosts for *B. procyonis* (Lee et al., 2010). *Toxocara canis* was the most common parasite detected in the feces of dogs in shelters in a national study in Canada (Villeneuve et al., 2015). Direct transmission from dogs to humans is possible if eggs that have larvated in the environment stick to the fur of the animal, but in general *T. canis* is thought to be acquired mainly from eggs in the environment (Keegan & Holland, 2010).

Eggs of both ascarid parasites undergo temperature-dependent development in the environment before becoming infective for humans. Therefore, the primary mechanisms by which these parasites may be affected by climate change are through local amplification due to more rapid development and increased survival of eggs shed in the feces of definitive hosts (i.e., those in which parasite reproduction occurs), and through northward range expansion due to changes in the distribution and abundance of the canine and raccoon hosts. Eggs of *T. canis* are freeze-susceptible (O'Lorcain, 1995) and undergo delayed development after chilling (Azam et al., 2012), but eggs of *B. procyonis* can survive freezing temperatures and freeze–thaw cycles (Shafir et al., 2011). This suggests that a changing climate may have different effects on these parasites. For *B. procyonis*, northward expansion may follow that of the primary host, raccoons, which are currently limited to the southern parts of Canadian provinces (Naughton, 2012). For *T. canis*, northward range expansion and local amplification may follow increased survival and development rate of eggs in the environment. Increased circulation of both parasites in dogs, with their close relationship to people, may result in increased disease in Canadians. No studies to date have explicitly investigated effects of climate change on these parasites. However, eggs of *T. canis* were recently reported in dogs north of 60 degrees north latitude in Canada for the first time (Salb et al., 2008), which may suggest northward range expansion of this species (Jenkins et al., 2011).

Until recently, the zoonotic cestode *Echinococcus multilocularis* was thought to be transmitted between wild canids and rodents only in southern parts of the Prairie Provinces and the Arctic tundra, and only one autochthonous human case had been documented in Canada (James & Boyd, 1937; Deplazes et al., 2017). Eggs of *Echinococcus* are shed in the feces of wild or domestic canids; they are immediately infective and can adhere to the host's fur. Infection can occur in humans via inadvertently consuming these eggs. Transmission can also occur via consumption of unwashed produce or drinking unfiltered surface water in heavily contaminated environments (Deplazes et al., 2017). In humans, the parasite establishes initially in the liver, and behaves like a parasitic tumour, eventually metastasizing throughout the abdomen unless aggressively surgically and medically managed. Recently, more cases of alveolar echinococcosis have been detected in both dogs and humans in Canada, and the parasite has expanded its range to include most of Western Canada (Deplazes et al., 2017) and the southern portion of Ontario (Kotwa et al., 2019). This emergence is likely linked to both the introduction of European strains of the parasite, which have now established successfully in wildlife, and increasing rates of contact between people and urban wildlife.

Possible mechanisms for the effects of climate change on this parasite include effects on egg survival, as eggs are environmentally resistant but susceptible to high temperatures and desiccation, and by stabilizing and amplifying rodent intermediate host populations, which were thought to be a limiting factor keeping this parasite in check (Rausch, 1956; Jenkins et al., 2013). Climatic variables, both temperature and precipitation, have been correlated with the prevalence of infection in definitive and intermediate hosts (i.e., hosts in which parasite reproduction does not occur) (Takeuchi-Storm et al., 2015), which may be associated with direct effects on the survival of eggs in the environment, or impacts on reservoir hosts (Mas-Coma et al., 2008). The parasite is now provincially notifiable in Alberta and Ontario. Dogs can serve as both definitive and intermediate hosts for *E. multilocularis*, and therefore regular cestocidal treatment of dogs known to consume rodent intermediate hosts may help mitigate human risk (Jenkins, 2017).

6.3.2.3 Bacterial Zoonoses

Brucella species bacteria, which are endemic to Canada and cause disease in humans, are *Brucella abortus* and *B. suis* biotype 4. *Brucella abortus* is maintained by cattle, when the disease is not prevented by control programs, and by wild ungulates, including deer and bison (Nishi et al., 2002). *Brucella suis* biotype 4 is maintained by caribou (Forbes, 1991). Brucellosis in humans causes persistent and often recurrent fever with chronic fatigue and other symptoms such as arthritis (Centers for Disease Control and Prevention, 2019b). In animals, the main effect of infection is abortion. The main transmission route to the human population is mostly food-borne, but direct transmission from tissues of infected livestock to those working in livestock and food-processing industries is possible (Hunter et al., 2015), as is direct transmission from infected tissues of wildlife to hunters (Franco-Paredes et al., 2017). Apart from possible direct effects of climate change on the survival of *Brucella* spp. bacteria in the environment (Aune et al., 2012), and thus on animal-to-animal transmission, climate change may affect transmission through effects on wild host population dynamics (Cross et al., 2007). While brucellosis may be a climate-sensitive disease, there have been no studies to explore possible effects of climate change.

Caused by the bacterium *Bacillus anthracis*, anthrax risk in the environment is amplified by infected wild and domesticated ungulates, which suffer hemorrhagic illness as a consequence of infection. The infected animal's blood and carcass, if and when it dies, contaminates soils with bacteria that form resistant and persistent spores (Valseth et al., 2017). Humans can acquire infection by inhaling spores, ingesting spores contaminating food or water, or by contamination of skin cuts with spores.

Manifestations in humans depend on the route of infection — cutaneous manifestations after the infection of cuts, gastrointestinal manifestations after ingestion, and respiratory manifestations after inhalation. There is high case fatality (approximately 25%) in untreated people (Centers for Disease Control and Prevention, 2017). High temperatures have been associated with outbreaks in wild and domesticated animals in northern countries, including Canada, and enhanced environmental suitability for anthrax transmission and *B. anthracis* survival in the North and in South-Central Canada is anticipated with a warming climate (Walsh et al., 2018). The persistent nature of *B. anthracis* spores in soils allows weather-driven outbreaks to occur, and these may become more common with climate change due to combined effects of warming and flooding (Maksimovic et al., 2017). Both anthrax and brucellosis are reportable diseases when they occur in livestock in Canada (Government of Canada, 2019c).

Q fever is caused by the bacterium *Coxiella burnetii*. This bacterium is transmitted to humans mainly by airborne pathways from infected ruminant farms, particularly sheep and goat farms. In humans, the infection causes fever as well as pneumonia, infections of the liver, and chronic infections of the heart, and has a high case-fatality rate without treatment (up to 25%) (Centers for Disease Control and Prevention, 2019c). In ruminants, there are few clinical manifestations beyond abortion if the animal is infected in late pregnancy. Infected animals excrete the bacteria in milk, urine, feces, and placenta and birthing fluids (Plummer et al., 2018). The bacteria persist in the environment; while farm workers are those most at risk, large outbreaks have occurred in Europe associated with long-distance airborne transmission from affected farms (Schneeberger et al., 2014). Q fever is not nationally notifiable in Canada but is thought to be particularly prevalent in farms in Quebec (Dolcé et al., 2003), although the reason for this is unknown. Greater incidence has been associated with increased precipitation in the Caribbean, suggesting sensitivity to weather (Eldin et al., 2015; Sivabalan et al., 2017). The dispersal of the bacteria is increased with wind speed and low humidity, but reduced precipitation associated with climate change in some regions may reduce the concentration of this airborne pathogen (van Leuken et al., 2016). There are no studies exploring possible effects of climate change.

6.3.3 Infectious Diseases Directly Transmitted from Human to Human

This section focuses on the subset of infections that are transmitted directly from human to human. Direct transmission can be defined as an infectious agent being transferred between people by direct contact or droplet spread rather than via food, water, or arthropod vectors. Direct contact occurs through skin-to-skin contact, whereas droplet spread refers to spray with relatively large, short-range aerosols produced by sneezing, coughing, or talking (Dicker et al., 2012). Directly transmitted infections cause a wide spectrum of illnesses, and many human population characteristics, such as changing demographics and human behaviour, patterns of connectivity, and compliance with public health recommendations (e.g., immunization against influenza), influence the burden of these diseases within the population (Heesterbeek et al., 2015).

The basic reproduction number (R_0) (i.e., the number of secondary cases created by a primary disease case in a totally susceptible population and in the absence of intervention), is an important metric of communicability (Pandemic Influenza Outbreak Research Modelling Team, 2009). For directly transmitted pathogens, R_0 is a function of duration of infectiousness, the effective contact rate of an infected individual, and the "infectivity" of an individual case (Pandemic Influenza Outbreak Research Modelling Team, 2009). If any of these factors are modified directly or indirectly by climate change, the result will be a change in disease epidemiology. Increases in R_0 can increase the burden of endemic diseases and can make disease outbreak and emergence events more likely. In fact, the impacts of climate change on human habitation, agricultural productivity, conflict, livelihoods, and political stability will likely result in the displacement of populations and changes in mixing patterns that will have knock-on effects on communicable diseases; the link between human conflict, displacement of populations, and large-scale migrations and communicable diseases has been repeatedly demonstrated in recent and distant history (Rabaan, 2019). Such second- and third-order impacts of climate change on communicable diseases may dwarf the first-order changes in epidemiology due to impacts on hosts and pathogens.

There have been many studies identifying impacts of weather and climate on infectious diseases transmitted directly from human to human, but there is a dearth of studies that have attempted to explicitly investigate the effects of climate change. Only effects for hand-foot-and-mouth disease (HFMD) have been studied to date, and there have been no efforts to attribute any changes in disease incidence to recent climate change.

A possible indicator of climate-related modification of the epidemiology of directly transmitted communicable diseases is their seasonality. The seasonality of such infections is well recognized and has worked its way into the vernacular (e.g., "flu season"). While mechanisms underlying the seasonality of communicable diseases remain poorly understood (Fisman, 2007; Greer et al., 2008; Fisman, 2012), a growing body of literature has sought to distinguish the contribution of environmental factors to disease transmission, from other seasonally varying factors, such as seasonal human behaviour (school attendance, holidays, indoor crowding, etc.) and neuroendocrine factors (melatonin, vitamin D, etc.) (Dowell, 2001). Many viral and bacterial pathogens, particularly those that cause respiratory and gastrointestinal infection, display marked seasonality in temperate climates such as Canada's, which suggests that environmental factors are important determinants of disease risk and environmental change may result in important changes in disease epidemiology.

6.3.3.1 Respiratory Infections

Respiratory infections are the greatest contributor to the overall burden of disease in the world (Ferkol & Schraufnagel, 2014) and were the third leading cause of death in 2015 worldwide (Global Burden of Disease, 2015; Mortality and Causes of Death Collaborators, 2016). Added to this now is COVID-19, but, to date, there is no evidence of the influence of weather and climate on the emergence and spread of this disease. Communicable respiratory diseases include diseases caused by both viral and bacterial pathogens. For many viral respiratory diseases, such as influenza, a broad spectrum of illness is common; most people suffer mild to moderate illness that is self-limited. However, a proportion of the population will experience more severe illness, or secondary bacterial infection, requiring hospitalization. It is estimated that, in Canada, an average of 12,200 hospitalizations (Schanzer et al., 2006; Schanzer et al., 2008; Schanzer et al., 2013a; Schanzer et al., 2013b) and approximately 3500 deaths are attributable to influenza annually (Schanzer et al., 2013b). Severe respiratory infections are most common at the extremes of age (Ampofo et al., 2006; Schanzer et al., 2006; Schanzer et al., 2008; Schanzer et al., 2013a; Schanzer et al., 2013b).

In temperate regions, viral respiratory infections, such as influenza and respiratory syncytial virus (RSV) can occur throughout the year, but seasonal epidemics peak in winter months (Thompson et al., 2006; Rohr et al., 2011). The predictable seasonality of wintertime viral respiratory infections has led investigators to evaluate whether environmental conditions could influence the time of onset and/or severity of seasonal influenza epidemics. There is some evidence that decreased absolute humidity (Shaman et al., 2010), decreased temperature (Earn et al., 2012; Skog et al., 2014), or both (Chattopadhyay et al., 2018) may trigger the onset of influenza season in temperate countries. Lower temperatures and decreased absolute humidity may also increase the transmissibility of influenza and influenza-like illness during epidemics (Tang et al., 2010; Roussel et al., 2016; Caini et al., 2018).

The severity of influenza seasons is diminished in the presence of strong El Niño–Southern Oscillation conditions (Viboud et al., 2004; Choi et al., 2006), providing further evidence of climate sensitivity. This thermal inversion in the Pacific Ocean is associated with unusually warm and rainy conditions, similar to those projected under climate change scenarios (Fisman et al., 2016). Given the apparent increase in influenza transmission in cold conditions, it might be expected that the effect of climate change would be to diminish the burden of illness associated with viral respiratory infections. However, climatic effects on influenza epidemiology may depend on time scale. An analysis of climate and past US influenza epidemic seasons from 1997 to 2013 found that mild winters were associated with early and severe epidemics in the subsequent year (Towers et al., 2013). Diminished influenza transmission in a given season may result in a larger population of susceptible individuals, and consequently a more explosive influenza epidemic, in the next season. Furthermore, it has been suggested that increased global temperatures may increase the rate of influenza diversification, which could diminish cross-protective immunity and give rise to more frequent influenza pandemics (Gatherer, 2010).

Several important bacterial respiratory human pathogens display stereotyped seasonality. Both *Streptococcus pneumoniae* and *Neisseria meningitidis* infections are more common in winter, which may be driven in part by increased risk due to prior influenza and/or respiratory syncytial virus infection (Tuite et al., 2010; Kuster et al., 2011). Direct environmental impacts on these infections are also possible. Invasive pneumococcal infections tend to be strongly seasonal in temperate climates, which leads to causal correlations with cold weather (Cilloniz et al., 2017). However, it has been suggested that diminished wintertime UV radiation, which is less likely to be influenced by climate change than temperature or precipitation patterns, may account for this wintertime seasonality (White et al., 2009). More recent modelling work suggests that pneumococcal seasonality may be complex and driven by interplays between population contact patterns, wintertime weather, and predisposing viral respiratory infections (Domenech de Cellès et al., 2019). Meningococcal infections have historically displayed highly seasonal occurrence in sub-Saharan Africa, with epidemic onset linked to the timing of the Harmattan winds (Sultan et al., 2005). In temperate regions, invasive meningococcal disease incidence often peaks in late winter or early spring (Rosenstein et al., 2001; Lindsay et al., 2002; Brachman & Abrutyn, 2009). However, links to environmental factors, while identified in individual regions, are inconsistent across regions (Collier, 1992; Lindsay et al., 2002; Sultan et al., 2005; Michele et al., 2006; Kinlin et al., 2009). Increased frequency of extreme weather events, including heavy rainfall events, are projected under climate change, and increases in respiratory illness have been associated with exposure to floodwaters (De Man et al., 2016). However, these illnesses are likely due to environmentally derived pathogens (e.g., *Legionella*, as described below) and water-borne pathogens, which are addressed elsewhere in this report (see Chapter 7: Water Quality, Quantity, and Security).

6.3.3.2 Gastrointestinal Infections

As with respiratory viral infections, gastrointestinal tract viral infections display highly seasonal occurrence. Enteroviral infections, including echovirus, coxsackie A and B viruses, and, before its control, poliovirus are associated with outbreaks in late summer and early autumn in temperate countries (Moore, 1982). Norovirus and rotavirus commonly occur in winter (Greer et al., 2009; Patel et al., 2013). Enteroviruses are usually transmitted via the fecal–oral route and can cause recognizable disease entities, including HFMD, neuroinvasive infections (e.g., acute flaccid paralysis), and non-specific syndromes, including viral meningitis, encephalitis, myocarditis, gastroenteritis, and conjunctivitis. Norovirus and rotavirus are associated with gastroenteritis, and norovirus in particular can cause large point-source outbreaks, including those in closed environments such as cruise ships and long-term care facilities (Rajagopalan & Yoshikawa, 2016; Mouchtouri et al., 2017).

Mechanisms underlying the seasonality of enteroviral infections are not fully understood. However, Dowell (2001) pointed out that the seasonality of polio becomes more evident with distance from the equator, and is absent peri-equatorially, implying that seasonal changes in weather are key drivers of enteroviral seasonality. It has been suggested that temperature modulates both viral reproduction and particle survival, and that humidity alters viral attachments to water droplets, facilitating transmission (Patz et al., 2005; Wong et al., 2010). Consistent with these hypotheses, elevated temperatures have been associated with increased HFMD risk in several Asian countries (e.g., Hii et al., 2011; Onozuka & Hashizume, 2011), at lags of one to two weeks. While some studies suggest that the relationship between temperature and disease risk is linear (Hii et al., 2011; Wang et al., 2016), or associated with high maximum daily temperatures (Sumi et al., 2017), others suggest more complex non-linear relationships between risk and temperature (Kim et al., 2016; Liao et al., 2016; Zhao et al., 2018).

Increased relative humidity and rainfall have also been associated with elevated HFMD risk in most studies (Hii et al., 2011; Onozuka & Hashizume, 2011; Zhao et al., 2017); humidity may modulate the effects of temperature (Kim et al., 2016; Sumi et al., 2017). It has been suggested that extreme precipitation events may enhance the risk of HFMD (Cheng et al., 2014; Yu et al., 2019). As noted above, the combination of increased temperature and heavy rains is associated with El Niño–Southern Oscillation, which are associated with near-term increases in HFMD in China (Lin et al., 2013). These observations have allowed parameterization of mathematical models that suggest a 5% increase in HFMD in China by 2090, which would represent a substantial increase in disease burden (Zhao et al., 2018). If such estimates are applicable to enteroviral infections generally, this could also present an increase in currently rare but severe manifestations of enteroviral disease, such as neuroinvasive infections and myocarditis.

Increased temperatures and rainy, humid weather associated with climate change could therefore increase the incidence of endemic enteroviral disease worldwide as well as the frequency of outbreaks, and spur the emergence of enteroviral strains in new geographic regions by elevating R_0 beyond the threshold for sustained person-to-person transmission. Indeed, with the recent emergence of acute flaccid paralysis due to non-polio enteroviruses in North America, including Canada, such a phenomenon may currently be occurring (Hassel et al., 2015; Holm-Hansen et al., 2016; Suresh et al., 2018). Candidate vaccines against enterovirus EV-71, which is an important agent of HFMD and strongly associated with neuroinvasive disease, are in development but are not yet available for use in North America (Zhu et al., 2014).

In contrast to enteroviruses, both noroviruses and rotavirus strains are associated with wintertime gastroenteritis in North America (Greer et al., 2009; Patel et al., 2013). In Spain, unusually cold weather has been associated with increased risk of rotavirus-related hospitalization (Morral-Puigmal et al., 2018). While rotavirus is highly transmissible via person-to-person spread, environmental reservoirs (particularly water) may be important for spread, and lower water temperatures delay environmental decay of the virus (see Chapter 7: Water Quality, Quantity, and Security). Cold, dry conditions have also been associated with norovirus activity in England and Wales (Lopman et al., 2009). Consequently, climate warming in Canada could reduce the incidence of some of these viral pathogens.

6.3.4 Infectious Diseases Acquired by Inhalation from Environmental Sources

Perhaps the best-known infectious diseases of humans that have environmental sources other than infected humans, animal reservoirs, or arthropod vectors, are legionellosis and cryptococcosis. These types of infections are caused by bacteria and fungi that persist in soils and water and that infect humans by inhalation after becoming aerosolized or airborne in dust. For all such infections, while there have been studies to identify influences of weather and climate on their occurrence, there has been little assessment of the possible impacts of climate change. Details of the pathogens, the diseases they cause, and their sensitivity to weather and climate are provided in the main text, while the possible effects of climate change are described in Box 6.5, Box 6.6, Box 6.7, Box 6.8, and Box 6.9.

6.3.4.1 Legionellosis

Infection with *Legionella* bacteria causes legionellosis, which presents as Legionnaires' disease, Pontiac fever, or as an asymptomatic infection. Legionnaires' disease manifests as pneumonia (Stout & Yu, 1997). Illness is often severe and can progress to respiratory and multi-organ failure, with a case-fatality rate of 11% to 25% (Marston et al., 1994; Stout & Yu, 1997). Pontiac fever is milder and characterized by fever, fatigue, myalgia, and headache, with or without cough (Tossa et al., 2006), and patients recover within two to five days without treatment. Individuals at increased risk of legionellosis include older adults, males, smokers, and those with underlying conditions, including immunosuppression, chronic lung disease, diabetes, and cancer (Marston et al., 1994; Stout & Yu, 1997).

Legionella bacteria occur naturally in freshwater and soil and multiply in environmental protozoa. They become a human health risk when they multiply in water between 25°C and 42°C, become aerosolized, and are inhaled into the lungs (Fields et al., 2002; WHO, 2007). Infection with *Legionella pneumophila* (which causes more than 70% of human infections) occurs through inhalation of aerosols from manufactured freshwater systems in homes or in the community (e.g., cooling towers, hot tubs, shower heads, fountains) (WHO, 2007). Transmission also occurs in care facilities due to a combination of inadequate design and/or maintenance of building infrastructure and risk factors present in the residents or patients (Silk et al., 2013). Infection with some species occurs through direct contact with, or via aerosolization of, contaminated soil or compost (WHO, 2007; Picard-Masson et al., 2016).

As an environmental bacterium, *Legionella* is sensitive to climatic factors. Legionellosis shows a marked seasonality, with higher incidence in the late summer and early fall (Simmering et al., 2017; Alarcon Falconi et al., 2018). It also shows regional differences, which may be associated with climatic factors (Beauté et al., 2016; Simmering et al., 2017). The most consistent and strongest climate association has been reported between legionellosis and precipitation. Several studies in North America, Asia, and Europe have found an increase in the risk of sporadic legionellosis following rainfall events (Fisman et al., 2005; Hicks et al., 2007; Garcia-Vidal et al., 2013). The increase occurs two to 11 days after rainfall (Fisman et al., 2005; Chen et al., 2014b; Beauté et al., 2016;) and has been associated with a 2.5 to 2.6-fold increase in incidence per 5 mm to 1 cm of rain (Hicks et al., 2007; Chen et al., 2014b) or 2.1 to 2.5-fold compared to periods with no rain (Fisman et al., 2005; Beauté et al., 2016). This may be because precipitation increases runoff and adds nutrients and protozoa to water sources, which can increase *Legionella* replication; it can also increase turbidity and organic matter, which decreases the effectiveness of water disinfection (Fisman et al., 2005).

In temperate zones, warmer temperatures have also been found to increase the risk of legionellosis (Fisman et al., 2005; Hicks et al., 2007; Conza et al., 2013; Halsby et al., 2014; Beauté et al., 2016; Simmering et al., 2017). An increase of 1°C has been associated with a 2.8% to 7% increase in risk (Fisman et al., 2005; Hicks et al., 2007; Conza et al., 2013), and the risk occurs after a lag of three to nine weeks (Halsby et al., 2014; Beauté et al., 2016). However, one study (Beauté et al., 2016) suggested that risk may decrease at higher temperature ranges (above 20°C). Finally, higher relative humidity and vapour pressure have been associated with legionellosis risk (Fisman et al., 2005; Conza et al., 2013; Gleason et al., 2016; Simmering et al., 2017). Higher humidity has been positively associated with legionellosis cases (Gleason et al., 2016). Simmering et al. (2017) found that temperature and humidity interact; the highest risk was between 16°C and 27°C and a relative humidity of more than 70%. In summary, the risk of legionellosis seems to increase following warmer, wetter weather (Chen et al., 2014a; Halsby et al., 2014), as warm, wet environments support *Legionella* growth and aerosolization.

Box 6.5 Effects of, and evidence for, climate change on the risk of infections from legionellosis

Expected effects of climate change:

No studies have directly assessed the impacts of climate change on legionellosis. However, given its known sensitivity to climate and weather, effects of climate change could be expected. An increased frequency of heavy precipitation events could increase the risk, while increases in temperature may increase outdoor activities by people and the use of aerosolizing water devices such as fountains and air conditioners, which are sources of *Legionella* infection (Sakamoto et al., 2009; Beauté et al., 2016). However, at a certain temperature threshold, it appears that risk may peak and begin to decrease (20°C) (Beauté et al., 2016). Extreme temperatures, combined with dry summers for some Canadian regions, may lead to a reduced risk of legionellosis.

Evidence of effects of climate change:

Legionellosis incidence has increased in many countries in the last two decades (Neil & Berkelman, 2008; Beauté, 2017; European Centre for Disease Prevention and Control, 2018). In Canada, the incidence increased more than six-fold, from 0.13 per 100,000 population in 2004 to 0.87 per 100,000 population in 2016 (Government of Canada, 2019d). While it is possible that recent climate change may have been a driver, other plausible causes include the widespread use of more sensitive diagnostic tests, an aging infrastructure, and an aging population (Beauté, 2017; Alarcon Falconi et al., 2018; European Centre for Disease Prevention and Control, 2018).

6.3.4.2 *Cryptococcus gattii* Infection

Cryptococcus gattii is an environmental fungus that causes infection in humans and multiple animal species (Chen et al., 2014b). *Cryptococcus gattii* occurs in soil and tree debris, but it can also be found in air, freshwater and saltwater, and on vehicles and fomites — objects or materials such as clothes, utensils, and furniture that can carry infection (Kidd et al., 2007a). Its spores are aerosolized from soil or trees and transported to other sites or inhaled by humans and animals (Kidd et al., 2007b). In humans, spores are inhaled into the lungs, where they cause pneumonia or pulmonary nodules. They may be disseminated through the bloodstream, particularly to the central nervous system, where they cause meningitis or brain nodules (Chen et al., 2014b) (Figure 6.7). The case-fatality rate is high, at 23% (Phillips et al., 2015). Individuals at higher risk of infection include those over 50 years of age, smokers, and people with chronic lung disease or immunocompromizing conditions or treatments (MacDougall et al., 2011).

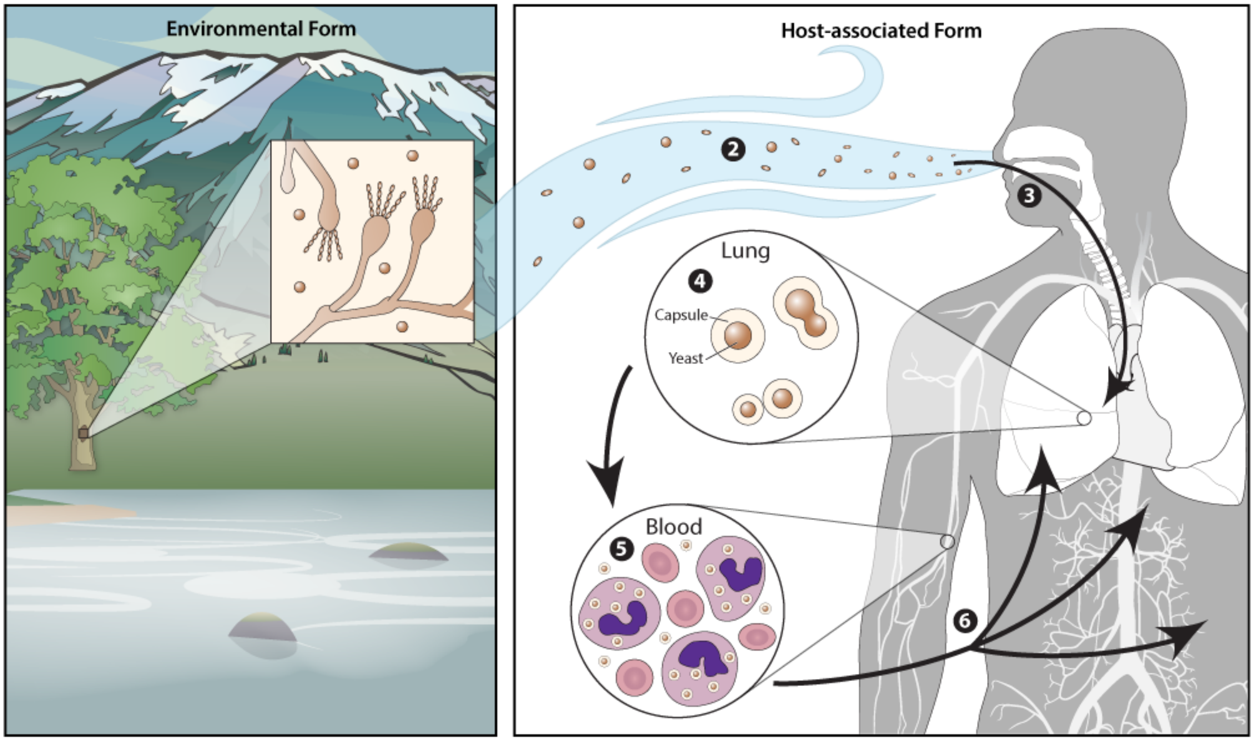


Figure 6.7 Biology of *Cryptococcus gatti*. *Cryptococcus gattii* lives as a yeast in the environment (1), usually in association with certain trees or soil around trees. Humans and animals can become infected with *C. gattii* after inhaling airborne, dehydrated yeast cells or spores (2), which travel through the respiratory tract and enter the lungs of the host (3). The small size of the yeast and/or spores allows them to become lodged deep in the lung tissue. The environment inside the host body signals *C. gattii* to transform into its yeast form, and the cells grow thick capsules to protect themselves (4). The yeasts then divide and multiply by budding. After infecting the lungs, *C. gattii* cells can travel through the bloodstream (5) — either on their own or within macrophage cells — to infect other areas of the body, typically the central nervous system (6). Source: US CDC, 2020.

Cryptococcus gattii is found worldwide. It first emerged in Canada on Vancouver Island in 1999, when it caused an outbreak among healthy animals and humans (Fyfe et al., 2008). Since then, incidence increased to reach a steady state of 0.2 to 0.5 cases per 100,000 population in British Columbia (BCCDC, 2019). Since 2004, the fungus has been found in the environment and in humans and animals on the British Columbia mainland and neighbouring Washington and Oregon states (MacDougall et al., 2007). It is unclear whether the range of *C. gattii* increased or whether *C. gattii* was already present in these regions (Roe et al., 2018). Very few locally acquired Canadian cases have been reported outside British Columbia, except for two human cases in Quebec in 2008 and 2015 (St-Pierre et al., 2018) and one case in a deer in Nova Scotia in 2014 (Overy et al., 2016).

As an environmental fungus, *C. gattii* is sensitive to climatic factors. Humidity, temperature, precipitation, evaporation, and solar radiation all affect the occurrence of *C. gattii* in the environment (Granados & Castañeda, 2006; Kidd et al., 2007b). An ecological niche model conducted in British Columbia described areas with environmental conditions supporting *C. gattii* establishment as those with low elevations, with a daily January average temperature of above 0°C, and within two coastal climatic zones of British Columbia, where winters are mild and wet and summers are warm and dry (Mak et al., 2010). Environmental sampling of *C. gattii* in British Columbia found that air sample concentrations were greatest during summer months with warm, dry conditions, and low relative humidity (Kidd et al., 2007b).

The response to climatic and other environmental factors has been inconsistent globally and may depend, in part, on where *C. gattii* is sampled (i.e., air, soil, or trees), on strain type, and on other factors. Wind increases aerosolization from the soil and enables spread (Uejio et al., 2015). Heavy rainfall or humidity may pull spores out of the air (Kidd et al., 2007b), although in most regions, *C. gattii* is more likely to be isolated from trees during the rainy season, suggesting it is more abundant at this time (Uejio et al., 2015). In British Columbia, higher temperatures decreased isolation from trees and concentration in soil, but in other parts of the world, the highest isolation frequency was during very high temperatures (Uejio et al., 2015). *Cryptococcus gattii* spores can withstand high levels of solar radiation, so summer conditions with high temperatures and high isolation are unlikely to preclude *C. gattii* survival (Rosas & Casadevall, 2006).

Box 6.6 Effects of, and evidence for, climate change on the risk of infections from *Cryptococcus gattii*

Expected effects of climate change:

Warming and increasing precipitation may increase the geographic range of *C. gattii* and the population exposed in Canada, given the association of this fungus with above-freezing temperatures and humid habitats. However, in areas where temperature becomes very high, the concentration of spores in the environment and risk to humans may decrease. Heavy precipitation events could decrease aerosolized spread and air concentrations, decreasing human risk. To date, no studies have directly assessed climate change impacts on *C. gattii* (Acheson et al., 2018).

Evidence of effects of climate change:

Because it was first described in tropical regions, it was thought that *C. gattii* was found only in tropical or subtropical climates (Kwon-Chung & Bennett, 1984) and that its emergence in British Columbia may have been associated with climate change. It is now believed that *C. gattii* originated in South America (Souto et al., 2016) and became widely distributed to multiple tropical and temperate areas in the years before and after it first appeared on Vancouver Island (Acheson et al., 2019). It is also now believed that *C. gattii* was introduced simultaneously into multiple areas of the northwestern coast of North America 60 to 100 years ago via human agency (Roe et al., 2018). Why it emerged as a human and animal pathogen in North America in the late 1990s remains unclear, but both climate and land-use changes are possible causes (Acheson et al., 2018). The more recent appearance of cases in Quebec and Nova Scotia could also have been facilitated by a changing climate, following introductions by human agency (Roe et al., 2018).

6.3.4.3 Blastomycosis

Blastomyces dermatitidis is a dimorphic fungus found in moist soil and decaying vegetation. Transmission occurs from the environment to humans and other animals through aerosolization and inhalation (Castillo et al., 2016). Spores inhaled into the lungs cause pulmonary blastomycosis, characterized by cough, fever, and shortness of breath (McBride et al., 2017). The yeast form may be disseminated through the blood to other organs, and cutaneous infection can occur from direct inoculation (Castillo et al., 2016). The case-fatality rate is high, at 5% to 20%, which may be associated with delayed diagnosis, particularly in less endemic areas (Crampton et al., 2002; Dalcin & Ahmed, 2015). The infection is treated with antifungals (Castillo et al., 2016). The incubation period is typically one to three months and cases mainly occur in immunocompromised individuals, smokers, and those with underlying diseases who are at higher risk of infection and mortality (Crampton et al., 2002; Dalcin & Ahmed, 2015; Castillo et al., 2016; McBride et al., 2017). Individuals are at increased risk of exposure through outdoor occupations and activities such as hunting and camping (Crampton et al., 2002). Most cases are sporadic, but activities that disrupt soil (e.g., construction, deforestation, outdoor activities) and exposure to riverbanks have been associated with point-source outbreaks (Baumgardner & Burdick, 1991; Proctor et al., 2002; Azar et al., 2015).

Blastomyces dermatitidis is endemic in certain parts of Canada, including Southern Saskatchewan, Manitoba, Ontario, and Southern Quebec (Crampton et al., 2002; Litvinov et al., 2013; Lohrenz et al., 2018). Blastomycosis is only reportable in Ontario and Manitoba and may be under-recognized in other parts of the country. It is hyperendemic in Northwest Ontario, characterized by persistent, high levels of disease occurrence. The Kenora, Ontario, area has the highest reported rates worldwide, with 35 hospitalizations per 100,000 population per year (Litvinjenko & Lunny, 2017; Brown et al., 2018). This endemic region is contiguous with endemic regions in US states that border the Mississippi and Ohio rivers, the Great Lakes, and St. Lawrence Seaway (McBride et al., 2017).

Blastomyces species are environmental fungi and therefore depend on climatic conditions for growth and dispersal. Specific ecological factors are poorly understood, in part because the organism has rarely been recovered from the environment, but moist soil near waterways and lakes seem to be the preferred niche for *Blastomyces* species fungi (Castillo et al., 2016). Soil disruption facilitates aerosolization (Baumgardner, 1997). It is hypothesized that proximity to waterways and drought followed by increased precipitation may help expose spores and facilitate their dispersal (McDonough et al., 1976; McTaggart et al., 2016). Although the peak onset for pulmonary infection is in the fall and winter, reflecting exposure during warmer weather (Morris et al., 2006; Light et al., 2008; Dalcin & Ahmed, 2015; Brown et al., 2018), few studies have specifically assessed the role of climatic factors and varying results have been reported. Baumgardner et al. (2011) found an association between total precipitation, temperature (low average temperatures during the season of infection, but high maximum temperatures the previous season), and canine cases. Seitz et al. (2015) found a higher risk of blastomycosis hospitalization with lower maximum temperature. Proctor et al. (2002) investigated an outbreak that followed a prolonged period of drought. Similarly, Pfister et al. (2011) found that moderate-to-severe drought, followed by above-normal precipitation and warming of yard waste, was associated with an outbreak in Wisconsin. Wind may be a factor, as some outbreaks have been associated with excavation dust (Baumgardner et al., 2011) or disruption of decomposing yard waste (Pfister et al., 2011). A Wisconsin ecological niche model found proximity to waterways and a summer vegetation index to be most predictive of the location of human and animal blastomycosis cases; bioclimatic factors did not play a significant role (Reed et al., 2008).

Box 6.7 Effects of, and evidence for, climate change on the risk of infections from blastomycosis

Expected effects of climate change:

Wetter winters and drier summers could provide conditions more conducive to the growth and dispersal of *Blastomyces* in currently endemic areas or new regions of Canada (Greer et al., 2008). However, there have been no studies to date to directly assess the impacts of climate change on *Blastomyces* infection.

Evidence of effects of climate change:

Blastomyces have been present in Canada for several decades and potentially longer (Kepron et al., 1972; Kane et al., 1983; St-Germain et al., 1993). In Northwestern Ontario, the incidence of blastomycosis increased between the late 1990s and the period from 2006 to 2015, from 17 cases to 35 cases per 100,000 (Litvinjenko & Lunny, 2017; Brown et al., 2018). The estimated incidence in Quebec also increased between 1988 and 2010, from approximately 4.4 to 10.3 cases per 100,000 (Litvinov et al., 2013). In Saskatchewan and Manitoba, animal cases increased from 1999 to 2001, but incidence plateaued from 2004 to 2010 (Davies et al., 2013). Climate change may have been a cause, but factors such as increased awareness and diagnosis, increased human exposure to endemic areas, changes in fungal pathogenicity or niche and land-use changes may have been involved. Interestingly, blastomycosis increased in Central Canada, and *C. gattii* emerged in Western Canada around the same time — in the late 1990s.

6.3.4.4 Histoplasmosis

Histoplasmosis is caused by the dimorphic fungus *Histoplasma capsulatum*. Spores grow in moist soil rich in bat or bird guano along waterways and in caves. Disruption of soil due to excavation and construction leads to aerosol generation and the risk of inhalation of spores. Infection develops seven to 14 days after exposure. It is often asymptomatic or causes self-limited illness with fever, headache, weakness, chest pain, and cough. It can lead to extrapulmonary infection and also cause more severe pulmonary infection in individuals with underlying lung conditions or immunocompromised individuals (Kauffman, 2007). *Histoplasma capsulatum* is endemic along the St. Lawrence and Great Lakes River Drainage Basins in Quebec and Ontario, the Ohio and Mississippi River valleys in the United States, and along waterways in Asia and South America. In Canada, the highest rate of diagnosed illness is in Quebec. In one study, 58 cases were identified as having occurred in Canada over three years (1992 to 1994), of which 72% were from Quebec (Nicolle et al., 1998). Cases in Alberta were first identified in 2003, and since then a small number are reported every year (Anderson et al., 2006; Alberta Health, 2018). The fungus is climatically sensitive, preferring moderate temperatures (18°C to 28°C), constant humidity, and low light (Teixeira et al., 2016).

Box 6.8 Effects of, and evidence for, climate change on the risk of infections from histoplasmosis

Expected effects of climate change:

Warming temperatures may increase the risk of histoplasmosis and other fungal diseases (Garcia-Solache & Casadevall, 2010), although there have been no formal studies to assess the effects of climate change.

Evidence of effects of climate change:

A change in geographic distribution of human outbreaks has been reported in the United States, with suitable environments expanding into the Missouri River basin, which may be due to recent climate change or changes to land use (Maiga et al., 2018). However, Ontario has not seen a change in incidence between 1990 and 2015 (Brown et al., 2018).

6.3.4.5 Coccidioidomycosis

Coccidioidomycosis is caused by *Coccidioides* species fungi, which are found in arid soil, including *C. immitis* found in California and *C. posadasii* found elsewhere (Maves & Crum-Cianflone, 2012). Spores are released into the air when soil is disturbed and can be inhaled by humans, causing coccidioidomycosis, also known as valley fever. The disease has an incubation period of one to three weeks, and many individuals remain asymptomatic or have mild symptoms. Approximately 40% develop pulmonary infection with cough, chest pain, dyspnea, and fever. This is usually self-limited and resolves within a few weeks. Disseminated infection occurs in 5% of individuals and leads to diffuse and chronic pulmonary illness, meningitis, or infection in other organs (Maves & Crum-Cianflone, 2012). This severe form requires prolonged antifungal treatment. Pregnant women and people with impaired cellular immunity, due to HIV infection or organ transplantation, are at higher risk of severe illness. Reactivation of latent disease is also possible (Maves & Crum-Cianflone, 2012). The geographic range of the fungus includes parts of South and Central America, Mexico, and the Southwestern United States (Maves & Crum-Cianflone, 2012). Certain areas of California and Arizona have the highest reported rates worldwide. Soil disruption, including construction, archaeological digs, earthquakes, and wind storms in endemic desert areas is the main source of exposure (Maves & Crum-Cianflone, 2012).

Coccidioides spp. are affected by climatic factors (Nguyen et al., 2013), requiring moisture to grow in soil and then a dry period to mature into spores that can be aerosolized (the "grow and blow" hypothesis) (Comrie & Glueck, 2007). The seasonal spike in human cases in the United States occurs mainly in the fall, after a period of rainy months followed by warm dry months. There is also a cyclical pattern, with incidence peaks approximately every two to five years, believed to be associated with droughts followed by rainy weather (Park et al., 2005; Tamerius & Comrie, 2011; Gorris et al., 2018). Warmer temperatures are associated with higher incidence in humans (Gorris et al., 2018), and incidence increases following large windstorms (Tong et al., 2017). However, regions with high mean annual precipitation or very moist soil (such as coastal regions) have a low incidence (Gorris et al., 2018).

Box 6.9 Effects of, and evidence for, climate change on the risk of infections from coccidioidomycosis

Expected effects of climate change:

Warmer temperatures could expand the range of *Coccidioides* into Canada, particularly into drier areas of Southern British Columbia. Wet winters and dry summers could provide conditions more conducive to growth and dispersal of *Coccidioides* in Canada. However, an earlier onset of the rainy season or heavier annual precipitation could decrease the risk. To date, there is no evidence of local transmission in Canada, although South-Central Washington state shares some ecological and climate characteristics with the Southern Okanagan Valley in British Columbia, 400 km to the north (Environmental Protection Agency, 2018). No studies have yet directly assessed the possible impacts of climate change on *Coccidioides* infection.

Evidence of effects of climate change:

In endemic areas of the United States, the incidence has increased from the early 1990s to recent years (Kirkland & Fierer, 1996; Sunenshine et al., 2007; Vugia et al., 2009). This has been attributed to population growth and construction in endemic areas, increased numbers of immunosuppressed persons, and improved awareness and diagnostic methods. However, there is evidence for northward range expansion toward the Canadian border, which may be related to climatic events; specifically, extensive droughts may have contributed to range expansion. It may also have been caused by increased human exposure due to increased population density (Litvintseva et al., 2015). In 2010–2011, three residents of South-Central Washington state who did not travel to known endemic areas were diagnosed with coccidioidomycosis (Marsden-Haug et al., 2013). Since then, 13 more locally acquired cases have been reported (Washington State Department of Health, 2021). Soil samples collected in 2010 and again in 2014 from this area identified *Coccidioides* with an identical genotype to index case samples (Marsden-Haug et al., 2013; Litvintseva et al., 2015). This is the most northerly location where *Coccidioides* has been found, again supporting the idea of northward range expansion.

6.4 Adaptation to Reduce Health Risks

Canada already has a robust public health system, which is networked with international public health organizations. Together, these systems contribute to infectious disease preparedness, surveillance, and monitoring and outbreak response. As infectious disease risks continue to grow in a changing climate, these activities will be increasingly important for adaptation success. Two streams of public health activities in the context of emerging and re-emerging infectious diseases are upstream preparedness and outbreak response. Within these streams, there are three key public health activities: risk assessment, to identify current and future risk; surveillance, for known risks or possible future emerging risks identified in risk assessments; and interventions, to prevent and control infectious diseases. These three activities are discussed individually, but, in practice, they should be highly connected; risk assessments guide rational implementation of surveillance activities, which, in turn, trigger interventions to protect the public when a hazard is detected (Figure 6.8).

Actions to protect health need to be robust and coordinated to address the increased risks from infectious diseases due to climate change. Furthermore, as many of the threats of emerging and re-emerging infectious diseases involve directly transmitted or vector-borne zoonoses, a One Health approach, which considers the interactions among human, animal, and environmental factors in disease transmission, emergence, and re-emergence, is required to develop effective responses (Ogden et al., 2017; Ogden et al., 2019).

In general, Canada and other high-income countries could be considered well-placed to respond to emerging and re-emerging infectious diseases through robust international institutions for surveillance and response, such as the WHO's International Health Regulations (IHR) (WHO, 2019c), the Global Outbreak Alert and Response Network (WHO, 2019d), as well as the health care system and public health institutions in Canada. The public health system in Canada centres around the Pan-Canadian Public Health Network (Pan-Canadian Public Health Network, 2016), a federal, provincial, and territorial partnership, with federal coordination by PHAC. This system is supported by high-quality academic institutions and industries in Canada that can facilitate innovation and responses to threats from emerging infectious diseases. Canada is a leader in the One Health approach in federal, provincial, and academic institutions, and the One Health approach is applied systematically in addressing these disease threats (Government of Canada, 2013; INSPQ, 2018a; CPHAZ, 2019; GREZOSP, 2019; Ogden et al., 2019). Despite this capacity, there are many unknowns ahead, and, as seen with COVID-19, even the best-prepared public health systems can be severely challenged by emerging infectious diseases.

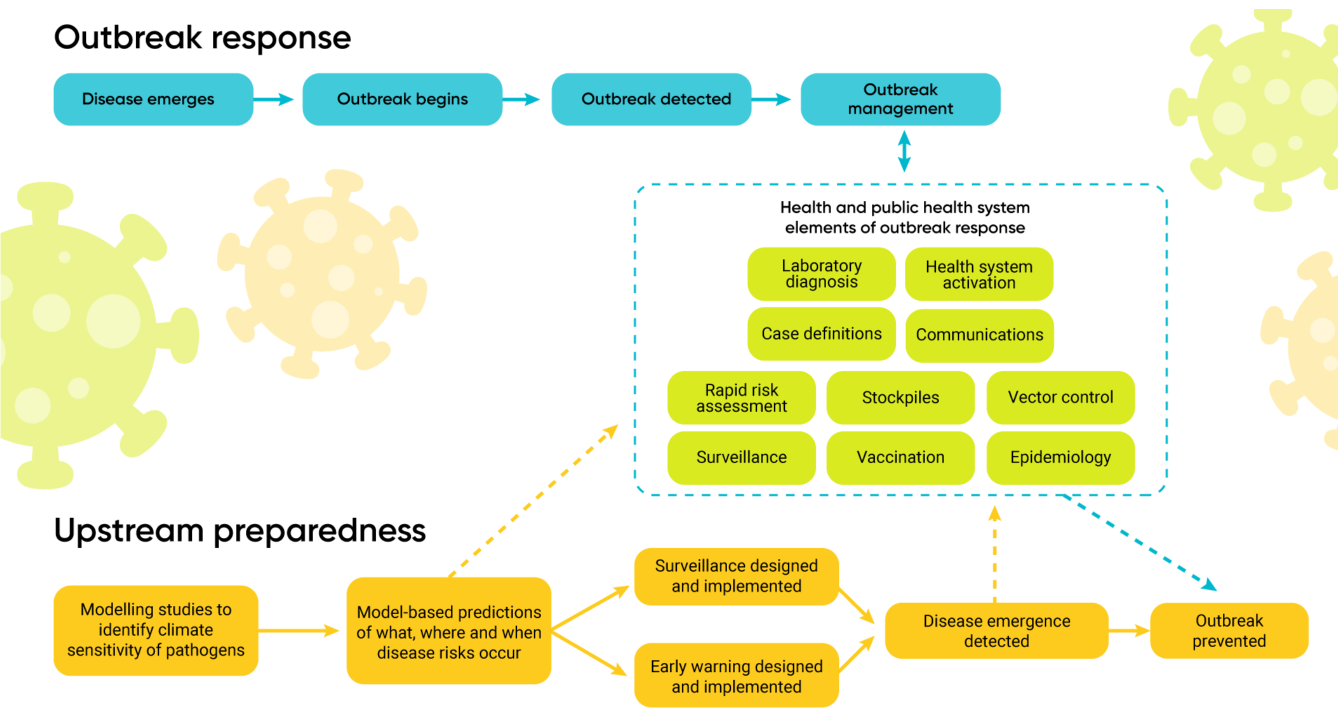


Figure 6.8 Two streams of public health actions to manage emerging and re-emerging infectious diseases. The blue boxes indicate outbreak response, and the orange boxes indicate upstream preparedness. Examples of activities that may be components of outbreak management are shown in the green boxes. Dashed lines indicate how outbreak response may be triggered by early detection of disease risk using an upstream preparedness approach.

Since the last national Canadian climate change and health assessment (Berry et al., 2014a), PHAC enhanced upstream preparedness for emerging and re-emerging vector-borne disease risks through an integrated program of adaptation, which comprises (Figure 6.8):

- prioritization of disease risks for study, now formalized in a multi-criteria decision analysis (MCDA) method (Ng et al., 2019);
- modelling studies to identify climate-disease risk associations and to project where and when diseases may emerge with climate change (Ng et al., 2019);
- implementation of surveillance programs to validate models and track emerging vector-borne diseases (Drebot, 2015; Ogden et al., 2014c); and
- development of synthesized knowledge (Hierlihy et al., 2019), disease forecasting (Ripoche et al., 2019), and risk communication tools (Figure 6.9) to support local efforts to adapt to increasing risks from vector-borne diseases.

6.4.1 Risk Assessment to Identify Current and Future Risks

6.4.1.1 Responsive Rapid Risk Assessments

Responsive rapid risk assessments (RRAs) are qualitative risk assessments developed in response to an immediate disease emergence event within Canada, or a perceived risk, such as an international disease event or threat, that requires rapid decision making. Responsive RRAs are developed using the scientific literature and knowledge of a disease at the moment in time that the disease emerges or re-emerges; they may be updated as knowledge increases in the light of the disease emergence event. They generally pre-date, and aim to guide, implementation of surveillance and/or intervention activities. Examples include those conducted in response to the threat of Zika virus in Canada nationally (Government of Canada, 2016) and provincially (INSPQ, 2016), as well as those developed by the European Centre for Disease Prevention and Control (ECDC) in response to a number of disease emergence events (ECDC, 2019). The World Health Organization has developed a protocol for their preparation (WHO, 2019e), which forms the basis for RRAs used in Canada. The capacity to perform RRAs in the face of disease emergence events is essential for public health officials in Canada to respond to unforeseen events, including those driven by climate change.

6.4.1.2 Predicting Future Populations at Risk, and Establishing Early Warning Systems, Through Quantitative Model-Based Risk Assessments

Quantitative risk assessments aim to predict where and when infectious diseases may emerge or re-emerge with a precision useful to public health officials in their efforts to prepare and respond to disease emergence with needed policies or programs. Risk assessments can be obtained using mathematical models that recreate the essential components of vector life cycles or disease transmission cycles, if there are sufficient quantitative data to calibrate these types of models. If not, statistical or ecological niche models can be used, providing there are surveillance data that include, at a minimum, information on presence, but preferably data on presence/absence and abundance, to calibrate them. In either case, the objective of the models is to assess where and when risk from climate-sensitive infectious diseases may change (i.e., they provide "early warning" of future disease risks). Predictive models are used for three main purposes (Ogden & Gachon, 2019):

- short-range forecasting of disease risks based on weather;
- long-range or seasonal forecasting based on climate; and
- projections of long-term effects of climate change on disease risks.

Models are developed by first identifying key associations between the presence of vectors and/or pathogens and weather (for short-term forecasting) or climatic variables, while accounting for important climate-independent determinants of their presence, which may include other environmental changes such as land-use change (Patz et al., 2003). Validation of deduced associations against real data is important to provide confidence in the use of model outputs. Once associations between climate and the occurrence of pathogens/vectors have been identified and quantified, the impacts of projected climate change, obtained from regional and global climate models, on pathogen/vector distributions and risk can be estimated.

Forecasting provides early warning of impending weather-driven disease outbreaks. This can include short-range forecasting on a time scale of days to weeks and long-range forecasting on a time scale of several months that can be used to implement prevention and control activities (Morin et al., 2018). The model-based assessments of the effects of climate change provide assessments of where and when diseases may emerge or re-emerge in coming decades, which are used in a number of contexts (Ogden et al., 2014c):

- high-level national policy decisions on whether and when public health preparedness for emerging risks may be needed (Centre for Food-borne, Environmental and Zoonotic Infectious Diseases, 2017);
- provincial, territorial, and municipal assessments of vulnerability to the health impacts of climate change and of needed adaptation measures (Berry et al., 2014b); and
- design and implementation of surveillance (Ogden et al., 2014).

As discussed earlier in this chapter, a number of model-based risk assessments have been conducted for Canada, including those for Lyme disease (Ogden et al., 2006; Ogden et al., 2014), relapsing fever (Sage et al., 2017), *Dermacentor variabilis* ticks (Minigan et al., 2018), exotic mosquito-borne diseases and their vectors (Ogden et al., 2014a; Ng et al., 2017), and WNV (Hongoh et al., 2012; Chen et al., 2013).

6.4.2 Prioritization

Since they were identified as an important methodological need by Charron et al. (2008) and by the WHO (WHO, 2019g), a number of MCDA methods have been explored to prioritize diseases for attention, based upon their public health importance, including their risk of emergence or re-emergence due to climate change (Ng & Sargeant, 2012; Cox et al., 2013). These types of methods have been adopted and occasionally adapted for disease prioritization at both federal (Otten et al., 2019) and provincial levels (INSPQ, 2018b), although not as yet by all jurisdictions in Canada.

6.4.3 Surveillance for Known Risks or Possible Future Risks

There are two types of surveillance to identify emerging infectious diseases to inform outbreak management. The first is vigilance for international disease emergence events, and the second is disease-specific surveillance, to be implemented once a disease is recognized as a significant public health risk for Canadians. The possible impact of climate change on increasing infectious disease emergence and re-emergence events globally, and on increasing dispersion of the disease agents through travel, trade, and migration, increases the need for effective vigilance for emerging infectious disease events in other countries. International efforts that support this type of surveillance include the IHR, under which all WHO member states are obliged to undertake surveillance for disease emergence events and to report any that are identified. In addition, as part of the global One Health initiative, the Food and Agriculture Organization, World Organization for Animal Health, and the WHO collaborate in the Global Early Warning System, which is a warning system for emerging disease threats at the human–animal–ecosystems interface. International "passive" surveillance programs include the GeoSentinel Surveillance Network, an international network of voluntarily participating medical clinics, and surveillance systems that scrutinize publicly available web content for signals of potential emerging threats. These include the Program for Monitoring Emerging Diseases (ProMed), HealthMap, and MediSys, as well as Canada's own Global Public Health Intelligence Network (GPHIN), operated by PHAC (Ogden et al., 2017).

In Canada, a number of methods are available and used for the surveillance of endemic and emerging infectious diseases, to follow trends in incidence, identify the spatiotemporal distribution and spread of cases (including clusters) and risk, and identify risk factors in the affected population. The standard method for acquiring data on human disease cases nationally is through the National Notifiable Disease Surveillance System, coordinated by PHAC (Government of Canada, 2019e). Some diseases that are not nationally notifiable may be notifiable at provincial and territorial levels. These notifiable diseases are identified using clinical and laboratory case definition criteria, and emergence or re-emergence (nationally or internationally) is one criterion. Other criteria for adding diseases to the list include diseases under international surveillance, considerations of incidence in Canada, severity, communicability, potential for outbreaks, socio-economic burden, preventability, risk perception, and necessity for public health response (Public Health Agency of Canada, 2009).

Other methods of capturing information on possible human disease cases during emergence events include syndromic surveillance; for example, the use of real-time data from pharmacies on sales of influenza remedies were used to track the evolution of pandemic H1N1 influenza in Canada in 2009 (Muchaal et al., 2015). Another method is passive laboratory-based surveillance. In response to possible increasing risks from arboviruses in Canada, PHAC's National Microbiology Laboratory instigated surveillance for human cases of non-WNV arboviruses by routinely taking sera submitted for WNV testing that were WNV-negative, and testing them for a panel of endemic and exotic arboviruses (Drebot, 2015). The Pan-Canadian Public Health Network has the capacity to instigate national human case surveillance for limited periods during disease emergence events. It recently used this capacity in response to the COVID-19 pandemic and to the the Zika outbreak in

Central and South America in 2015–2016, which infected more than 500 Canadian travellers (Government of Canada, 2019f).

There has been much effort in Canada to use surveillance in sentinel animals and vectors to detect risks from emerging vector-borne zoonoses, particularly WNV, Lyme disease, and other *Ixodes* species-transmitted pathogens, as a method of early warning of the spread of emerging diseases, and, for WNV, of impending outbreaks (Thomas-Bachli et al., 2015). For vector-borne diseases, vector surveillance includes active surveillance to capture vector mosquitoes, which are then tested for mosquito-borne pathogens, particularly WNV, which is carried out routinely in many jurisdictions in Canada (Government of Canada, 2019a). It also includes the collection of ticks by drag sampling, the capture of tick hosts, and the testing of ticks and hosts for tick-borne pathogens (Ogden et al., 2014). Passive surveillance for ticks, involving submission of ticks from the patients of medical and veterinary clinics, has been a key surveillance activity in Canada, providing a uniquely long dataset that has supported attribution of *I. scapularis* range expansion in Canada to impacts of climate change (Leighton et al., 2012).

For both mosquitoes and ticks, the surveillance for vectors is capable of capturing multiple species of vectors and pathogens. Mosquito surveillance targeting WNV has identified incursions of exotic *Aedes* spp. vectors in Southern Ontario, which are vectors of dengue virus and Zika virus (Windsor-Essex County Health Unit, 2019a, Windsor-Essex County Health Unit, 2019b). Tick surveillance is undertaken predominantly by two methods: passive tick surveillance, involving submission of ticks that members of the public found on themselves or their pets via participating veterinary and medical practices; and active tick surveillance, through collecting host-seeking ticks by dragging a flannel across the ground (drag sampling), or through examining captured wild rodents (Ogden et al., 2014c). These forms of tick surveillance were originally designed to identify risk from Lyme disease, but can detect risk from other species of tick vectors of disease (Gabriele-Rivet et al., 2015; Nelder et al., 2019). Ticks from both types of surveillance are routinely tested for a wide range of pathogens, in addition to the bacteria causing Lyme disease (Dibernardo et al., 2014). In Canada, most ticks collected through surveillance are currently identified to species in provincial laboratories, and then tested for pathogens at the National Microbiology Laboratory. However, this method will not be sustainable once ticks become more widespread, given the expected and observed (Gasmi et al., 2018) large increase in the number of tick submissions across Canada. New and less resource-intensive surveillance systems are needed to protect Canadians from the increasing risks of these diseases.

A citizen science project called eTick was launched in 2014. It is a web-based platform that allows members of the public to submit images of ticks for species identification by an entomologist (eTick, 2019). It greatly expands the potential geographical coverage of tick monitoring, in addition to providing an opportunity to deliver timely public health information directly to the population exposed to ticks. It allows for the real-time monitoring and mapping of various tick species, including changes in distribution. The program is currently available in Quebec, Ontario, and New Brunswick. In Manitoba, an image-identification system called the Tick Checker, which is similar to eTick, was implemented in 2017 (Government of Manitoba, 2019a). This effort is part of Manitoba's black-legged tick passive surveillance program, which identifies locations where new tick populations and Lyme disease risk may be emerging, before confirmation by active tick surveillance (Government of Manitoba, 2018).

Livestock health organizations, such as the Canadian Food Inspection Agency, track some zoonoses in sentinel animals (for example, EEEV in horses) when they fall within the mandate of these organizations (Government of Canada, 2018c). Wildlife health organizations, such as the Canadian Wildlife Health Cooperative, assist in tracking some wildlife-borne zoonoses in sentinel animals (CWHC, 2019).

6.4.4 Interventions to Prevent and Control Disease Incidence

International responses to emerging infectious disease outbreaks are mandated under the IHR through the Global Outbreak Alert and Response Network (GOARN) (WHO, 2019d). This network brings together technical and operational resources from relevant institutions in WHO member states, including surveillance initiatives, networks of laboratories, United Nations organizations (e.g., UNICEF, UNHCR), the Red Cross, and international humanitarian non-governmental organizations, such as Médecins sans frontières. The network has the capacity to assemble and deploy technical teams to countries affected by outbreaks to assist with coordination, clinical disease management, epidemiological analysis, as well as logistics and communications that are needed to control outbreaks. PHAC is the lead for Canada's extensive participation in GOARN. The agency was created in 2004, in part to ensure and enhance national coordination of responses to emerging infectious diseases through the Pan-Canadian Public Health Network and to participate in the IHR and GOARN.

A key capacity for reducing risks to Canadians from outbreaks is the health care system and its ability to identify human disease cases and treat them. Diagnosis and treatment of cases reduces transmission and contributes to controlling outbreaks. However, this requires vigilance by front-line health care workers; in some outbreaks, health care facilities can become a focus for transmission, as occurred during the SARS outbreak in Canada (Varia et al., 2003). Increasing antimicrobial and antiviral drug resistance challenge the capacity of health care systems to treat emerging diseases (WHO, 2019f).

Canada's technological capacity to prevent and control infectious diseases is well developed. The Federal/Provincial/Territorial Canadian Public Health Laboratory Network, supported by PHAC's National Microbiology Laboratory, which is one of only seven level-4 containment facilities in North America, has the capacity to develop, improve, and implement diagnostic tests for emerging infectious diseases such as Zika virus (Safronetz et al., 2017). The global network of public health organizations and pharmaceutical industries are capable of developing vaccines in response to outbreaks (Carlsen & Glenton, 2016; Henao-Restrepo et al., 2017). The WHO has developed a list of priority pathogens for which vaccines are urgently needed; several of these diseases are zoonoses with the potential for person-to-person spread, and emergence risk may be enhanced by climate change. However, the time it takes to develop vaccines, and to assess them for safety and efficacy to ensure their public acceptability (Carlsen & Glenton, 2016), emphasizes the need for upstream preparedness rather than simply relying on vaccine development to manage outbreaks. While there is much capacity for vaccine discovery in Canada (Plummer & Jones, 2017), the COVID-19 pandemic has highlighted the lack of Canadian capacity for vaccine manufacture.

Other technological adaptations are important for current and future vector-borne disease control in Canada. For mosquito-borne diseases, such as WNV, mosquito control methods are effective mainstay methods; these include killing larvae in their aquatic habitat (larviciding) using non-chemical biological control agents such *Bacillus thuringiensis israelensis*, and killing adult mosquitoes (adulticiding) using chemical sprays such as deltamethrin (Reisen & Brault, 2007). For tick-borne diseases, such as Lyme disease, vector control methods, such as area-wide spraying with acaricides, remain unlicensed, and thus unavailable, or at an experimental stage of development in Canada (Ogden et al., 2015). Personal protection measures remain the most effective of control of vector-borne diseases, and these include insect repellents, which prevent tick bites, insecticide (permethrin)-treated clothing, and prompt removal of feeding ticks from the body to prevent transmission of *B. burgdorferi* (Ogden et al., 2015). For these measures to be effective, the public needs to understand the risks, perceive them to be worth acting on, know what protective actions to take, and be willing to take them. In turn, this requires effective communications from public health organizations at all levels, which is an increasingly difficult task because misinformation, particularly from the internet, is an increasing problem (Greenberg et al., 2017). As well as communicating information about personal disease protection in Canada, information for travellers will become increasingly important. This will help prevent them from introducing infections upon returning to Canada, particularly exotic vector-borne diseases, which may be increasingly likely to be autochthonously transmitted in this country under climate change (Berrang-Ford et al., 2009).

6.4.5 Adaptation Challenges for Communities and Members of Society at Increased Risk

Vulnerability to infectious disease health risks related to climate change is complex and determined by a number of factors that interact to influence an individual's exposure, sensitivity, and adaptive capacity. While all Canadians are vulnerable to climate change, the experiences of impacts and risks are not uniform, and some individuals and communities will be disproportionately affected (see Chapter 9: Climate Change and Health Equity). Existing health inequities, and variations in the status of determinants of health, in combination with exposure (e.g., geographic location) and genetic and biological factors, can increase or decrease climate change vulnerability. There are existing knowledge gaps regarding the combination of variables that enhance vulnerability to infectious disease risks related to climate change. However, it is expected that individuals with determinants of ill health (e.g., low income, living in substandard housing, food-insecure) are more likely to experience disproportionate impacts and have limited ability to take protective measures. For example, in general, poorer health status is associated with lower socio-economic status, which, in turn, is associated with higher rates of unhealthy behaviours and dietary habits (Hajizadeh et al., 2016) that lead to higher rates of chronic diseases (Roberts et al., 2015) and can increase health risks associated with infectious diseases related to climate change.

In Canada, First Nations, Inuit, and Métis peoples experience lasting, systemic health inequities, which are associated with a legacy of colonization and intergenerational trauma (PHAC, 2019). They experience significantly higher rates of infectious diseases compared to non-Indigenous populations, which increases their risk of climate change-related infectious diseases (Adekoya et al., 2015). While greater sensitivity to infectious diseases, which may be due to genetic factors or high rates of chronic co-morbidities (Badawi et al., 2018), have been observed (e.g., genetic susceptibility to H1N1 influenza), existing health inequities, such as limited availability and accessibility of acceptable health care services, overcrowded housing, and lack of culturally relevant disease-prevention information (National Collaborating Centre for Aboriginal Health,

2016) can compound vulnerability (see Chapter 9: Climate Change and Health Equity). In addition, First Nations, Inuit, and Métis peoples may be at increased risk of exposure due to a strong reliance on traditionally harvested foods and land-based activities, such as hunting. For example, outbreaks of trichinellosis have been associated with the consumption of marine mammals in Arctic regions (Yansouni et al., 2016), and a rise in the abundance of mosquitoes, ticks, and other biting insects that have the potential to transmit new vector-borne diseases is of increasing concern (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Geographic location may also increase exposure; for example, risk of exposure to Arctic fox rabies is higher for Arctic communities.

Policies to address these underlying causes of vulnerability are generally not within the mandate of public health organizations (Adler & Newman, 2002); however, there is increasing recognition in the public health field that climate change will exacerbate health inequities (Friel, 2019). Efforts to strengthen determinants of health should be combined with climate change and health activities (e.g., adaptation measures) (see Chapter 9: Climate Change and Health Equity).

6.4.6 Adaptation Gaps and Opportunities

6.4.6.1 Adaptation Gaps

Prioritizing adaptation options to manage infectious disease risks from climate change in Canada should take into consideration multiple criteria, including the immediacy and level of the risks, the technical viability of the options, human and financial resources, compatibility with current policies, and other constraints (Ebi et al., 2006a; Ebi et al., 2006b). For many of the infectious disease risks associated with climate change discussed in this chapter, surveillance, monitoring, and disease control will only be successful with local action, so enabling local public health and health care systems to undertake these activities will be important in enhancing resilience to these threats. In a review of national-level adaptation planning for climate change impacts on infectious diseases in 14 Organization for Economic Co-operation and Development member nations, a number of limitations to current planning were observed. These included negligible consideration of the needs of population groups that experience disproportionate impacts, limited engagement at local government levels to assess health risks, and inadequate logistics and support related to funding, timelines for assessments, and development of adaptation plans (Panic & Ford, 2013). The report highlighted that these limitations need to be addressed in Canadian adaptation plans. Post-pandemic evaluation of Canadian public health responses to COVID-19 will likely be highly informative of the current adaptive capacity gaps.

In addition, adaptation to climate-related infectious diseases is constrained by existing research gaps. For many climate-related infectious diseases, there is a lack of knowledge of their ecology, little surveillance data for calibration of statistical/ecological niche models and for validation of predictive models, and a lack of long-term monitoring that is required to attribute changes in disease risk to climate change (Ebi et al., 2017). Effective control of tick-borne diseases in the environment is particularly difficult, and research is needed in this field. Knowledge and research gaps are being identified using scoping and systematic reviews about specific vector-borne disease risks prioritized by MCDA methods (Otten et al., 2019).

A significant challenge in protecting the health of Canadians is that, globally, the capacity to control vectors is diminishing because of increasing resistance against insecticides. However, techniques such as the introduction of genetically modified mosquitoes that control populations by producing non-viable offspring, and mosquitoes carrying *Wolbachia* bacteria in their guts, rendering them incompetent as vectors, are a focus of research. These techniques may become available to public health officials in the near future.

6.4.6.2 Adaptation Opportunities

Existing information on the ecology and epidemiology of vector-borne diseases that threaten Canadians (Corrin et al., 2018), as well as prevention and control methods and their efficacy (Hierlihy et al., 2019), are being provided to public health officials at all levels of government to assist in developing response plans. The expected increased epidemic behaviour of mosquito-borne diseases such as WNV and EEEV means that weather-based forecasting of disease risk, as recommended by the IPCC, would be helpful for use in early warning systems. Much progress has been made to develop methods for weather-based forecasting for WNV, but implementation in Canadian public health programs will require further work (Ogden et al., 2019).

The increasing possibility of autochthonous transmission of exotic diseases poses a challenge for public health activities and the Canadian health care system. Since exotic diseases have been absent in Canada, health professionals have screened them out as possible diagnoses in patients without a history of travel to well-known endemic areas. An increase in modelling of disease risks will enhance preparedness for disease emergence events, and greater surveillance of new non-endemic infectious diseases among patients seeking care would be prudent.

Similarly, enhanced surveillance is required for vector-borne diseases that are currently exotic to North America but could be carried into Canada by travellers, those that are absent from Canada but could expand northward into Canada from the United States, and those that are Canada-endemic and may re-emerge in the form of outbreaks. Education of health care providers about these possible new emerging diseases in Canada will be important for early diagnosis and treatment from the perspective of affected individuals, but also for early detection of outbreaks from a public health perspective. Citizen-based approaches to surveillance, such as the eTick program (eTick, 2019), are also an increasingly recognized opportunity. These approaches could also be enhanced by Indigenous knowledge and observation (Tomaselli et al., 2017; Henri et al., 2018).

There are opportunities to employ “big data” and technologies such as artificial intelligence (AI) that help analyze big data to address growing risks to health from infectious diseases. The first big data source that is being used in this regard is modern genomics. Whole genome sequencing (WGS) is now mainstreamed in Canadian enteric disease surveillance through PulseNet, as it is in the United States and Europe. PulseNet allows for more sensitive detection of disease clusters and outbreaks and greater capacity to reliably attribute sources of infection (Gilmour et al., 2013). The immense size of the data generated by WGS means that complex bioinformatics analysis methods have had to be developed for timely analysis of the data (IRIDA, 2019). Application of WGS to other applications in infectious disease diagnosis and surveillance, and further development of molecular epidemiology to make full use of the data, will continue and will support more robust efforts to tackle these risks. Metagenomic and meta-barcoding methods, which allow the identification of the range of species present in complex mixed-species samples, lend themselves to widened surveillance of mosquitoes and mosquito-borne diseases, including exotic mosquitoes and pathogens. Through these methods, the range of mosquito species and mosquito-borne pathogens, rather than simply WNV, is identified in mosquito-trap captures obtained during mosquito surveillance. These methods may also revolutionize the detection of pathogens in other environmental DNA samples from drinking and recreational water and from soil.

The second big data source is web media and social media, obtained by web crawling methods (Mukhi et al., 2016). This source can provide early signals of disease emergence events to enhance management efforts by organizations such as GPHIN. The third big data source is Earth observation data obtained by satellites. Earth observation data provide proxies for environmental data such as weather, climate, habitats, and land use, which can be used in risk modelling to identify where there are risks of emergence and re-emergence of environmentally sensitive diseases (Ceccato et al., 2018). There are many examples of Earth observation data being used to identify disease risk (particularly Lyme disease) in Canada, in the form of static risk maps (Figure 6.9). Earth observation data are becoming increasingly “big” due to an increase in the numbers and types of satellites, with data at increasingly fine spatial resolution. In the near future, a higher frequency of images may allow for real-time identification of risks from vector-borne diseases such as WNV. At least theoretically, Earth observation data, synthesized by risk modelling to produce risk information could replace surveillance as a way to trigger public health responses well in advance of human cases of disease (Ogden et al., 2019).

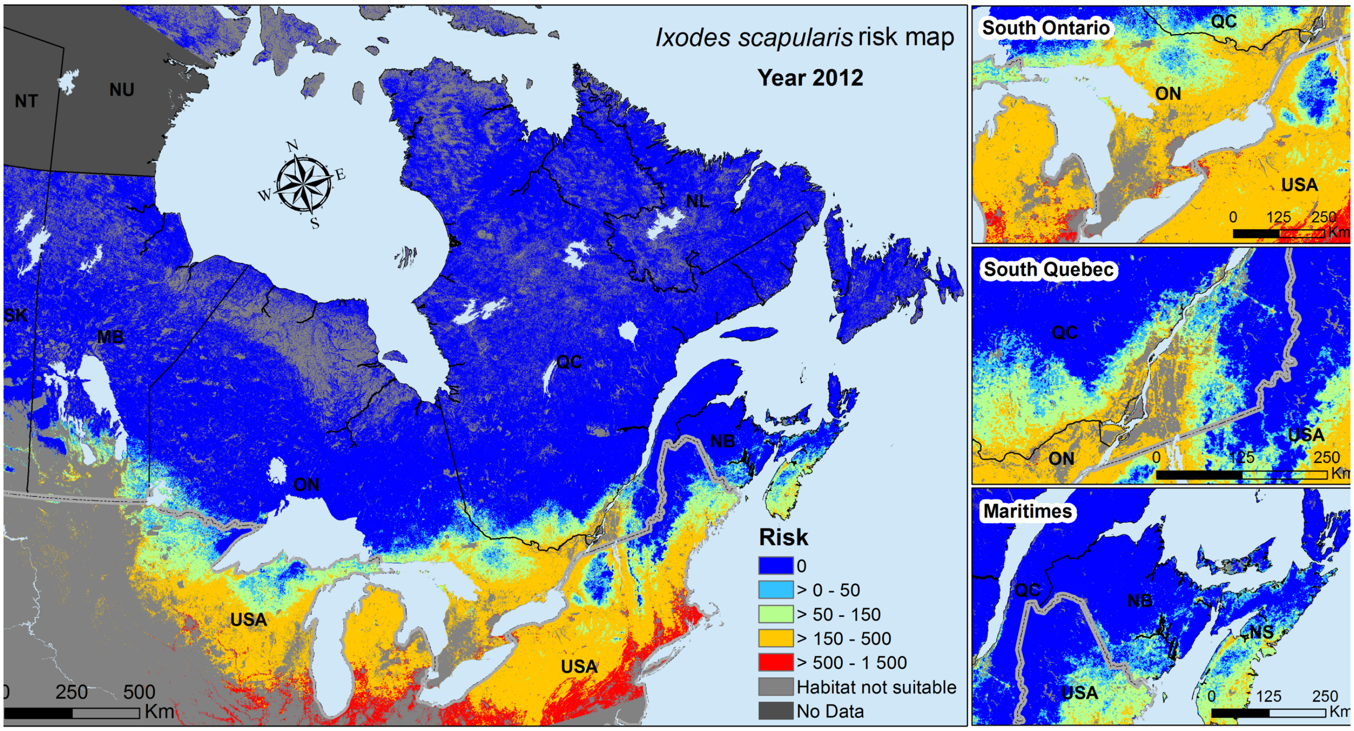


Figure 6.9 Risk maps for Lyme disease in Eastern Canada based on the risk of *Ixodes scapularis* populations, using Earth observation data on climatic and habitat suitability. These risk maps measure the environmental suitability for the tick vector of Lyme disease *Ixodes scapularis* in Eastern and Central Canada using Earth observation data proxies for temperature (annual cumulative degree-days above 0°C) and woodland habitat. The environmental suitability is zero where there is no woodland habitat (lighter grey areas) and where the climate is too cold (dark blue areas). In areas of woodland habitat, and where climate is warm enough, risk of occurrence of tick populations varies from low risk (pale blue areas) through moderate, moderate-high, and high-risk areas (represented by green, orange, and red areas, respectively). The scale of suitability for the tick according to temperature conditions (with values from 0 to 1500) is obtained from a mathematical model of *I. scapularis* populations. Earth observation data for this map were not available for parts of Nunavut and the Northwest Territories (shown by dark grey areas). Source: Kotchi et al., 2019.

There has been much work done to identify and quantify the effects of weather on mosquito vectors of WNV and on WNV risk in Canada (see section 6.3.1.3 Canada-Endemic Mosquito-Borne Diseases), which would serve as a basis for developing forecasting of WNV outbreaks. Combining weather data and Earth observation data on habitat in predictive models in geographic information systems would allow forecasting at high spatiotemporal resolution.

Many of the challenges posed by emerging vectors and diseases that threaten public health in the context of climate change are shared by other disciplines, such as agriculture (including both plant and animal health), environment and biodiversity management, and natural resources, where species invasions (infectious or otherwise) will likely be driven by climate change, among other factors. Collaboration on risk assessment, surveillance, and management activities through a robust One Health approach may convey significant advantages over the siloed management of sector-specific risks (Ogden et al., 2019). This will require more systematic collaboration between disciplines and government departments, who are all dealing with the emergence of threats to health (human, animal, and environment) associated with climate change.

6.5 Knowledge Gaps

Existing knowledge gaps related to the impact of climate change on infectious diseases in Canada hinder development of local and regional climate change and health vulnerability assessments and adaptation plans. They also thwart the ability of public health officials to detect infectious disease emergence and re-emergence, and to prevent and control such emergence. The key gaps are described below.

Greater knowledge is needed of the ecology and epidemiology of infectious diseases and arthropod vectors to support development of risk assessments and early warning systems. In addition, systematic surveillance of human cases, arthropod vectors, infected sentinel animals, and environmental samples, as well as use of citizen science methods, at useful spatiotemporal scales is needed to identify emerging diseases and vectors. While this is happening already to some extent, surveillance methods, such as metagenomics, that detect multiple, possibly emerging pathogens and vectors, are needed to move from surveillance targeting a single disease to programs that address broad ranges of pathogens and vectors that threaten Canadians. Infectious disease diagnostic methods and algorithms need to be developed so that diseases currently considered exotic to Canada are detected more readily in Canadians who have not travelled to countries where these diseases are historically known to occur. Surveillance should be long-term to support attribution of the effects of climate change.

There is a wide range of infectious diseases for which sensitivity to weather and climate is known, yet, for many of these, the possible impacts of climate change have not been assessed. In Canada, assessments that have been completed have focused on vector-borne diseases. The methods used for vector-borne diseases need to be applied to a wider range of infectious diseases, including human-to-human-transmitted diseases, and wind/airborne infectious diseases from environmental sources.

To attribute emergence and re-emergence of infectious diseases in Canada to climate change, information is required that supports analysis of statistical strength of association, consistency among studies, specificity of effects of climate, temporally appropriate timescales of climate change and disease emergence, biological gradient (greater effects of greater changes in climate), and plausibility (Hill, 1965).

There need to be greater linkages between the public health efforts to understand and respond to infectious and chronic diseases. It is increasingly recognized that infectious diseases can result in chronic illnesses (O'Connor et al., 2006), and that infectious diseases are more severe in those affected by chronic illnesses (Badawi et al., 2018). In addition, socio-economic status affects vulnerability to both infectious and chronic diseases as well as perceptions of risk, and knowledge of and willingness to use protective measures (Bouchard et al., 2018). The changing age demographic in Canada, as in other high-income countries, coupled with increasing incidence of chronic diseases in these populations (Dye, 2014), and the anticipated effects of climate change on both infectious and chronic diseases, mean that public health officials and researchers need to understand, consider, and respond to the impacts of climate change on these diseases in a coordinated fashion.

There are considerable gaps in Canada's capacity to prevent and control vector-borne diseases. These gaps include a limited knowledge of a range of effective measures to control vectors in the environment and for people to protect themselves, as well as a lack of established protocols for vector-borne disease control programs for front-line public health responders. The need for innovation in prevention and control is highlighted by the increasing global challenges of antimicrobial resistance and resistance to insecticides.

Validation of early warning systems (Morin et al., 2018) is needed for those infectious diseases, such as mosquito-borne diseases, that may become more epidemic with climate change and that threaten Canada with rapid spread following introduction, as happened with WNV. In addition, Canadian communities at municipal and provincial or territorial levels require comprehensive assessments of vulnerability to the effects of climate change on all aspects of health, such as heat-related illnesses and deaths, chronic diseases, and risks from infectious diseases. These assessments are the first step to reducing future disease risks, as well as identifying knowledge and public health system gaps that need filling by investment and/or research (see Chapter 10: Health Sector Adaptation and Resilience).

Addressing existing knowledge gaps to support effective adaptation requires direct, well-planned, collaboration with public health and health end users (Nyström et al., 2018). Collaborations, such as that established between PHAC and Université de Montréal in their Groupe de recherche en épidémiologie des zoonoses et santé publique, would accelerate capacity to innovate and respond to emerging disease threats (GREZOSP, 2019). However, such collaborations require long-term investment; alignment of goals and objectives between partners; mutual skill, respect and trust; and geographical proximity to succeed (Rycroft-Malone et al., 2015).

6.6 Conclusion

Since the first comprehensive Canadian assessment of climate change and health vulnerability and adaptation was published in 2008, there has been considerable effort to assess risks from emerging diseases (particularly vector-borne diseases), implement surveillance, and disseminate information on effective prevention and control to public health professionals and the public. Since that time, the tick vector of Lyme disease has spread into Canada, as projected, and carried with it the rapid emergence of Lyme and other tick-borne diseases. EEEV has also expanded its range into Canada, an outbreak of WNV occurred in Eastern Canada, and the mosquito species *Ae. albopictus* has become established in Southern Ontario. These events demonstrate increasing risks of northward spread of vectors and vector-borne diseases from the United States and of weather-driven epidemics of endemic mosquito-borne diseases, as identified in the 2008 assessment. They also highlight the reality of vector-borne disease emergence and re-emergence driven by climate change.

The emergence of, first, chikungunya virus infection and, then, Zika virus in the Americas has also increased concern among public health officials in and outside Canada of the risks associated with the spread of exotic diseases from far away and their introduction and endemic transmission. Whether these disease emergence events were driven by climate change, in whole or in part, has been the subject of debate (Paz & Semenza, 2016). Either way, the identification in Southern Ontario of populations of *Ae. albopictus*, a vector of both these diseases, means that the possibility of autochthonous transmission of exotic diseases in Canada is now more than speculation. Evidence presented in this chapter suggests that the most important exotic vector-borne diseases that could emerge in Canada by long-distance dispersal include dengue and Rift Valley fever. In addition, although plague and directly transmitted zoonoses such as hantavirus were identified as climate-sensitive diseases in the 2008 assessment, there have been no major emergence or re-emergence events associated with these diseases since that time. However, there have also been no efforts to further explore possible future effects of climate change on these pathogens.

Climate change and weather may increase risks from human-to-human-transmitted infectious diseases and airborne infectious diseases from environmental sources. Outbreaks or emergence events of these climate-sensitive diseases, such as acute flaccid paralysis and blastomycosis, have occurred in Canada or North America generally (Trudel et al., 2014; Elrick et al., 2019). Therefore, more research on the possible effects of climate change on these diseases is warranted.

Similar to other high-income countries, the adaptive capacity in Canada to manage emerging and re-emerging infectious disease risks is considered strong. This is due to the combined contribution of international and national public health systems, as well as robust health care services and technological capacity. Nevertheless, knowledge gaps and gaps in public health activities remain. These include the need for further risk assessments of the effects of climate change on infectious diseases; more systematic vulnerability assessments by municipalities, provinces, and territories; enhancements to surveillance, including long-term surveillance programs to monitor effects of climate change; and greater capacity for prevention and control. These gaps can be filled only by increased research and investment in public health responses, more direct collaboration between public health end users and academic researchers, and application of multidisciplinary One Health approaches.

6.7 References

Acheson, E. S., Galanis, E., Bartlett, K., Klinkenberg, B. (2019). Climate classification system-based determination of temperate climate detection of *Cryptococcus gattii* sensu lato. *Emerging Infectious Diseases, 25*(9), 1723-1726.

Acheson, E. S., Galanis, E., Bartlett, K., Mak, S., & Klinkenberg, B. (2018). Searching for clues for eighteen years: Deciphering the ecological determinants of *Cryptococcus gattii* on Vancouver Island, British Columbia. *Medical Mycology, 56*(2), 129-144. <https://doi.org/10.1093/mmy/myx037>

Adekoya N, Truman B, Landen M; Centers for Disease Control and Prevention. (2015). Incidence of notifiable diseases among American Indians/Alaska Natives - United States, 2007-2011. *MMWR Morb Mortal Weekly Report, 64*(1), 16-9.

Adler NE, Newman K. (2002). Socioeconomic disparities in health: pathways and policies. *Health Affairs (Project Hope), 21*(2), 60-76. <https://doi.org/10.1377/hlthaff.21.2.60>

Aenishaenslin, C., Simon, A., Forde, T., Ravel, A., Proulx, J.-F., Fehlner-Gardiner, C., . . . Belanger, D. (2014). Characterizing rabies epidemiology in remote Inuit communities in Québec, Canada: A "One Health" approach. *EcoHealth, 11*(3), 343-355. <https://doi.org/10.1007/s10393-014-0923-1>

Alarcon Falconi, T. M., Cruz, M. S., & Naumova, E. N. (2018). The shift in seasonality of legionellosis in the USA. *Epidemiology & Infection, 146*(14), 1824-1833. <https://doi.org/10.1017/S0950268818002182>

Altizer, S., Ostfeld, R. S., Johnson, P. T. J., Kutz, S., & Harvell, C. D. (2013). Climate change and infectious diseases: From evidence to a predictive framework. *Science, 341*(6145), 514-519. <https://doi.org/10.1126/science.1239401>

Ampofo, K., Gesteland, P. H., Bender, J., Mills, M., Daly, J., Samore, M., . . . Srivastava, R. (2006). Epidemiology, complications, and cost of hospitalization in children with laboratory-confirmed influenza infection. *Pediatrics, 118*(6), 2409-2417. <https://doi.org/10.1542/peds.2006-1475>

Andersen, K. G., Rambaut, A., Lipkin, W. I., Holmes, E. C., & Garry, R. F. (2020). The proximal origin of SARS-CoV-2. *Nature medicine, 26*(4), 450–452. <https://doi.org/10.1038/s41591-020-0820-9>

Anderson, H., Honish, L., Taylor, G., Johnson, M., Tovstiuk, C., Fanning, A., Tyrrell, G., Rennie, R., Jaipaul, J., Sand, C., & Probert, S. (2006). Histoplasmosis cluster, golf course, Canada. *Emerging infectious diseases, 12*(1), 163–165. <https://doi.org/10.3201/eid1201.051083>

Anderson, R. M., & May, R. M. (1991). *Infectious diseases of humans: Dynamics and control*. Oxford, England: Oxford University Press.

Andreadis, T. G., Anderson, J. F., Armstrong, P. M., & Main, A. J. (2008). Isolations of Jamestown Canyon virus (Bunyaviridae: Orthobunyavirus) from field-collected mosquitoes (Diptera: Culicidae) in Connecticut, USA: A ten-year analysis, 1997–2006. *Vector-Borne and Zoonotic Diseases, 8*(2), 175-188. <https://doi.org/10.1089/vbz.2007.0169>

Anyamba, A., Linthicum, K. J., Small, J. L., Collins, K. M., Tucker, C. J., Pak, E. W., . . . Russell, K. L. (2012). Climate teleconnections and recent patterns of human and animal disease outbreaks. *PLOS Neglected Tropical Diseases, 6*(1), 1-14. <https://doi.org/10.1371/journal.pntd.0001465>

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology, 8*(1), 19-32. <https://doi.org/10.1080/1364557032000119616>

Armstrong, P. M., & Andreadis, T. G. (2010). Eastern equine encephalitis virus in mosquitoes and their role as bridge vectors. *Emerging Infectious Diseases, 16*(12), 1869-1874. <https://doi.org/10.3201/eid1612.100640>

Artsob, H. (1988). Powassan encephalitis. In T. P. Monath (Ed.), *The arboviruses: Epidemiology and ecology* (Vol. 4, pp. 29-49). Boca Raton, FL: CRC Press.

Artsob, H. (2000). Arthropod-borne disease in Canada: A clinician's perspective from the 'Cold Zone'. *Paediatrics & Child Health, 5*(4), 206-212. <https://doi.org/10.1093/pch/5.4.206>

Artsob, H., Gubler, D. J., Enria, D. A., Morales, M. A., Pupo, M., Bunning, M. L., & Dudley, J. P. (2009). West Nile virus in the New World: Trends in the spread and proliferation of West Nile virus in the Western Hemisphere. *Zoonoses and Public Health, 56*(6-7), 357-369. <https://doi.org/10.1111/j.1863-2378.2008.01207.x>

Asad, H., & Carpenter, D. O. (2018). Effects of climate change on the spread of Zika virus: A public health threat. *Reviews on Environmental Health, 33*(1), 31-42. <https://doi.org/10.1515/reveh-2017-0042>

Ashraf, U., Ye, J., Ruan, X., Wan, S., Zhu, B., & Cao, S. (2015). Usutu virus: An emerging flavivirus in Europe. *Viruses, 7*(1), 219-238. <https://doi.org/10.3390/v7010219>

Aune, K., Rhyan, J. C., Russell, R., Roffe, T. J., & Corso, B. (2012). Environmental persistence of *Brucella abortus* in the Greater Yellowstone Area. *The Journal of Wildlife Management, 76*(2), 253-261. <https://doi.org/10.1002/jwmg.274>

Ayers, V. B., Huang, Y.-J. S., Lyons, A. C., Park, S. L., Higgs, S., Dunlop, J. I., . . . Vanlandingham, D. L. (2018). *Culex tarsalis* is a competent vector species for Cache Valley virus. *Parasites & Vectors, 11*, 1-6. <https://doi.org/10.1186/s13071-018-3103-2>

Azam, D., Ukpai, O. M., Said, A., Abd-Allah, G. A., & Morgan, E. R. (2012). Temperature and the development and survival of infective *Toxocara canis* larvae. *Parasitology Research, 110*(2), 649-656. <https://doi.org/10.1007/s00436-011-2536-8>

Azar, M. M., Assi, R., Relich, R. F., Schmitt, B. H., Norris, S., Wheat, L. J., & Hage, C. A. (2015). Blastomycosis in Indiana. *Chest, 148*(5), 1276-1284. <https://doi.org/10.1378/chest.15-0289>

Badawi, A., Velummailum, R., Ryoo, S. G., Senthinathan, A., Yaghoubi, S., Vasileva, D., . . . Arora, P. (2018). Prevalence of chronic comorbidities in dengue fever and West Nile virus: A systematic review and meta-analysis. *PLOS ONE, 13*(7), 1-27. <https://doi.org/10.1371/journal.pone.0200200>

Barclay, E. (2008). Is climate change affecting dengue in the Americas? *The Lancet, 371*(9617), 973-974. <https://doi.org/10.1016/S0140-6736(08)60435-3>

Baumgardner, D. J. (1997). Fungal infection after excavation or natural disaster. *Wilderness & Environmental Medicine, 8*(3), 177. Retrieved from <https://www.wemjournal.org/article/S1080-6032(97)70965-7/>

Baumgardner, D. J., & Burdick, J. S. (1991). An outbreak of human and canine blastomycosis. *Reviews of Infectious Diseases, 13*(5), 898-905. <https://doi.org/10.1093/clinids/13.5.898>

Baumgardner, D. J., Paretsky, D. P., Baeseman, Z. J., & Schreiber, A. (2011). Effects of season and weather on blastomycosis in dogs: Northern Wisconsin, USA. *Medical Mycology, 49*(1), 49-55. <https://doi.org/10.3109/13693786.2010.488658>

Beard, C. B., Eisen, R. J., Barker, C. M., Garofalo, J. F., Hahn, M., Hayden, M., . . . Schramm, P. J. (2016). Vector-borne diseases. In A. Crimmins, J. Balbus, J. L. Gamble, C. B. Beard, J. E. Bell, D. Dodgen, R. J. Eisen, N. Fann, M. D. Hawkins, S. C. Herring, L. Jantarasami, D. M. Mills, S. Saha, M. C. Sarofim, J. Trtanj, & L. Ziska (Eds.), *The impacts of climate change on human health in the United States: A scientific assessment* (pp. 129-156). Washington, DC: U.S. Global Change Research Program. <https://doi.org/10.7930/J0765C7V>

Beaudoin, M., & Gosselin, P. (2016). An effective public health program to reduce urban heat islands in Québec, Canada. *Pan American Journal of Public Health, 40*(3), 160-166. Retrieved from <http://iris.paho.org/xmlui/handle/123456789/31230>

Beauté, J. (2017). Legionnaires' disease in Europe, 2011 to 2015. *Eurosurveillance, 22*(27), 1-8. <https://doi.org/10.2807/1560-7917.ES.2017.22.27.30566>

Beauté, J., Sandin, S., Uldum, S. A., Rota, M. C., Brandsema, P., Giesecke, J., & Sparén, P. (2016). Short-term effects of atmospheric pressure, temperature, and rainfall on notification rate of community-acquired Legionnaires' disease in four European countries. *Epidemiology & Infection, 144*(16), 3483-3493. <https://doi.org/10.1017/S0950268816001874>

Ben Ari, T., Gershunov, A., Gage, K. L., Snäll, T., Ettestad, P., Kausrud, K. L., & Stenseth, N. C. (2008). Human plague in the USA: The importance of regional and local climate. *Biology Letters, 4*(6), 737-740. <https://doi.org/10.1098/rsbl.2008.0363>

Ben Ari, T., Gershunov, A., Tristan, R., Cazelles, B., Gage, K., & Stenseth, N. C. (2010). Interannual variability of human plague occurrence in the western United States explained by tropical and North Pacific Ocean climate variability. *The American Journal of Tropical Medicine and Hygiene, 83*(3), 624-632. <https://doi.org/10.4269/ajtmh.2010.09-0775>

Bern, C., & Montgomery, S. P. (2009). An estimate of the burden of Chagas disease in the United States. *Clinical Infectious Diseases, 49*(5), e52-e54. <https://doi.org/10.1086/605091>

Berrang-Ford, L., Maclean, J. D., Gyorkos, T. W., Ford, J. D., & Ogden, N. H. (2009). Climate change and malaria in Canada: A systems approach. *Interdisciplinary Perspectives on Infectious Diseases, 2009*, 1-13. <https://doi.org/10.1155/2009/385487>

Berry, P. (2008). Vulnerabilities, adaptation and adaptive capacity in Canada. In J. Séguin (Ed.), *Human health in a changing climate: A Canadian assessment of vulnerabilities and adaptive capacity* (pp. 367-448). Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/pub?id=9.691579&sl=0>

Berry, P., Clarke, K.-L., Fleury, M. D., & Parker, S. (2014a). Human health. In F. J. Warren & D. S. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (pp. 191-232). Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/pub?id=9.699408&sl=0>

Berry, P., Patterson, J., Buse, C. (2014b). Assessment of Vulnerability to the Health Impacts of Climate Change in Middlesex-London. Retrieved from <https://www.healthunit.com/climate-change>

Berteaux, D., de Blois, S., Angers, J.-F., Bonin, J., Casajus, N., Darveau, M., . . . Vescovi, L. (2010). The CC-Bio project: Studying the effects of climate change on Quebec biodiversity. *Diversity, 2*(11), 1181-1204. <https://doi.org/10.3390/d2111181>

Berteaux, D., & Stenseth, N. C. (2006). Measuring, understanding and projecting the effects of large-scale climatic variability on mammals. *Climate Research, 32*(2), 95-97. Retrieved from <https://www.int-res.com/articles/cr_oa/c032p095.pdf>

Biggs, H. M., Behravesh, C. B., Bradley, K. K., Dahlgren, F. S., Drexler, N. A., Dumler, J. S., . . . Traeger, M. S. (2016). Diagnosis and management of tickborne rickettsial diseases: Rocky Mountain spotted fever and other spotted fever group Rickettsioses, Ehrlichioses, and Anaplasmosis - United States. *MMWR Recommendations and Reports, 65*(2), 1-44. <https://doi.org/10.15585/mmwr.rr6502a1>

Blancher, P., Cadman, M. D., Pond, B. A., Couturier, A. R., Dunn, E. H., Francis, C. M., & Rempel, R. S. (2008). Changes in bird distributions between atlases. In M. D. Cadman, D. A. Sutherland, G. G. Beck, D. Lepage, & A. R. Couturier (Eds.), *Atlas of the breeding birds of Ontario, 2001-2005* (pp. 32-48). Toronto, ON: Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources, & Ontario Nature.

Bouchard, C., Aenishaenslin, C., Rees, E. E., Koffi, J. K., Pelcat, Y., Ripoche, M., . . . Leighton, P. A. (2018). Integrated social-behavioral and ecological risk maps to prioritize local public health responses to Lyme disease. *Environmental Health Perspectives, 126*(4). <https://doi.org/10.1289/EHP1943>

Bouchard, C., Dibernardo, A., Koffi, J., Wood, H., Leighton, P. A., & Lindsay, L. R. (2019). Increased risk of tick-borne diseases with climate and environmental changes. *Canada Communicable Disease Report, 45*(4), 83-89. <https://doi.org/10.14745/ccdr.v45i04a02>

Bouchard, C., Leonard, E., Koffi, J. K., Pelcat, Y., Peregrine, A., Chilton, N., . . . Ogden, N. H. (2015). The increasing risk of Lyme disease in Canada. *The Canadian Veterinary Journal, 56*(7), 693-699. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4466818/>

Bouri, N., Sell, T. K., Franco, C., Adalja, A. A., Henderson, D. A., & Hynes, N. A. (2012). Return of epidemic dengue in the United States: Implications for the public health practitioner. *Public Health Reports, 127*(3), 259-266. <https://doi.org/10.1177/003335491212700305>

Brachman, P. S., & Abrutyn, E. (Eds.). (2009). *Bacterial infections of humans: Epidemiology and control* (4th ed.). New York, NY: Springer.

Brady, O. J., Johansson, M. A., Guerra, C. A., Bhatt, S., Golding, N., Pigott, D. M., . . . Hay, S. I. (2013). Modelling adult *Aedes aegypti* and *Aedes* **albopictus** survival at different temperatures in laboratory and field settings. *Parasites & Vectors, 6*, 1-12. <https://doi.org/10.1186/1756-3305-6-35>

Brierley, L., Vonhof, M. J., Olival, K. J., Daszak, P., & Jones, K. E. (2016). Quantifying global drivers of zoonotic bat viruses: A process-based perspective. *The American Naturalist, 187*(2), E53-E64. <https://doi.org/10.1086/684391>

British Columbia Centre for Disease Control. (2019). Reportable Diseases Data Dashboard. Retrieved from <http://www.bccdc.ca/health-professionals/data-reports/reportable-diseases-data-dashboard>

Brook, R. K., Kutz, S. J., Veitch, A. M., Popko, R. A., Elkin, B. T., & Guthrie, G. (2009). Fostering community-based wildlife health monitoring and research in the Canadian North. *EcoHealth, 6*(2), 266-278. <https://doi.org/10.1007/s10393-009-0256-7>

Brown, E. M., McTaggart, L. R., Dunn, D., Pszczolko, E., Tsui, K. G., Morris, S. K., . . . Richardson, S. E. (2018). Epidemiology and geographic distribution of blastomycosis, histoplasmosis, and coccidioidomycosis, Ontario, Canada, 1990–2015. *Emerging Infectious Diseases, 24*(7), 1257-1266. <https://doi.org/10.3201/eid2407.172063>

Brownstein, J. S., Holford, T. R., & Fish, D. (2005a). Effect of climate change on Lyme disease risk in North America. *EcoHealth, 2*(1), 38-46. <https://doi.org/10.1007/s10393-004-0139-x>

Brownstein, J. S., Skelly, D. K., Holford, T. R., & Fish, D. (2005b). Forest fragmentation predicts local scale heterogeneity of Lyme disease risk. *Oecologia, 146*(3), 469-475. <https://doi.org/10.1007/s00442-005-0251-9>

Bullard, J. M. P., Ahsanuddin, A. N., Perry, A. M., Lindsay, L. R., Iranpour, M., Dibernardo, A., & Van Caeseele, P. G. (2014). The first case of locally acquired tick-borne *Babesia microti* infection in Canada. *Canadian Journal of Infectious Diseases and Medical Microbiology, 25*(6), e87-e89. <https://doi.org/10.1155/2014/209521>

Bush, E. and Lemmen, D.S. (Eds.). (2019). *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019/>

Cable, J., Barber, I., Boag, B., Ellison, A. R., Morgan, E. R., Murray, K., . . . Booth, M. (2017). Global change, parasite transmission and disease control: Lessons from ecology. *Philosophical Transactions of the Royal Society B: Biological Sciences, 372*(1719), 1-17. <https://doi.org/10.1098/rstb.2016.0088>

Caini, S., Spreeuwenberg, P., Donker, G., Korevaar, J., & Paget, J. (2018). Climatic factors and long-term trends of influenza-like illness rates in the Netherlands, 1970–2016. *Environmental Research, 167*, 307-313. <https://doi.org/10.1016/j.envres.2018.07.035>

Campbell, L. P., Luther, C., Moo-Llanes, D., Ramsey, J. M., Danis-Lozano, R., & Peterson, A. T. (2015). Climate change influences on global distributions of dengue and chikungunya virus vectors. *Philosophical Transactions of the Royal Society B: Biological Sciences, 370*(1665), 1-9. <https://doi.org/10.1098/rstb.2014.0135>

Canadian Food Inspection Agency. (2019). Rabies in Canada. Retrieved from <http://www.inspection.gc.ca/animals/terrestrial-animals/diseases/reportable/rabies/rabies-in-canada/eng/1356156989919/1356157139999>

Canadian Wildlife Health Cooperative. (2019). Retrieved from <http://www.cwhc-rcsf.ca/disease_surveillance.php>

Carlsen, B., & Glenton, C. (2016). The swine flu vaccine, public attitudes, and researcher interpretations: A systematic review of qualitative research. *BMC Health Services Research, 16*, 1-15. <https://doi.org/10.1186/s12913-016-1466-7>

Carmona-Castro, O., Moo-Llanes, D. A., & Ramsey, J. M. (2018). Impact of climate change on vector transmission of *Trypanosoma cruzi* (Chagas, 1909) in North America. *Medical and Veterinary Entomology, 32*(1), 84-101. <https://doi.org/10.1111/mve.12269>

Castillo, C. G., Kauffman, C. A., & Miceli, M. H. (2016). Blastomycosis. *Infectious Disease Clinics of North America, 30*(1), 247-264. <https://doi.org/10.1016/j.idc.2015.10.002>

Ceccato, P., Ramirez, B., Manyangadze, T., Gwakisa, P., & Thomson, M. C. (2018). Data and tools to integrate climate and environmental information into public health. *Infectious Diseases of Poverty, 7*, 1-11. <https://doi.org/10.1186/s40249-018-0501-9>

Centers for Disease Control and Prevention (2017). *Anthrax*. Retrieved from <https://www.cdc.gov/anthrax/index.html>

Centers for Disease Control and Prevention. (2018a). *La Crosse encephalitis: Epidemiology & geographic distribution.* Retrieved from <https://www.cdc.gov/lac/tech/epi.html>

Centers for Disease Control and Prevention. (2018b). *Saint Louis encephalitis: Statistics & maps*. Retrieved from <https://www.cdc.gov/sle/technical/epi.html>

Centers for Disease Control and Prevention. (2018c). *Technical fact sheet: Eastern equine encephalitis*. Retrieved from <https://www.cdc.gov/easternequineencephalitis/tech/factsheet.html>

Centers for Disease Control and Prevention. (2018d). *Technical fact sheet: St Louis encephalitis.* Retrieved from <https://www.cdc.gov/sle/technical/fact.html>

Centers for Disease Control and Prevention. (2018e). *Chagas provider fact sheet*. Retrieved from <https://www.cdc.gov/parasites/chagas/resources/factsheet.pdf>

Centers for Disease Control and Prevention. (2019a). *Plague fact sheet.* Retrieved from <https://www.cdc.gov/plague/resources/235098_Plaguefactsheet_508.pd>

Centers for Disease Control and Prevention. (2019b). *Brucellosist.* Retrieved from <https://www.cdc.gov/brucellosis/index.html>

Centers for Disease Control and Prevention. (2019c). *Q Fever*. Retrieved from <https://www.cdc.gov/qfever/symptoms/index.html>

Centre for Food-borne, Environmental and Zoonotic Infectious Diseases. (2017). Synopsis: Lyme Disease in Canada – A Federal Framework. *Canada communicable disease report*, *43*(10), 212-214. <https://doi.org/10.14745/ccdr.v43i10a04>

Centre for Public Health and Zoonoses. (2019). *One Health*. Retrieved from <http://cphaz.ca/onehealth/>

Chambers, D., Périé, C., Casajus, N., & de Blois, S. (2013). Challenges in modelling the abundance of 105 tree species in eastern North America using climate, edaphic, and topographic variables. *Forest Ecology and Management, 291*, 20-29. <https://doi.org/10.1016/j.foreco.2012.10.046>

Charron, D., Fleury, M., Lindsay, L. R., Ogden, N., & Schuster, C. J. (2008). The impacts of climate change on water-, food-, vector- ,and rodent-borne diseases. In J. Séguin (Ed.), *Human health in a changing climate: A Canadian assessment of vulnerabilities and adaptive capacity* (pp. 171-210). Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/pub?id=9.691579&sl=0>

Chattopadhyay, I., Kiciman, E., Elliott, J. W., Shaman, J. L., & Rzhetsky, A. (2018). Conjunction of factors triggering waves of seasonal influenza. *eLife, 7*, 1-44. <https://doi.org/10.7554/eLife.30756>

Chen, C. C., Jenkins, E., Epp, T., Waldner, C., Curry, P. S., & Soos, C. (2013). Climate change and West Nile virus in a highly endemic region of North America. *International Journal of Environmental Research and Public Health, 10*(7), 3052-3071. <https://doi.org/10.3390/ijerph10073052>

Chen, N.-T., Chen, M.-J., Guo, C.-Y., Chen, K.-T., & Su, H.-J. (2014a). Precipitation increases the occurrence of sporadic Legionnaires' disease in Taiwan. *PLOS ONE, 9*(12), 1-11. <https://doi.org/10.1371/journal.pone.0114337>

Chen, S. C.-A., Meyer, W., & Sorrell, T. C. (2014b). *Cryptococcus gattii* infections. *Clinical Microbiology Reviews, 27*(4), 980-1024. <https://doi.org/10.1128/CMR.00126-13>

Cheng, J., Wu, J., Xu, Z., Zhu, R., Wang, X., Li, K., . . . Su, H. (2014). Associations between extreme precipitation and childhood hand, foot and mouth disease in urban and rural areas in Hefei, China. *Science of the Total Environment, 497-498*, 484-490. <https://doi.org/10.1016/j.scitotenv.2014.08.006>

Choi, K. M., Christakos, G., & Wilson, M. L. (2006). El Niño effects on influenza mortality risks in the state of California. *Public Health, 120*(6), 505-516. <https://doi.org/10.1016/j.puhe.2006.01.011>

Chretien, J.-P., Anyamba, A., Bedno, S. A., Breiman, R. F., Sang, R., Sergon, K., . . . Linthicum, K. J. (2007). Drought-associated chikungunya emergence along coastal East Africa. *The American* <https://doi.org/10.4269/ajtmh.2007.76.405>

Cilloniz, C., Ewig, S., Gabarrus, A., Ferrer, M., Puig de la Bella Casa, J., Mensa, J., & Torres, A. (2017). Seasonality of pathogens causing community-acquired pneumonia. *Respirology, 22*(4), 778-785. <https://doi.org/10.1111/resp.12978>

Click Lambert, R., Kolivras, K. N., Resler, L. M., Brewster, C. C., & Paulson, S. L. (2008). The potential for emergence of Chagas disease in the United States. *Geospatial Health, 2*(2), 227-239. <https://doi.org/10.4081/gh.2008.246>

Clow, K. M., Leighton, P. A., Ogden, N. H., Lindsay, L. R., Michel, P., Pearl, D. L., & Jardine, C. M. (2017). Northward range expansion of *Ixodes scapularis* evident over a short timescale in Ontario, Canada. *PLOS ONE, 12*(12), 1-15. <https://doi.org/10.1371/journal.pone.0189393>

Collier, C. G. (1992). Weather conditions prior to major outbreaks of meningococcol meningitis in the United Kingdom. *International Journal of Biometeorology, 36*(1), 18-29. <https://doi.org/10.1007/BF01208730>

Comrie, A. C., & Glueck, M. F. (2007). Assessment of climate-coccidioidomycosis model: Model sensitivity for assessing climatologic effects on the risk of acquiring coccidioidomycosis. *Annals of the New York Academy of Sciences, 1111*(1), 83-95. <https://doi.org/10.1196/annals.1406.024>

Conza, L., Casati, S., Limoni, C., & Gaia, V. (2013). Meteorological factors and risk of community-acquired Legionnaires' disease in Switzerland: An epidemiological study. *BMJ Open, 3*(3). <https://doi.org/10.1136/bmjopen-2012-002428>

Corrin, T., Greig, J., Harding, S., Young, I., Mascarenhas, M., & Waddell, L. A. (2018). Powassan virus, a scoping review of the global evidence. *Zoonoses and Public Health, 65*(6), 595-624. <https://doi.org/10.1111/zph.12485>

Cox, R., Sanchez, J., & Revie, C. W. (2013). Multi-criteria decision analysis tools for prioritising emerging or re-emerging infectious diseases associated with climate change in Canada. *PLOS ONE, 8*(8). <https://doi.org/10.1371/journal.pone.0068338>

Crampton, T. L., Light, R. B., Berg, G. M., Meyers, M. P., Schroeder, G. C., Hershfield, E. S., & Embil, J. M. (2002). Epidemiology and clinical spectrum of blastomycosis diagnosed at Manitoba hospitals. *Clinical Infectious Diseases, 34*(10), 1310-1316. <https://doi.org/10.1086/340049>

Cross, P. C., Edwards, W. H., Scurlock, B. M., Maichak, E. J., & Rogerson, J. D. (2007). Effects of management and climate on elk brucellosis in the Greater Yellowstone Ecosystem. *Ecological Applications, 17*(4), 957-964. <https://doi.org/10.1890/06-1603>

Cutler, S. J. (2010). Relapsing fever — A forgotten disease revealed. *Journal of Applied Microbiology, 108*(4), 1115-1122. <https://doi.org/10.1111/j.1365-2672.2009.04598.x>

Dalcin, D., & Ahmed, S. Z. (2015). Blastomycosis in northwestern Ontario, 2004 to 2014. *Canadian Journal of Infectious Diseases and Medical Microbiology, 26*(5), 259-262. <https://doi.org/10.1155/2015/468453>

Davies, J. L., Epp, T., & Burgess, H. J. (2013). Prevalence and geographic distribution of canine and feline blastomycosis in the Canadian prairies. *The Canadian Veterinary Journal, 54*(8), 753-760. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3711163/>

Davis, N. C. (1932). The effect of various temperatures in modifying the extrinsic incubation period of the yellow fever virus in *Aëdes aegypti*. *American Journal of Epidemiology, 16*(1), 163-176. <https://doi.org/10.1093/oxfordjournals.aje.a117853>

DeFelice, N. B., Schneider, Z. D., Little, E., Barker, C., Caillouet, K. A., Campbell, S. R., . . . Shaman, J. (2018). Use of temperature to improve West Nile virus forecasts. *PLoS computational biology, 14*(3). <https://doi.org/10.1371/journal.pcbi.1006047>

Delisle, E., Rousseau, C., Broche, B., Leparc-Goffart, I., L'Ambert, G., Cochet, A., . . . Golliot, F. (2015). Chikungunya outbreak in Montpellier, France, September to October 2014. *Eurosurveillance, 20*(17), 1-6. <https://doi.org/10.2807/1560-7917.ES2015.20.17.21108>

De Man, H., Mughini Gras, L., Schimmer, B., Friesema, I. H. M., De Roda Husman, A. M., & Van Pelt, W. (2016). Gastrointestinal, influenza-like illness and dermatological complaints following exposure to floodwater: A cross-sectional survey in the Netherlands. *Epidemiology & Infection, 144*(7), 1445-1454. <https://doi.org/10.1017/S0950268815002654>

Deplazes, P., Rinaldi, L., Alvarez Rojas, C. A., Torgerson, P. R., Harandi, M. F., Romig, T., . . . Jenkins, E. J. (2017). Global distribution of alveolar and cystic echinococcosis. *Advances in Parasitology, 95*, 315-493. <https://doi.org/10.1016/bs.apar.2016.11.001>

Dergousoff, S. J., Galloway, T. D., Lindsay, L. R., Curry, P. S., & Chilton, N. B. (2013). Range expansion of *Dermacentor variabilis* and *Dermacentor andersoni* (Acari: Ixodidae) near their northern distributional limits. *Journal of Medical Entomology, 50*(3), 510-520. <https://doi.org/10.1603/me12193>

DesGranges, J.-L., & Morneau, F. (2010). Potential sensitivity of Québec's breeding birds to climate change. *Avian Conservation and Ecology, 5*(2). <https://doi.org/10.5751/ace-00410-050205>

Dibernardo, A., Cote, T., Ogden, N. H., & Lindsay, L. R. (2014). The prevalence of *Borrelia miyamotoi* infection, and co-infections with other *Borrelia* spp. in *Ixodes scapularis* ticks collected in Canada. *Parasites & Vectors, 7*, 1-8. <https://doi.org/10.1186/1756-3305-7-183>

Dicker, R. C., Coronado, F. t., Koo, D., & Gibson Parrish, R., II. (Eds.). (2012). *Principles of epidemiology in public health practice: An introduction to applied epidemiology and biostatistics* (3rd ed.). Atlanta, GA: Centers for Disease Control and Prevention.

Dolcé, P., Bélanger, M.-J., Tumanowicz, K., Gauthier, C. P., Jutras, P., Massé, R., . . . Artsob, H. (2003). *Coxiella burnetii* seroprevalence of shepherds and their flocks in the lower Saint-Lawrence River region of Quebec, Canada. *Canadian Journal of Infectious Diseases, 14*(2), 97-102. <https://doi.org/10.1155/2003/504796>

Domenech de Cellès, M., Arduin, H., Lévy-Bruhl, D., Georges, S., Souty, C., Guillemot, D., . . . Opatowski, L. (2019). Unraveling the seasonal epidemiology of pneumococcus. *Proceedings of the National Academy of Sciences of the United States of America, 116*(5), 1802-1807. <https://doi.org/10.1073/pnas.1812388116>

Dowell, S. F. (2001). Seasonal variation in host susceptibility and cycles of certain infectious diseases. *Emerging Infectious Diseases, 7*(3), 369-374. <https://doi.org/10.3201/eid0703.010301>

Drebot, M. A. (2015). Emerging mosquito-borne bunyaviruses in Canada. *Canada Communicable Disease Report, 41*(6), 117-123. <https://doi.org/10.14745/ccdr.v41i06a01>

Drebot, M. A., Artsob, H., & Werker, D. (2000). Hantavirus pulmonary syndrome in Canada, 1989-1999. *Canada Communicable Disease Report, 26*(8), 65-69. Retrieved from <http://publications.gc.ca/pub?id=9.507730&sl=0>

Dworkin, M. S., Schwan, T. G., Anderson, D. E., & Borchardt, S. M. (2008). Tick-borne relapsing fever. *Infectious Disease Clinics of North America, 22*(3), 449-468. <https://doi.org/10.1016/j.idc.2008.03.006>

Dye, C. (2014). After 2015: Infectious diseases in a new era of health and development. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1645), 1-9. <https://doi.org/10.1098/rstb.2013.0426>

Eads, D. A., & Hoogland, J. L. (2017). Precipitation, climate change, and parasitism of prairie dogs by fleas that transmit plague. *Journal of Parasitology, 103*(4), 309-319. <https://doi.org/10.1645/16-195>

Earn, D. J. D., He, D., Loeb, M. B., Fonseca, K., Lee, B. E., & Dushoff, J. (2012). Effects of school closure on incidence of pandemic influenza in Alberta, Canada. *Annals of Internal Medicine, 156*(3), 173-181. <https://doi.org/10.7326/0003-4819-156-3-201202070-00005>

Earn, D. J. D., Ma, J., Poinar, H., Dushoff, J., Bolker, B. M. (2020). Acceleration of plague outbreaks in the second pandemic *Proceedings of the National Academies of Science of the U S A, 117*(44), 27703-27711.

Ebi, K.L., Balbus J.M., Luber G., Bole A., Crimmins A., Glass G., Saha S., Shimamoto M.M., Trtanj J., & White-Newsome J.L. (2018). Human Health. In Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (Eds.), *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* (pp. 572–603). Washington, DC: U.S. Global Change Research Program. doi: 10.7930/NCA4.2018.CH14

Ebi, K. L., Kovats, R. S., & Menne, B. (2006a). An approach for assessing human health vulnerability and public health interventions to adapt to climate change. *Environmental Health Perspectives, 114*(12), 1930-1934. <https://doi.org/10.1289/ehp.8430>

Ebi, K. L., Lewis, N. D., & Corvalan, C. (2006b). Climate variability and change and their potential health effects in small island states: Information for adaptation planning in the health sector. *Environmental Health Perspectives, 114*(12), 1957-1963. <https://doi.org/10.1289/ehp.8429>

Ebi, K. L., Ogden, N. H., Semenza, J. C., & Woodward, A. (2017). Detecting and attributing health burdens to climate change. *Environmental Health Perspectives, 125*(8), 1-8. <https://doi.org/10.1289/EHP1509>

Edginton, S., Guan, T. H., Evans, G., & Srivastava, S. (2018). Human granulocytic anaplasmosis acquired from a blacklegged tick in Ontario. *CMAJ, 190*(12), E363-E366. <https://doi.org/10.1503/CMAJ.171243>

Eisen, R. J., Eisen, L., Ogden, N. H., & Beard, C. B. (2016). Linkages of weather and climate with *Ixodes scapularis* and *Ixodes pacificus* (Acari: Ixodidae), enzootic transmission of *Borrelia burgdorferi*, and Lyme disease in North America. *Journal of Medical Entomology, 53*(2), 250-261. <https://doi.org/10.1093/jme/tjv199>

Eldin, C., Mahamat, A., Djossou, F., & Raoult, D. (2015). Rainfall and sloth births in May, Q fever in July, Cayenne, French Guiana. *The American Journal of Tropical Medicine and Hygiene, 92*(5), 979-981. <https://doi.org/10.4269/ajtmh.14-0751>

Elrick, M. J., Gordon-Lipkin, E., Crawford, T. O., Van Haren, K., Messacar, K., Thornton, N., . . . Duggal, P. (2019). Clinical subpopulations in a sample of North American children diagnosed with acute flaccid myelitis, 2012-2016. *JAMA Pediatrics, 173*(2), 134-139. <https://doi.org/10.1001/jamapediatrics.2018.4890>

Embil, J. A., Tanner, C. E., Pereira, L. H., Staudt, M., Morrison, E. G., & Gualazzi, D. A. (1988). Seroepidemiologic survey of *Toxocara canis* infection in urban and rural children. *Public Health, 102*(2), 129-133. <https://doi.org/10.1016/S0033-3506(88)80039-8>

Enscore, R. E., Biggerstaff, B. J., Brown, T. L., Fulgham, R. E., Reynolds, P. J., Engelthaler, D. M., . . . Gage, K. L. (2002). Modeling relationships between climate and the frequency of human plague cases in the southwestern United States, 1960-1997. *The American Journal of Tropical Medicine and Hygiene, 66*(2), 186-196. <https://doi.org/10.4269/ajtmh.2002.66.186>

Environmental Protection Agency. (2018). *Level III and IV Ecoregions of the Continental United States*. Retrieved from <https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states>

Escobar, L. E., Romero-Alvarez, D., Leon, R., Lepe-Lopez, M. A., Craft, M. E., Borbor-Cordova, M. J., & Svenning, J.-C. (2016). Declining prevalence of disease vectors under climate change. *Scientific Reports, 6*, 1-8. <https://doi.org/10.1038/srep39150>

etick. (2019). Retrieved from <https://www.etick.ca/>

European Centre for Disease Prevention and Control. (2018). *Legionnaires' disease — Annual epidemiological report for 2016*. Stockholm, Sweden: European Centre for Disease Prevention and Control. Retrieved from <https://ecdc.europa.eu/en/publications-data/legionnaires-disease-annual-epidemiological-report-2016>

European Centre for Disease Prevention and Control. (2019). *Risk assessments*. Retrieved from <https://www.ecdc.europa.eu/en/threats-and-outbreaks/reports-and-data/risk-assessments>

Federal, Provincial, & Territorial Governments of Canada. (2010). *Canadian biodiversity: Ecosystem status and trends 2010*. Ottawa, ON: Canadian Councils of Resource Ministers. Retrieved from <https://biodivcanada.chm-cbd.net/ecosystem-status-trends-2010/canadian-biodiversity-ecosystem-status-and-trends-2010-full-report>

Ferkol, T., & Schraufnagel, D. (2014). The global burden of respiratory disease. *Annals of the American Thoracic Society, 11*(3), 404-406. <https://doi.org/10.1513/AnnalsATS.201311-405PS>

Fields, B. S., Benson, R. F., & Besser, R. E. (2002). Legionella and Legionnaires' disease: 25 years of investigation. *Clinical Microbiology Reviews, 15*(3), 506-526. <https://doi.org/10.1128/cmr.15.3.506-526.2002>

Filejski, C. (2016). The changing face of rabies in Canada. *Canada Communicable Disease Report, 42*(6), 118-120. <https://doi.org/10.14745/ccdr.v42i06a01>

Findlater, A., & Bogoch, I. I. (2018). Human mobility and the global spread of infectious diseases: A focus on air travel. *Trends in Parasitology, 34*(9), 772-783. https://doi.org/10.1016/j.pt.2018.07.004>

Fisman, D. N. (2007). Seasonality of infectious diseases. *Annual Review of Public Health, 28*, 127-143. <https://doi.org/10.1146/annurev.publhealth.28.021406.144128>

Fisman, D. N. (2012). Seasonality of viral infections: Mechanisms and unknowns. *Clinical Microbiology and Infection, 18*(10), 946-954. <https://doi.org/10.1111/j.1469-0691.2012.03968.x>

Fisman, D. N., Lim, S., Wellenius, G. A., Johnson, C., Britz, P., Gaskins, M., . . . Newbern, C. (2005). It's not the heat, it's the humidity: Wet weather increases legionellosis risk in the greater Philadelphia metropolitan area. *The Journal of Infectious Diseases, 192*(12), 2066-2073. <https://doi.org/10.1086/498248>

Fisman, D. N., Tuite, A. R., & Brown, K. A. (2016). Impact of El Niño Southern Oscillation on infectious disease hospitalization risk in the United States. *Proceedings of the National Academy of Sciences of the United States of America, 113*(51), 14589-14594. <https://doi.org/10.1073/pnas.1604980113>

Fitzhenry, R., Weiss, D., Cimini, D., Balter, S., Boyd, C., Alleyne, L., . . . Varma, J. K. (2017). Legionnaires' disease outbreaks and cooling towers, New York City, New York, USA. *Emerging Infectious Diseases, 23*(11), 1769-1776. <https://doi.org/10.3201/eid2311.161584>

Fonseca, K., Prince, G. D., Bratvold, J., Fox, J. D., Pybus, M., Preksaitis, J. K., & Tilley, P. (2005). West Nile virus infection and conjunctival exposure. *Emerging Infectious Diseases, 11*(10), 1648-1649. <https://doi.org/10.3201/eid1110.040212>

Food and Agriculture Organization, & World Health Organization. (2014). *Multicriteria-based ranking for risk management of food-borne parasites: Report of a joint FAO/WHO expert meeting, 3-7 September 2012, FAO headquarters, Rome, Italy* (Microbiological risk assessment series 23). Geneva, Switzerland: World Health Organization. Retrieved from <https://www.who.int/foodsafety/publications/mra_23/en/>

Forbes, L. B. (1991). Isolates of *Brucella suis* biovar 4 from animals and humans in Canada, 1982-1990. *The Canadian Veterinary Journal, 32*(11), 686-688. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1481085/>

Franco-Paredes, C., Chastain, D., Taylor, P., Stocking, S., & Sellers, B. (2017). Boar hunting and brucellosis caused by *Brucella suis*. *Travel Med Infect Dis, 16*, 18-22. <https://doi.org/10.1016/j.tmaid.2017.03.006>

Friel, S. (2019). Climate change and the people's health (N. Krieger, Ed.). Oxford University Press. doi:10.1093/oso/9780190492731.001.0001

Fuglei, E., & Ims, R. A. (2008). Global warming and effects on the Arctic fox. *Science Progress, 91*(2), 175-191. <https://doi.org/10.3184/003685008X327468>

Fyfe, M., MacDougall, L., Romney, M., Starr, M., Pearce, M., Mak, S., . . . Kibsey, P. (2008). *Cryptococcus gattii* infections on Vancouver Island, British Columbia, Canada: Emergence of a tropical fungus in a temperate environment. *Canada Communicable Disease Report, 34*(6), 1-12. Retrieved from <https://www.canada.ca/en/public-health/services/reports-publications/canada-communicable-disease-report-ccdr/monthly-issue/2008-34/34-06.html>

Gabriele-Rivet, V., Arsenault, J., Badcock, J., Cheng, A., Edsall, J., Goltz, J., . . . Ogden, N. H. (2015). Different ecological niches for ticks of public health significance in Canada. *PLOS ONE, 10*(7), 1-19. <https://doi.org/10.1371/journal.pone.0131282>

Gallant, D., Slough, B. G., Reid, D. G., & Berteaux, D. (2012). Arctic fox versus red fox in the warming Arctic: Four decades of den surveys in north Yukon. *Polar Biology, 35*(9), 1421-1431. <https://doi.org/10.1007/s00300-012-1181-8>

Garcia-Solache, M. A., & Casadevall, A. (2010). Global warming will bring new fungal diseases for mammals. *mBio, 1*(1), 1-3. <https://doi.org/10.1128/mBio.00061-10>

Garcia-Vidal, C., Labori, M., Viasus, D., Simonetti, A., Garcia-Somoza, D., Dorca, J., . . . Carratalà, J. (2013). Rainfall is a risk factor for sporadic cases of *Legionella pneumophila* pneumonia. *PLOS ONE, 8*(4), 1-5. <https://doi.org/10.1371/journal.pone.0061036>

Gargan, T. P., II., Clark, G. G., Dohm, D. J., Turell, M. J., & Bailey, C. L. (1988). Vector potential of selected North American mosquito species for Rift Valley fever virus. *The American Journal of Tropical Medicine and Hygiene, 38*(2), 440-446. <https://doi.org/10.4269/ajtmh.1988.38.440>

Garroway, C. J., Bowman, J., Cascaden, T. J., Holloway, G. L., Mahan, C. G., Malcolm, J. R., . . . Wilson, P. J. (2010). Climate change induced hybridization in flying squirrels. *Global Change Biology, 16*(1), 113-121. <https://doi.org/10.1111/j.1365-2486.2009.01948.x>

Garroway, C. J., Bowman, J., Holloway, G. L., Malcolm, J. R., & Wilson, P. J. (2011). The genetic signature of rapid range expansion by flying squirrels in response to contemporary climate warming. *Global Change Biology, 17*(5), 1760-1769. <https://doi.org/10.1111/j.1365-2486.2010.02384.x>

Gasmi, S., Bouchard, C., Ogden, N. H., Adam-Poupart, A., Pelcat, Y., Rees, E. E., . . . Thivierge, K. (2018). Evidence for increasing densities and geographic ranges of tick species of public health significance other than *Ixodes scapularis* in Québec, Canada. *PLOS ONE, 13*(8), 1-15. <https://doi.org/10.1371/JOURNAL.PONE.0201924>

Gasmi, S., Ogden, N. H., Lindsay, L. R., Burns, S., Fleming, S., Badcock, J., . . . Koffi, J. K. (2017). Surveillance for Lyme disease in Canada: 2009-2015. *Canada Communicable Disease Report, 43*(10), 194-199. <https://doi.org/10.14745/ccdr.v43i10a01>

Gatherer, D. (2010). The Little Ice Age and the emergence of influenza A. *Medical Hypotheses, 75*(4), 359-362. <https://doi.org/10.1016/j.mehy.2010.03.032>

Gilbert, M., Slingenbergh, J., & Xiao, X. (2008). Climate change and avian influenza. *OIE Scientific and Technical Review, 27*(2), 459-466. <https://doi.org/10.20506/rst.27.2.1821>

Gilmour, M. W., Graham, M., Reimer, A., & Van Domselaar, G. (2013). Public health genomics and the new molecular epidemiology of bacterial pathogens. *Public Health Genomics, 16*(1-2), 25-30. <https://doi.org/10.1159/000342709>

Giordano, B. V., Gasparotto, A., & Hunter, F. F. (2015). A checklist of the 67 mosquito species of Ontario, Canada. *Journal of the American Mosquito Control Association, 31*(1), 101-103. <https://doi.org/10.2987/14-6456r.1>

Giordano, B. V., Kaur, S., & Hunter, F. F. (2017). West Nile virus in Ontario, Canada: A twelve-year analysis of human case prevalence, mosquito surveillance, and climate data. *PLOS ONE, 12*(8), 1-15. <https://doi.org/10.1371/journal.pone.0183568>

Giordano, B. V., Turner, K. W., & Hunter, F. F. (2018). Geospatial analysis and seasonal distribution of West Nile virus vectors (Diptera: Culicidae) in Southern Ontario, Canada. *International Journal of Environmental Research and Public Health, 15*(4), 1-18. <https://doi.org/10.3390/ijerph15040614>

Githeko, A. K., Lindsay, S. W., Confalonieri, U. E., & Patz, J. A. (2000). Climate change and vector-borne diseases: A regional analysis. *Bulletin of the World Health Organization, 78*(9), 1136-1147. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2560843/>

Gleason, J. A., Kratz, N. R., Greeley, R. D., & Fagliano, J. A. (2016). Under the weather: Legionellosis and meteorological factors. *EcoHealth, 13*(2), 293-302. <https://doi.org/10.1007/s10393-016-1115-y>

Global Burden of Disease 2015 Mortality and Causes of Death Collaborators. (2016). Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980–2015: A systematic analysis for the Global Burden of Disease Study 2015. *The Lancet, 388*(10053), 1459-1544. <https://doi.org/10.1016/S0140-6736(16)31012-1>

Global Commission on Adaptation. (2019). Adapt now: a global call for leadership on climate resilience. Retrieved from <https://cdn.gca.org/assets/2019-09/GlobalCommission_Report_FINAL.pdf>

Golnar, A. J., Kading, R. C., & Hamer, G. L. (2018). Quantifying the potential pathways and locations of Rift Valley fever virus entry into the United States. *Transboundary and Emerging Diseases, 65*(1), 85-95. <https://doi.org/10.1111/tbed.12608>

Golnar, A. J., Turell, M. J., LaBeaud, A. D., Kading, R. C., & Hamer, G. L. (2014). Predicting the mosquito species and vertebrate species involved in the theoretical transmission of Rift Valley fever virus in the United States. *PLOS Neglected Tropical Diseases, 8*(9), 1-11. <https://doi.org/10.1371/journal.pntd.0003163>

Goneau, L. W., Mehta, K., Wong, J., L'Huillier, A. G., & Gubbay, J. B. (2018). Zoonotic influenza and human health — Part 1: Virology and epidemiology of zoonotic influenzas. *Current Infectious Disease Reports, 20*(10), 1-12. <https://doi.org/10.1007/s11908-018-0642-9>

Gorris, M. E., Cat, L. A., Zender, C. S., Treseder, K. K., & Randerson, J. T. (2018). Coccidioidomycosis dynamics in relation to climate in the southwestern United States. *GeoHealth, 2*(1), 6-24. <https://doi.org/10.1002/2017GH000095>

Government of Canada. (2013). Environmental Public Health and Climate Change. Retrieved from https://www.canada.ca/en/public-health/services/health-promotion/environmental-public-health-climate-change.html>

Government of Canada. (2015). *Surveillance of hantavirus related diseases.* Retrieved from <https://www.canada.ca/en/public-health/services/diseases/hantaviruses/surveillance-hantavirus-related-diseases.html>

Government of Canada. (2016). Rapid Risk Assessment: the risk of Zika virus to Canadians (first update). Retrieved from <https://www.canada.ca/en/public-health/services/publications/diseases-conditions/rapid-risk-assessment-risk-zika-virus-canadians-first-update.html>

Government of Canada. (2017). *Avian Influenza Surveillance*. Retrieved from <http://www.inspection.gc.ca/animals/terrestrial-animals/diseases/surveillance/avian-influenza-surveillance/eng/1329693810008/1329694298513>

Government of Canada. (2018a). Surveillance of plague. Retrieved from <https://www.canada.ca/en/public-health/services/diseases/plague/surveillance-plague.html>

Government of Canada. (2018b). How Canada prepares for Pandemic Flu. Retrieved from <https://www.canada.ca/en/health-canada/services/health-concerns/emergencies-disasters/emergency-preparedness/pandemic-influenza-preparedness.html>

Government of Canada. (2018c). Terrestrial animals - Immediately Notifiable Diseases. Retrieved from <http://www.inspection.gc.ca/animals/terrestrial-animals/diseases/immediately-notifiable/eng/1305670991321/1305671848331>

Government of Canada. (2019a). *Surveillance of West Nile virus*. Retrieved from <https://www.canada.ca/en/public-health/services/diseases/west-nile-virus/surveillance-west-nile-virus.html>

Government of Canada. (2019b). Flu (influenza): FluWatch surveillance. Retrieved from <https://www.canada.ca/en/public-health/services/diseases/flu-influenza/influenza-surveillance.html>

Government of Canada. (2019c). Reportable diseases: Terrestrial animals. Retrieved from <http://www.inspection.gc.ca/animals/terrestrial-animals/diseases/reportable/eng/1303768471142/1303768544412>

Government of Canada. (2019d). Reported cases from 1924 to 2017 in Canada - Notifiable diseases on-line. Retrieved from <https://diseases.canada.ca/notifiable/charts?c=pl>

Government of Canada. (2019e). Notifiable diseases on-line. Retrieved from <https://diseases.canada.ca/notifiable/>

Government of Canada. (2019f). Zika virus - surveillance in Canada. Retrieved from <https://www.cmaj.ca/content/189/9/E334>

Government of Manitoba. (2018). Blacklegged tick risk areas in Manitoba. Retrieved from <https://www.gov.mb.ca/health/publichealth/cdc/tickborne/surveillance.html>

Government of Manitoba. (2019a). Manitoba tick checker. Retrieved from <https://forms.gov.mb.ca/tickSubmission/>

Government of Manitoba. (2019b). Manitoba Health, Seniors and Active Living West Nile Virus Program 2019: Planning Documents for Municipalities III. Adult Mosquito Control Package. Retrieved from <https://www.gov.mb.ca/health/wnv/docs/amcontrolontrolpackage.pdf>

Granados, D. P., & Castañeda, E. (2006). Influence of climatic conditions on the isolation of members of the *Cryptococcus neoformans* species complex from trees in Colombia from 1992-2004. *FEMS Yeast Research, 6*(4), 636-644. <https://doi.org/10.1111/j.1567-1364.2006.00090.x>

Greenberg, J., Dubé, E., & Driedger, M. (2017). Vaccine hesitancy: In search of the risk communication comfort zone. *PLOS Currents: Outbreaks, 1*. Retrieved from <http://currents.plos.org/outbreaks/index.html%3Fp=70808.html>

Greer, A., Ng, V., & Fisman, D. (2008). Climate change and infectious diseases in North America: The road ahead. *CMAJ, 178*(6), 715-722. <https://doi.org/10.1503/cmaj.081325>

Greer, A. L., Drews, S. J., & Fisman, D. N. (2009). Why “winter” vomiting disease? Seasonality, hydrology, and norovirus epidemiology in Toronto, Canada. *EcoHealth, 6*(2), 192-199. <https://doi.org/10.1007/s10393-009-0247-8>

Griot, C., Gonzalez-Scarano, F., & Nathanson, N. (1993). Molecular determinants of the virulence and infectivity of California serogroup bunyaviruses. *Annual Review of Microbiology, 47*, 117-138. <https://doi.org/10.1146/annurev.mi.47.100193.001001>

Groupe de recherche en épidémiologie des zoonoses et santé publique. (2019). Retrieved from <https://grezosp.com/>

Gubler, D. J. (2007). The continuing spread of West Nile virus in the Western Hemisphere. *Clinical Infectious Diseases, 45*(8), 1039-1046. <https://doi.org/10.1086/521911>

Guerra, M., Walker, E. D., Jones, C., Paskewitz, S., Cortinas, M. R., Stancil, A., . . . Kitron, U. (2002). Predicting the risk of Lyme disease: Habitat suitability for *Ixodes scapularis* in the North Central United States. *Emerging Infectious Diseases, 8*(3), 289-297. Retrieved from <https://wwwnc.cdc.gov/eid/article/8/3/01-0166_article>

Gupta, S., Parker, J., Smits, S., Underwood, J., & Dolwani, S. (2020). Persistent viral shedding of SARS-CoV-2 in faeces - a rapid review. *Colorectal disease: the official journal of the Association of Coloproctology of Great Britain and Ireland, 22*(6), 611–620. <https://doi.org/10.1111/codi.15138>

Hajizadeh M, Mitnitski A, Rockwood K. 2016. Socioeconomic gradient in health in Canada: Is the gap widening or narrowing? *Health Policy, 120*(9), 1040-50. doi: 10.1016/j.healthpol.2016.07.019.

Halsby, K. D., Joseph, C. A., Lee, J. V., & Wilkinson, P. (2014). The relationship between meteorological variables and sporadic cases of Legionnaires’ disease in residents of England and Wales. *Epidemiology & Infection, 142*(11), 2352-2359. <https://doi.org/10.1017/S0950268813003294>

Halstead, S. B. (2008). Dengue virus-mosquito interactions. *Annual Review of Entomology, 53*, 273-291. <https://doi.org/10.1146/annurev.ento.53.103106.093326>

Han G. Z. (2020). Pangolins Harbor SARS-CoV-2-Related Coronaviruses. *Trends in microbiology, 28*(7), 515–517. <https://doi.org/10.1016/j.tim.2020.04.001>

Harrigan, R. J., Thomassen, H. A., Buermann, W., & Smith, T. B. (2014). A continental risk assessment of West Nile virus under climate change. *Global Change Biology, 20*(8), 2417-2425. <https://doi.org/10.1111/gcb.12534>

Hassel, C., Mirand, A., Lukashev, A., Terletskaia-Ladwig, E., Farkas, A., Schuffenecker, I., . . . Bailly, J.-L. (2015). Transmission patterns of human enterovirus 71 to, from and among European countries, 2003 to 2013. *Eurosurveillance, 20*(34), 1-11. <https://doi.org/10.2807/1560-7917.ES.2015.20.34.30005>

Heesterbeek, H., Anderson, R. M., Andreasen, V., Bansal, S., De Angelis, D., Dye, C., . . . Isaac Newton Institute IDD Collaboration. (2015). Modeling infectious disease dynamics in the complex landscape of global health. *Science, 347*(6227), 1-10. <https://doi.org/10.1126/science.aaa4339>

Henao-Restrepo, A. M., Camacho, A., Longini, I. M., Watson, C. H., Edmunds, W. J., Egger, M., . . . Kieny, M.-P. (2017). Efficacy and effectiveness of an rVSV-vectored vaccine in preventing Ebola virus disease: Final results from the Guinea ring vaccination, open-label, cluster-randomised trial (Ebola Ça Suffit!). *The Lancet, 389*(10068), 505-518. <https://doi.org/10.1016/S0140-6736(16)32621-6>

Henri, D.A., Jean-Gagnon, F., & Grant Gilchrist, H. (2018). Using Inuit traditional ecological knowledge for detecting and monitoring avian cholera among Common Eiders in the eastern Canadian Arctic. *Ecology and Society, 23*(1), 22.

Hersteinsson, P., & MacDonald, D. W. (1992). Interspecific competition and the geographical distribution of red and arctic foxes *Vulpes vulpes* and *Alopex lagopus*. *Oikos, 64*(3), 505-515. <https://doi.org/10.2307/3545168>

Hertig, E. (2019). Distribution of *Anopheles* vectors and potential malaria transmission stability in Europe and the Mediterranean area under future climate change. *Parasites & Vectors, 12*, 1-9. <https://doi.org/10.1186/s13071-018-3278-6>

Hicks, L. A., Rose, C. E., Fields, B. S., Drees, M. L., Engel, J. P., Jenkins, P. R., . . . Whitney, C. G. (2007). Increased rainfall is associated with increased risk for legionellosis. *Epidemiology & Infection, 135*(5), 811-817. <https://doi.org/10.1017/S0950268806007552>

Hierlihy, C., Waddell, L., Young, I., Greig, J., Corrin, T., & Mascarenhas, M. (2019). A systematic review of individual and community mitigation measures for prevention and control of chikungunya virus. *PLOS ONE, 14*(2), 1-27. <https://doi.org/10.1371/journal.pone.0212054>

Hii, Y. L., Rocklöv, J., & Ng, N. (2011). Short term effects of weather on hand, foot and mouth disease. *PLOS ONE, 6*(2), 1-6. <https://doi.org/10.1371/journal.pone.0016796>

Hill A.B. (1965). The environment and disease: association or causation? *Proceedings of the Royal Society of Medicine, 58*(5), 295–300.

Hitch, A. T., & Leberg, P. L. (2007). Breeding distributions of North American bird species moving north as a result of climate change. *Conservation Biology, 21*(2), 534-539. <https://doi.org/10.1111/j.1523-1739.2006.00609.x>

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., . . . Zhou, G. (2019). Impacts of 1.5°C of global warming on natural and human systems. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global warming of 1.5°C: An IPCC special report*. In Press. Retrieved from <https://www.ipcc.ch/sr15/chapter/chapter-3/>

Holm-Hansen, C. C., Midgley, S. E., & Fischer, T. K. (2016). Global emergence of enterovirus D68: a systematic review. *The Lancet Infectious Diseases, 16*(5), e64-e75. <https://doi.org/10.1016/S1473-3099(15)00543-5>

Holt, A. C., Salkeld, D. J., Fritz, C. L., Tucker, J. R., & Gong, P. (2009). Spatial analysis of plague in California: Niche modeling predictions of the current distribution and potential response to climate change. *International Journal of Health Geographics, 8*, 1-14. <https://doi.org/10.1186/1476-072x-8-38>

Hongoh, V., Berrang-Ford, L., Scott, M. E., & Lindsay, L. R. (2012). Expanding geographical distribution of the mosquito, *Culex pipiens*, in Canada under climate change. *Applied Geography, 33*, 53-62. <https://doi.org/10.1016/j.apgeog.2011.05.015>

Huettmann, F., Magnuson, E. E., & Hueffer, K. (2017). Ecological niche modeling of rabies in the changing Arctic of Alaska. *Acta Veterinaria Scandinavica, 59*, 1-11. <https://doi.org/10.1186/s13028-017-0285-0>

Hunter, M., Donnelly, C., Smart, D., Smyth, B., Menzies, F., & Hedderwick, S. (2015). Brucellosis in people with occupational cattle exposure in Northern Ireland: Clinical features of 53 cases. *Journal of Infection, 70*(1), 101-103. <https://doi.org/10.1016/j.jinf.2014.08.004>

Institut national de santé publique du Québec. (2016). Risk assessment: Emergence and Vector-Borne Transmission of Zika Virus in Quebec. Retrieved from <https://www.inspq.qc.ca/sites/default/files/publications/2270_risk_emergence_transmission_zika_quebec.pdf>

Institut national de santé publique du Québec. (2018a). Observatoire multipartite québécois sur les zoonoses et l'adaptation aux changements climatiques. Retrieved from <https://www.inspq.qc.ca/zoonoses/observatoire>

Institut national de santé publique du Québec. (2018b). Priorisation des zoonoses au Québec dans un contexte d'adaptation aux changements climatiques à l'aide d'un outil d'aide à la décision multicritère. Retrieved from <https://www.inspq.qc.ca/publications/2432>

Intergovernmental Panel on Climate Change (IPCC). (2014). Summary for policymakers. In Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Iranpour, M., Hebert, P., Dibernardo, A., & Lindsay, R. (2017). Ochlerotatus ventrovittis *Dyar (Diptera: Culicidae): A new record for the mosquito fauna of Canada*. Paper presented at the Joint Meeting of the Entomological Societies of Canada and Manitoba: October 22-25, 2017, Winnipeg, MB. Retrieved from <https://home.cc.umanitoba.ca/~fieldspg/pdf/Proceedings/ESMproceedings_V73.pdf>

Iranpour, M., Lindsay, L. R., & Dibernardo, A. (2009). *Culiseta melanura* (Diptera: Culicidae), a new record for the Manitoba mosquito fauna. *Proceedings of the Entomological Society of Manitoba, 65*, 21-25. Retrieved from <https://home.cc.umanitoba.ca/~fieldspg/pdf/Proceedings/ESMproceedings_V65.pdf>

Iranpour, M., Turell, M. J., & Lindsay, L. R. (2011). Potential for Canadian mosquitoes to transmit Rift Valley fever virus. *Journal of the American Mosquito Control Association, 27*(4), 363-369. <https://doi.org/10.2987/11-6169.1>

Integrated Rapid Infectious Disease Analysis (IRIDA). (2019). Platform overview. Retrieved from <https://www.irida.ca/platform-overview/>

James, E., & Boyd, W. (1937). *Echinococcus* alveolaris (with the report of a case). *CMAJ, 36*(4), 354-356. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1562016/>

Jenkins, E. (2017). *Echinococcus* spp. tapeworms in dogs & cats. *Clinician's Brief, 15*(7), 14-18. Retrieved from <https://www.cliniciansbrief.com/article/echinococcus-spp-tapeworms-dogs-cats>

Jenkins, E. J., Castrodale, L. J., de Rosemond, S. J. C., Dixon, B. R., Elmore, S. A., Gesy, K. M., . . . Thompson, R. C. A. (2013). Tradition and transition: Parasitic zoonoses of people and animals in Alaska, northern Canada, and Greenland. *Advances in Parasitology, 82*, 33-204. <https://doi.org/10.1016/B978-0-12-407706-5.00002-2>

Jenkins, E. J., Schurer, J. M., & Gesy, K. M. (2011). Old problems on a new playing field: Helminth zoonoses transmitted among dogs, wildlife, and people in a changing northern climate. *Veterinary Parasitology, 182*(1), 54-69. <https://doi.org/10.1016/j.vetpar.2011.07.015>

Jetten, T. H., & Focks, D. A. (1997). Potential changes in the distribution of dengue transmission under climate warming. *The American Journal of Tropical Medicine and Hygiene, 57*(3), 285-297. <https://doi.org/10.4269/ajtmh.1997.57.285>

Ji, W., Huh, K., Kang, M., Hong, J., Bae, G. H., Lee, R., Na, Y., Choi, H., Gong, S. Y., Choi, Y. H., Ko, K. P., Im, J. S., & Jung, J. (2020). Effect of Underlying Comorbidities on the Infection and Severity of COVID-19 in Korea: a Nationwide Case-Control Study. *Journal of Korean medical science, 35*(25), e237. <https://doi.org/10.3346/jkms.2020.35.e237>

Jones, B., & O'Neill, B. C. (2016). Spatially explicit global population scenarios consistent with the Shared Socioeconomic Pathways. *Environmental Research Letters, 11*(8), 1-10. <https://doi.org/10.1088/1748-9326/11/8/084003>

Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L., & Daszak, P. (2008). Global trends in emerging infectious diseases. *Nature, 451*(7181), 990-993. <https://doi.org/10.1038/nature06536>

Jüni, P., Rothenbühler, M., Bobos, P., Thorpe, K. E., da Costa, B. R., Fisman, D. N., Slutsky, A. S., & Gesink, D. (2020). Impact of climate and public health interventions on the COVID-19 pandemic: a prospective cohort study. *CMAJ : Canadian Medical Association journal = journal de l'Association medicale canadienne*, *192*(21), E566–E573. <https://doi.org/10.1503/cmaj.200920>

Junxiong, P., & Yee-Sin, L. (2015). Clustering, climate and dengue transmission. *Expert Review of Anti-infective Therapy, 13*(6), 731-740. <https://doi.org/10.1586/14787210.2015.1028364>

Kamal, M., Kenawy, M. A., Rady, M. H., Khaled, A. S., & Samy, A. M. (2019). Mapping the global potential distributions of two arboviral vectors *Aedes aegypti* and *Ae. albopictus* under changing climate. *PLOS ONE, 13*(12), 1-21. <https://doi.org/10.1371/journal.pone.0210122>

Kane, J., Righter, J., Krajden, S., & Lester, R. S. (1983). Blastomycosis: A new endemic focus in Canada. *CMAJ, 129*(7), 728-731. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1875443/>

Kanzawa, M., Spindler, H., Anglemyer, A., & Rutherford, G. W. (2020). Will Coronavirus Disease 2019 Become Seasonal? *The Journal of infectious diseases*, *222*(5), 719–721. <https://doi.org/10.1093/infdis/jiaa345>

Kauffman, C. A. (2007). Histoplasmosis: A clinical and laboratory update. *Clinical Microbiology Reviews, 20*(1), 115-132. <https://doi.org/10.1128/CMR.00027-06>

Kausrud, K. L., Begon, M., Ari, T. B., Viljugrein. H., Esper, J., Büntgen, U., Leirs, H., Junge, C., Yang, B., Yang, M., Xu, L., Stenseth, N. C. (2010) Modeling the epidemiological history of plague in Central Asia: palaeoclimatic forcing on a disease system over the past millennium. *BMC Biology, 8*, 112. doi: 10.1186/1741-7007-8-112.

Kausrud, K. L., Mysterud, A., Steen, H., Vik, J. O., Østbye, E., Cazelles, B., . . . Stenseth, N. C. (2008). Linking climate change to lemming cycles. *Nature, 456*(7218), 93-97. <https://doi.org/10.1038/nature07442>

KC, S., & Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. *Global Environmental Change, 42*, 181-192. <https://doi.org/10.1016/j.gloenvcha.2014.06.004>

Keegan, J. D., & Holland, C. V. (2010). Contamination of the hair of owned dogs with the eggs of *Toxocara* spp. *Veterinary Parasitology, 173*(1-2), 161-164. <https://doi.org/10.1016/j.vetpar.2010.06.010>

Kepron, M. W., Schoemperlen, C. B., Hershfield, E. S., Zylak, C. J., & Cherniack, R. M. (1972). North American blastomycosis in Central Canada: A review of 36 cases. *CMAJ, 106*(3), 243-246. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1940364/>

Kidd, S. E., Hagen, F., Tscharke, R. L., Huynh, M., Bartlett, K. H., Fyfe, M., Macdougall, L., Boekhout, T., Kwon-Chung, K. J., & Meyer, W. (2004). A rare genotype of Cryptococcus gattii caused the cryptococcosis outbreak on Vancouver Island (British Columbia, Canada). *Proceedings of the National Academy of Sciences of the United States of America, 101*(49), 17258–17263. <https://doi.org/10.1073/pnas.0402981101>

Kidd, S. E., Bach, P. J., Hingston, A. O., Mak, S., Chow, Y., MacDougall, L., . . . Bartlett, K. H. (2007a). *Cryptococcus gattii* dispersal mechanisms, British Columbia, Canada. *Emerging Infectious Diseases, 13*(1), 51-57. <https://doi.org/10.3201/eid1301.060823>

Kidd, S. E., Chow, Y., Mak, S., Bach, P. J., Chen, H., Hingston, A. O., . . . Bartlett, K. H. (2007b). Characterization of environmental sources of the human and animal pathogen *Cryptococcus gattii* in British Columbia, Canada, and the Pacific Northwest of the United States. *Applied and Environmental Microbiology, 73*(5), 1433-1443. <https://doi.org/10.1128/AEM.01330-06>

Kilpatrick, A. M., Dobson, A. D. M., Levi, T., Salkeld, D. J., Swei, A., Ginsberg, H. S., . . . Diuk-Wasser, M. A. (2017). Lyme disease ecology in a changing world: Consensus, uncertainty and critical gaps for improving control. *Philosophical Transactions of the Royal Society B: Biological Sciences, 372*(1722). <https://doi.org/10.1098/rstb.2016.0117>

Kilpatrick, A. M., Kramer, L. D., Jones, M. J., Marra, P. P., & Daszak, P. (2006). West Nile virus epidemics in North America are driven by shifts in mosquito feeding behavior. *PLOS Biology, 4*(4), 0606-0610. <https://doi.org/10.1371/journal.pbio.0040082>

Kim, B. I., Ki, H., Park, S., Cho, E., & Chun, B. C. (2016). Effect of climatic factors on hand, foot, and mouth disease in South Korea, 2010-2013. *PLOS ONE, 11*(6), 1-9. <https://doi.org/10.1371/journal.pone.0157500>

Kinlin, L. M., Spain, C. V., Ng, V., Johnson, C. C., White, A. N. J., & Fisman, D. N. (2009). Environmental exposures and invasive meningococcal disease: An evaluation of effects on varying time scales. *American Journal of Epidemiology, 169*(5), 588-595. <https://doi.org/10.1093/aje/kwn383>

Kirkland, T. N., & Fierer, J. (1996). Coccidioidomycosis: A reemerging infectious disease. *Emerging Infectious Diseases, 3*(2), 192-199. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2626789/>

Kissler, S. M., Tedijanto, C., Goldstein, E., Grad, Y. H., & Lipsitch, M. (2020). Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. *Science (New York, N.Y.), 368*(6493), 860–868. <https://doi.org/10.1126/science.abb5793>

Knobel, D. L., Cleaveland, S., Coleman, P. G., Fèvre, E. M., Meltzer, M. I., Miranda, M. E. G., . . . Meslin, F.-X. (2005). Re-evaluating the burden of rabies in Africa and Asia. *Bulletin of the World Health Organization, 83*(5), 360-368. Retrieved from <https://www.who.int/bulletin/volumes/83/5/360.pdf>

Kotchi S.-O., Bouchard, C., Brazeau, S., Ogden, N.H. (2021) Earth Observation-informed risk maps of the Lyme disease vector *Ixodes scapularis* in Central and Eastern Canada. *Remote Sensing, 13*(3), 524.

Kotwa, J. D., Isaksson, M., Jardine, C. M., Campbell, G. D., Berke, O., Pearl, D. L., . . . Peregrine, A. S. (2019). *Echinococcus multilocularis* infection, Southern Ontario, Canada. *Emerging Infectious Diseases, 25*(2), 265-272. <https://doi.org/10.3201/eid2502.180299>

Kraemer, M. U. G., Reiner, R. C., Jr., Brady, O. J., Messina, J. P., Gilbert, M., Pigott, D. M., . . . Golding, N. (2019). Past and future spread of the arbovirus vectors *Aedes aegypti* and *Aedes albopictus*. *Nature Microbiology, 4*, 854-863. <https://doi.org/10.1038/s41564-019-0376-y>

Kraemer, M. U. G., Sinka, M. E., Duda, K. A., Mylne, A., Shearer, F. M., Brady, O. J., . . . Hay, S. I. (2015). The global compendium of *Aedes aegypti* and *Ae. albopictus* occurrence. *Scientific Data, 2*, 1-8. <https://doi.org/10.1038/sdata.2015.35>

Kramer, L. D., Styer, L. M., & Ebel, G. D. (2008). A global perspective on the epidemiology of West Nile virus. *Annual Review of Entomology, 53*, 61-81. <https://doi.org/10.1146/annurev.ento.53.103106.093258>

Kulkarni, M. A., Berrang-Ford, L., Buck, P. A., Drebot, M. A., Lindsay, L. R., & Ogden, N. H. (2015). Major emerging vector-borne zoonotic diseases of public health importance in Canada. *Emerging Microbes & Infections, 4*(1), 1-7. <https://doi.org/10.1038/emi.2015.33>

Kuster, S. P., Tuite, A. R., Kwong, J. C., McGeer, A., The Toronto Invasive Bacterial Diseases Network, & Fisman, D. N. (2011). Evaluation of coseasonality of influenza and invasive pneumococcal disease: Results from prospective surveillance. *PLOS Medicine, 8*(6), 1-9. <https://doi.org/10.1371/journal.pmed.1001042>

Kwon-Chung, K. J., & Bennett, J. E. (1984). High prevalence of *Cryptococcus neoformans* var. gattii in tropical and subtropical regions. *Zentralblatt für Bakteriologie, Mikrobiologie, und Hygiene Serie A - Medical microbiology, infectious diseases, virology, parasitology, 257*(2), 213-218.

Lafferty, K. D. (2009). The ecology of climate change and infectious diseases. *Ecology, 90*(4), 888-900. <https://doi.org/10.1890/08-0079.1>

Larrieu, S., Cassadou, S., Rosine, J., Chappert, J. L., Blateau, A., Ledrans, M., & Quénel, P. (2014). Lessons raised by the major 2010 dengue epidemics in the French West Indies. *Acta Tropica, 131*, 37-40. <https://doi.org/10.1016/j.actatropica.2013.11.023>

Larsen, J. N., Anisimov, O. A., Constable, A., Hollowed, A. B., Maynard, N., Prestrud, P., . . . Stone, J. M. R. (2014). Polar regions. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1567-1612). Cambridge, United Kingdom: Cambridge University Press. Retrieved from <https://www.ipcc.ch/report/ar5/wg2/>

Lau, L., Wudel, B., Kadkhoda, K., & Keynan, Y. (2017). Snowshoe hare virus causing meningoencephalitis in a young adult from northern Manitoba, Canada. *Open Forum Infectious Diseases, 4*(3), 1-3. <https://doi.org/10.1093/ofid/ofx150>

Lau, S., Luk, H., Wong, A., Li, K., Zhu, L., He, Z., Fung, J., Chan, T., Fung, K., & Woo, P. (2020). Possible Bat Origin of Severe Acute Respiratory Syndrome Coronavirus 2. *Emerging infectious diseases*, *26*(7), 1542–1547. <https://doi.org/10.3201/eid2607.200092>

Lee, A. C. Y., Schantz, P. M., Kazacos, K. R., Montgomery, S. P., & Bowman, D. D. (2010). Epidemiologic and zoonotic aspects of ascarid infections in dogs and cats. *Trends in Parasitology, 26*(4), 155-161. <https://doi.org/10.1016/j.pt.2010.01.002>

Leighton, P. A., Koffi, J. K., Pelcat, Y., Lindsay, L. R., & Ogden, N. H. (2012). Predicting the speed of tick invasion: An empirical model of range expansion for the Lyme disease vector *Ixodes scapularis* in Canada. *Journal of Applied Ecology, 49*(2), 457-464. <https://doi.org/10.1111/j.1365-2664.2012.02112.x>

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: Advancing the methodology. *Implementation Science, 5*, 69. <https://doi.org/10.1186/1748-5908-5-69>

Levine RS, Hedeen DL, Hedeen MW, Hamer GL, Mead DG, Kitron UD. (2017). Avian species diversity and transmission of West Nile virus in Atlanta, Georgia. *Parasites & Vectors, 10*(1), 62. doi: 10.1186/s13071-017-1999-6.

Liao, J., Yu, S., Yang, F., Yang, M., Hu, Y., & Zhang, J. (2016). Short-term effects of climatic variables on hand, foot, and mouth disease in mainland China, 2008-2013: A multilevel spatial Poisson regression model accounting for overdispersion. *PLOS ONE, 11*(1), 1-14. <https://doi.org/10.1371/journal.pone.0147054>

Light, R. B., Kralt, D., Embil, J. M., Trepman, E., Wiebe, L., Limerick, B., . . . Macdonald, K. (2008). Seasonal variations in the clinical presentation of pulmonary and extrapulmonary blastomycosis. *Medical Mycology, 46*(8), 835-841. <https://doi.org/10.1080/13693780802132763>

Likos, A., Griffin, I., Bingham, A. M., Stanek, D., Fischer, M., White, S., . . . Philip, C. (2016). Local mosquito-borne transmission of Zika virus—Miami-Dade and Broward counties, Florida, June–August 2016. *Morbidity and Mortality Weekly Report, 65*(38), 1032-1038. <https://doi.org/10.15585/mmwr.mm6538e1>

Lin, H., Zou, H., Wang, Q., Liu, C., Lang, L., Hou, X., & Li, Z. (2013). Short-term effect of El Niño-Southern Oscillation on pediatric hand, foot and mouth disease in Shenzhen, China. *PLOS ONE, 8*(7), 1-7. <http://doi.org/10.1371/journal.pone.0065585>

Lindquist, E. E., Galloway, T. D., Artsob, H., Lindsay, L. R., Drebot, M., Wood, H., & Robbins, R. G. (2016). *A handbook to the ticks of Canada (Ixodida: Ixodidae, Argasidae): Biological Survey of Canada Monograph Series No. 7*: Biological Survey of Canada. Retrieved from <https://biologicalsurvey.ca/public/Bsc/Controller/Page/AGR-001-Ticks-Monograph.pdf>

Lindsay, A. P., Hope, V., Marshall, R. J., & Salinger, J. (2002). Meningococcal disease and meteorological conditions in Auckland, New Zealand. *Australian and New Zealand Journal of Public Health, 26*(3), 212-218. <https://doi.org/10.1111/j.1467-842X.2002.tb00676.x>

Lindsay, L. R., Barker, I. K., Surgeoner, G. A., Mcewen, S. A., Gillespie, T. J., & Addison, E. M. (1998). Survival and development of the different life stages of *Ixodes scapularis* (Acari: Ixodidae) held within four habitats on Long Point, Ontario, Canada. *Journal of Medical Entomology, 35*(3), 189-199. <https://doi.org/10.1093/jmedent/35.3.189>

Lindsey, N. P., Staples, J. E., & Fischer, M. (2018). Chikungunya virus disease among travelers—United States, 2014-2016. *The American Journal of Tropical Medicine and Hygiene, 98*(1), 192-197. <https://doi.org/10.4269/ajtmh.17-0668>

Litvinjenko, S., & Lunny, D. (2017). Blastomycosis hospitalizations in northwestern Ontario: 2006-2015. *Canada Communicable Disease Report, 43*(10), 200-205. <https://doi.org/10.14745/ccdr.v43i10a02>

Litvinov, I. V., St-Germain, G., Pelletier, R., Paradis, M., & Sheppard, D. C. (2013). Endemic human blastomycosis in Quebec, Canada, 1988–2011. *Epidemiology & Infection, 141*(6), 1143-1147. <https://doi.org/10.1017/S0950268812001860>

Litvintseva, A. P., Marsden-Haug, N., Hurst, S., Hill, H., Gade, L., Driebe, E. M., . . . Chiller, T. (2015). Valley fever: Finding new places for an old disease: *Coccidioides immitis* found in Washington State soil associated with recent human infection. *Clinical Infectious Diseases, 60*(1), e1-e3. <https://doi.org/10.1093/cid/ciu681>

Lohrenz, S., Minion, J., Pandey, M., & Karunakaran, K. (2018). Blastomycosis in southern Saskatchewan 2000–2015: Unique presentations and disease characteristics. *Medical Mycology, 56*(7), 787-795. <https://doi.org/10.1093/mmy/myx131>

Lopman, B., Armstrong, B., Atchison, C., & Gray, J. J. (2009). Host, weather and virological factors drive norovirus epidemiology: Time-series analysis of laboratory surveillance data in England and Wales. *PLOS ONE, 4*(8), 1-10. <https://doi.org/10.1371/journal.pone.0006671>

Ludwig, A., Bigras-Poulin, M., Michel, P., & Bélanger, D. (2010). Risk factors associated with West Nile virus mortality in American Crow populations in southern Quebec. *Journal of Wildlife Diseases, 46*(1), 195-208. <https://doi.org/10.7589/0090-3558-46.1.195>

Ludwig, A., Zheng, H., Vrbova, L., Drebot, M. A., Iranpour, M., & Lindsay, L. R. (2019). Increased risk of endemic mosquito-borne diseases in Canada due to climate change. *Canada Communicable Disease Report, 45*(4), 90-97. <https://doi.org/10.14745/ccdr.v45i04a03>

MacDougall, L., Fyfe, M., Romney, M., Starr, M., & Galanis, E. (2011). Risk factors for *Cryptococcus gattii* infection, British Columbia, Canada. *Emerging Infectious Diseases, 17*(2), 193-199. <https://doi.org/10.3201/eid1702.101020>

MacDougall, L., Kidd, S. E., Galanis, E., Mak, S., Leslie, M. J., Cieslak, P. R., . . . Bartlett, K. H. (2007). Spread of *Cryptococcus gattii* in British Columbia, Canada, and detection in the Pacific Northwest, USA. *Emerging Infectious Diseases, 13*(1), 42-50. <https://doi.org/10.3201/eid1301.060827>

Machado-Machado, E. A. (2012). Empirical mapping of suitability to dengue fever in Mexico using species distribution modeling. *Applied Geography, 33*, 82-93. <https://doi.org/10.1016/j.apgeog.2011.06.011>

Maiga, A. W., Deppen, S., Scaffidi, B. K., Baddley, J., Aldrich, M. C., Dittus, R. S., & Grogan, E. L. (2018). Mapping *Histoplasma capsulatum* exposure, United States. *Emerging Infectious Diseases, 24*(10), 1835-1839. <https://doi.org/10.3201/eid2410.180032>

Mak, S., Morshed, M., & Henry, B. (2010). Ecological niche modeling of Lyme disease in British Columbia, Canada. *Journal of Medical Entomology, 47*(1), 99-105. <https://doi.org/10.1603/033.047.0114>

Maksimovic, Z., Cornwell, M. S., Semren, O., & Rifatbegovic, M. (2017). The apparent role of climate change in a recent anthrax outbreak in cattle. *OIE Scientific and Technical Review, 36*(3), 959-963. <https://doi.org/10.20506/rst.36.3.2727>

Marsden-Haug, N., Goldoft, M., Ralston, C., Limaye, A. P., Chua, J., Hill, H., . . . Chiller, T. (2013). Coccidioidomycosis acquired in Washington state. *Clinical Infectious Diseases, 56*(6), 847-850. <https://doi.org/10.1093/cid/cis1028>

Marston, B. J., Lipman, H. B., & Breiman, R. F. (1994). Surveillance for Legionnaires' disease: Risk factors for morbidity and mortality. *Archives of Internal Medicine, 154*(21), 2417-2422. <https://doi.org/10.1001/archinte.1994.00420210049006>

Mas-Coma, S., Valero, M. A., & Bargues, M. D. (2008). Effects of climate change on animal and zoonotic helminthiasis. *OIE Scientific and Technical Review, 27*(2), 443-457. <https://doi.org/10.20506/rst.27.2.1822>

Maves, R. C., & Crum-Cianflone, N. F. (2012). Coccidioidomycosis: A review. *Infectious Diseases in Clinical Practice, 20*(1), 18-24. <https://doi.org/10.1097/IPC.0b013e31823c4b85>

Mayhew, S., & Hanefeld, J. (2014). Planning adaptive health systems: The climate challenge. *The Lancet Global health, 2*(11), e625-e626. <https://doi.org/10.1016/S2214-109X(14)70313-4>

McBride, J. A., Gauthier, G. M., & Klein, B. S. (2017). Clinical manifestations and treatment of blastomycosis. *Clinics in Chest Medicine, 38*(3), 435-449. <https://doi.org/10.1016/j.ccm.2017.04.006>

McDonough, E. S., Wisniewski, T. R., Penn, L. A., Chan, D. M., & McNamara, W. J. (1976). Preliminary studies on conidial liberation of *Blastomyces dermatitidis* and *Histoplasma capsulatum*. *Sabouraudia, 14*(2), 199-204. <https://doi.org/10.1080/00362177685190271>

McMichael, C., Barnett, J., & McMichael, A. J. (2012). An ill wind? Climate change, migration, and health. *Environmental Health Perspectives, 120*(5), 646-654. <https://doi.org/10.1289/ehp.1104375>

McTaggart, L. R., Brown, E. M., & Richardson, S. E. (2016). Phylogeographic analysis of *Blastomyces dermatitidis* and *Blastomyces gilchristii* reveals an association with North American freshwater drainage basins. *PLOS ONE, 11*(7), 1-22. <https://doi.org/10.1371/journal.pone.0159396>

Medlock, J. M., & Vaux, A. G. C. (2011). Assessing the possible implications of wetland expansion and management on mosquitoes in Britain. *European Mosquito Bulletin, 29*, 38-65. Retrieved from <http://e-m-b.org/sites/e-m-b.org/files/EMB%2829%2938-65.pdf>

Melles, S. J., Fortin, M. J., Lindsay, K., & Badzinski, D. (2011). Expanding northward: Influence of climate change, forest connectivity, and population processes on a threatened species' range shift. *Global Change Biology, 17*(1), 17-31. <https://doi.org/10.1111/j.1365-2486.2010.02214.x>

Michele, M., Alberto, M., Liana, S., & Francesco, D. (2006). Do environmental factors influence the occurrence of acute meningitis in industrialized countries? An epidemic of varying aetiology in Northern Italy. *European Journal of Epidemiology, 21*(6), 465-468. <https://doi.org/10.1007/s10654-006-9013-1>

Millins, C., Gilbert, L., Medlock, J., Hansford, K., Thompson, D. B. A., & Biek, R. (2017). Effects of conservation management of landscapes and vertebrate communities on Lyme borreliosis risk in the United Kingdom. *Philosophical Transactions of the Royal Society B: Biological Sciences, 372*(1722), 1-12. <https://doi.org/10.1098/rstb.2016.0123>

Minigan, J. N., Hager, H. A., Peregrine, A. S., & Newman, J. A. (2018). Current and potential future distribution of the American dog tick (*Dermacentor variabilis*, Say) in North America. *Ticks and Tick-borne Diseases, 9*(2), 354-362. <https://doi.org/10.1016/j.ttbdis.2017.11.012>

Mitchell, R., & Kandola, K. (2005). Rabies in the Northwest Territories Part 2: Rabies surveillance in the Northwest Territories. *EpiNorth, 17*, 4-6.

Monaghan, A. J., Moore, S. M., Sampson, K. M., Beard, C. B., & Eisen, R. J. (2015). Climate change influences on the annual onset of Lyme disease in the United States. *Ticks and Tick-borne Diseases, 6*(5), 615-622. <https://doi.org/10.1016/j.ttbdis.2015.05.005>

Moore, M. (1982). Enteroviral disease in the United States, 1970–1979. *The Journal of Infectious Diseases, 146*(1), 103-108. <https://doi.org/10.1093/infdis/146.1.103>

Moreno-Madriñán, M. J., & Turell, M. (2018). History of mosquitoborne diseases in the United States and implications for new pathogens. *Emerging Infectious Diseases, 24*(5), 821-826. <https://doi.org/10.3201/eid2405.171609>

Morin, C. W., Semenza, J. C., Trtanj, J. M., Glass, G. E., Boyer, C., & Ebi, K. L. (2018). Unexplored opportunities: Use of climate- and weather-driven early warning systems to reduce the burden of infectious diseases. *Current Environmental Health Reports, 5*(4), 430-438. <https://doi.org/10.1007/s40572-018-0221-0>

Morral-Puigmal, C., Martínez-Solanas, È., Villanueva, C. M., & Basagaña, X. (2018). Weather and gastrointestinal disease in Spain: A retrospective time series regression study. *Environment International, 121*(1), 649-657. <https://doi.org/10.1016/j.envint.2018.10.003>

Morris, S. K., Brophy, J., Richardson, S. E., Summerbell, R., Parkin, P. C., Jamieson, F., . . . Ford-Jones, E. L. (2006). Blastomycosis in Ontario, 1994-2003. *Emerging Infectious Diseases, 12*(2), 274-279. <https://doi.org/10.3201/eid1202.050849>

Mouchtouri, V. A., Verykouki, E., Zamfir, D., Hadjipetris, C., Lewis, H. C., Hadjichristodoulou, C., & The EU SHIPSAN ACT Partnership. (2017). Gastroenteritis outbreaks on cruise ships: Contributing factors and thresholds for early outbreak detection. *Eurosurveillance, 22*(45), 1-8. <https://doi.org/10.2807/1560-7917.ES.2017.22.45.16-00576>

Muchaal, P. K., Parker, S., Meganath, K., Landry, L., & Aramini, J. (2015). Evaluation of a national pharmacy-based syndromic surveillance system. *Canada Communicable Disease Report, 41*(9), 203-208. <https://doi.org/10.14745/ccdr.v41i09a01>

Mukhi, S. N., Andres, E., Demianyk, B., Gammon, B., & Kloeze, H. (2016). KIWI: A technology for public health event monitoring and early warning detection. *Online Journal of Public Health Informatics, 8*(3), 1-16. <https://doi.org/10.5210/ojphi.v8i3.6937>

Murray, D. L. (2003). Relapsing fever. In C. D. Rudolph, A. M. Rudolph, M. K. Hostetter, G. Lister, & N. J. Siegel (Eds.), *Rudolph's pediatrics* (21st ed.). New York, NY: McGraw-Hill.

Nakazawa, Y., Williams, R., Peterson, A. T., Mead, P., Staples, E., & Gage, K. L. (2007). Climate change effects on plague and tularemia in the United States. *Vector-Borne and Zoonotic Diseases, 7*(4), 529-540. <https://doi.org/10.1089/vbz.2007.0125>

Nash, D., & Geng, E. (2020). Goal-Aligned, Epidemic Intelligence for the Public Health Response to the COVID-19 Pandemic. *American journal of public health*, *110*(8), 1154–1156. <https://doi.org/10.2105/AJPH.2020.305794>

National Collaborating Centre for Aboriginal Health. (2016). Determinants of the prevalence and severity of influenza infection in Indigenous populations in Canada. Prince George, BC: National Collaborating Centre for Aboriginal Health.

Naughton, D. (2012). *The natural history of Canadian mammals*. Toronto, ON: University of Toronto Press.

Neil, K., & Berkelman, R. (2008). Increasing incidence of Legionellosis in the United States, 1990–2005: Changing epidemiologic trends. *Clinical Infectious Diseases, 47*(5), 591-599. <https://doi.org/10.1086/590557>

Nelder, M. P., Russell, C. B., Clow, K. M., Johnson, S., Weese, J. S., Cronin, K., . . . Patel, S. N. (2019). Occurrence and distribution of *Ambylomma americanum* as determined by passive surveillance in Ontario, Canada (1999–2016). *Ticks and Tick-borne Diseases, 10*(1), 146-155. <https://doi.org/10.1016/J.TTBDIS.2018.10.001>

Neumann, G. (2015). H5N1 influenza virulence, pathogenicity and transmissibility: What do we know? *Future Virology, 10*(8), 971-980. <https://doi.org/10.2217/fvl.15.62>

Neumann, G., Noda, T., & Kawaoka, Y. (2009). Emergence and pandemic potential of swine-origin H1N1 influenza virus. *Nature, 459*(7249), 931-939. <https://doi.org/10.1038/nature08157>

Ng, V., Fazil, A., Gachon, P., Deuymes, G., Radojević, M., Mascarenhas, M., . . . Ogden, N. H. (2017). Assessment of the probability of autochthonous transmission of chikungunya virus in Canada under recent and projected climate change. *Environmental Health Perspectives, 125*(6), 1-12. <https://doi.org/10.1289/ehp669>

Ng, V., Rees, E. E., Lindsay, R. L., Drebot, M. A., Brownstone, T., Sadeghieh, T., & Khan, S. U. (2019). Could exotic mosquito-borne diseases emerge in Canada with climate change? *Canada Communicable Disease Report, 45*(4), 98-107. <https://doi.org/10.14745/ccdr.v45i04a04>

Ng, V., & Sargeant, J. M. (2012). A stakeholder-informed approach to the identification of criteria for the prioritization of zoonoses in Canada. *PLOS ONE, 7*(1), 1-12. <https://doi.org/10.1371/journal.pone.0029752>

Nguyen, C., Barker, B. M., Hoover, S., Nix, D. E., Ampel, N. M., Frelinger, J. A., . . . Galgiani, J. N. (2013). Recent advances in our understanding of the environmental, epidemiological, immunological, and clinical dimensions of coccidioidomycosis. *Clinical Microbiology Reviews, 26*(3), 505-525. <https://doi.org/10.1128/CMR.00005-13>

Nicolle, L., Rotstein, C., Bourgault, A., St-Germain, G., Garber, G., & Canadian Infectious Diseases Society Invasive Fungal Registry (1998). Invasive fungal infections in Canada from 1992 to 1994. *The Canadian journal of infectious diseases = Journal canadien des maladies infectieuses, 9*(6), 347–352. doi:10.1155/1998/473219

Nishi, J. S., Stephen, C., & Elkin, B. T. (2002). Implications of agricultural and wildlife policy on management and eradication of bovine tuberculosis and brucellosis in free-ranging wood bison of northern Canada. *Annals of the New York Academy of Sciences, 969*(1), 236-244. <https://doi.org/10.1111/j.1749-6632.2002.tb04385.x>

Nyström, M.E., Karltun, J., Keller, C., Andersson Gäre B. (2018). Collaborative and partnership research for improvement of health and social services: researcher's experiences from 20 projects. *Health Research Policy and Systems, 16*, 46 doi:10.1186/s12961-018-0322-0

O'Brien, S. F., Delage, G., Scalia, V., Lindsay, R., Bernier, F., Dubuc, S., . . . Fearon, M. A. (2016). Seroprevalence of *Babesia microti* infection in Canadian blood donors. *Transfusion, 56*(1), 237-243. <https://doi.org/10.1111/trf.13339>

O'Connor, S. M., Taylor, C. E., & Hughes, J. M. (2006). Emerging infectious determinants of chronic diseases. *Emerging Infectious Diseases, 12*(7), 1051-1057. <https://doi.org/10.3201/eid1207.060037>

O'Lorcain, P. (1995). The effects of freezing on the viability of *Toxocara canis* and *T. cati* embryonated eggs. *Journal of Helminthology, 69*(2), 169-171. <https://doi.org/10.1017/S0022149X00014073>

Ogden, N. H. (2014). Lyme disease and climate change. In C. D. Butler (Ed.), *Climate change and global health* (pp. 145-157). Wallingford, United Kingdom: CABI.

Ogden, N. H. (2017). Climate change and vector-borne diseases of public health significance. *FEMS Microbiology Letters, 364*(19), 1-8. <https://doi.org/10.1093/femsle/fnx186>

Ogden, N. H., AbdelMalik, P., & Pulliam, J. R. C. (2017). Emerging infectious diseases: Prediction and detection. *Canada Communicable Disease Report, 43*(10), 206-211. <https://doi.org/10.14745/ccdr.v43i10a03>

Ogden, N. H., Bigras-Poulin, M., O'Callaghan, C. J., Barker, I. K., Lindsay, L. R., Maarouf, A., . . . Charron, D. (2005). A dynamic population model to investigate effects of climate on geographic range and seasonality of the tick *Ixodes scapularis*. *International Journal for Parasitology, 35*(4), 375-389. <https://doi.org/10.1016/j.ijpara.2004.12.013>

Ogden, N. H., Bouchard, C., Kurtenbach, K., Margos, G., Lindsay, L. R., Trudel, L., . . . Milord, F. (2010). Active and passive surveillance and phylogenetic analysis of *Borrelia burgdorferi* elucidate the process of Lyme disease risk emergence in Canada. *Environmental Health Perspectives, 118*(7), 909-914. <https://doi.org/10.1289/ehp.0901766>

Ogden, N. H., & Gachon, P. (2019). Climate change and infectious diseases: What can we expect?. *Canada communicable disease report = Releve des maladies transmissibles au Canada*, *45*(4), 76–80. <https://doi.org/10.14745/ccdr.v45i04a01>

Ogden, N. H., Koffi, J. K., Pelcat, Y., & Lindsay, L. R. (2014c). Environmental risk from Lyme disease in central and eastern Canada: A summary of recent surveillance information. *Canada Communicable Disease Report, 40*(5), 74-82. <https://doi.org/10.14745/ccdr.v40i05a01>

Ogden, N.H., Maarouf, A., Barker, I.K., Bigras-Poulin, M., Lindsay, L.R., Morshed, M.G., O'Callaghan, C.J., Ramay, F., Waltner-Toews, D. & Charron, D.F. (2006). Climate change and the potential for range expansion of the Lyme disease vector *Ixodes scapularis* in Canada. *International Journal for Parasitology*, *36*, 63-70.

Ogden, N. H., & Lindsay, L. R. (2016). Effects of climate and climate change on vectors and vector-borne diseases: Ticks are different. *Trends in Parasitology, 32*(8), 646-656. <https://doi.org/10.1016/j.pt.2016.04.015>

Ogden, N. H., Lindsay, L. R., Hanincová, K., Barker, I. K., Bigras-Poulin, M., Charron, D. F., . . . Thompson, R. A. (2008). Role of migratory birds in introduction and range expansion of *Ixodes scapularis* ticks and of *Borrelia burgdorferi* and *Anaplasma phagocytophilum* in Canada. *Applied and Environmental Microbiology, 74*(6), 1780-1790. <https://doi.org/10.1128/AEM.01982-07>

Ogden, N. H., Lindsay, L. R., & Leighton, P. A. (2013). Predicting the rate of invasion of the agent of Lyme disease, *Borrelia burgdorferi*. *Journal of Applied Ecology, 50*(2), 510-518. <https://doi.org/10.1111/1365-2664.12050>

Ogden, N. H., Lindsay, L. R., Ludwig, A., Morse, A. P., Zheng, H., & Zhu, H. (2019). Weather-based forecasting of mosquito-borne disease outbreaks in Canada. *Canada Communicable Disease Report, 45*(5), 127-132. <https://doi.org/10.14745/ccdr.v45i05a03>

Ogden, N. H., Lindsay, L. R., & Schofield, S. W. (2015). Methods to prevent tick bites and Lyme disease. *Clinics in Laboratory Medicine, 35*(4), 883-899. <https://doi.org/10.1016/j.cll.2015.07.003>

Ogden, N. H., Margos, G., Artsob, H., & Tsao, J. I. (2014b). Non-rickettsial tick-borne bacteria and the diseases they cause. In D. E. Sonenshine & R. M. Roe (Eds.), *Biology of ticks* (2nd ed., Vol. 2, pp. 278-312). New York, NY: Oxford University Press.

Ogden, N. H., Pang, G., Ginsberg, H. S., Hickling, G. J., Burke, R. L., Beati, L., & Tsao, J. I. (2018). Evidence for geographic variation in life-cycle processes affecting phenology of the Lyme disease vector *Ixodes scapularis* (Acari: Ixodidae) in the United States. *Journal of Medical Entomology, 55*(6), 1386-1401. <https://doi.org/10.1093/jme/tjy104>

Ogden, N. H., Radojević, M., Caminade, C., & Gachon, P. (2014a). Recent and projected future climatic suitability of North America for the Asian tiger mosquito *Aedes albopictus*. *Parasites & Vectors, 7*, 1-14. <https://doi.org/10.1186/s13071-014-0532-4>

Ogden, N. H., Wilson, J. R. U., Richardson, D. M., Hui, C., Davies, S. J., Kumschick, S., . . . Pulliam, J. R. C. (2019). Emerging infectious diseases and biological invasions: A call for a One Health collaboration in science and management. *Royal Society Open Science, 6*(3), 1-15. <https://doi.org/10.1098/rsos.181577>

Oliveira, A. R. S., Piaggio, J., Cohnstaedt, L. W., McVey, D. S., & Cernicchiaro, N. (2018). A quantitative risk assessment (QRA) of the risk of introduction of the Japanese encephalitis virus (JEV) in the United States via infected mosquitoes transported in aircraft and cargo ships. *Preventive Veterinary Medicine, 160*, 1-9. <https://doi.org/10.1016/j.prevetmed.2018.09.020>

Onozuka, D., & Hashizume, M. (2011). The influence of

\temperature and humidity on the incidence of hand, foot, and mouth disease in Japan. *Science of the Total Environment, 410-411*, 119-125. <https://doi.org/10.1016/j.scitotenv.2011.09.055>

Ooi, E.-E., & Gubler, D. J. (2009). Global spread of epidemic dengue: the influence of environmental change. *Future Virology, 4*(6), 571-580. 10.2217/fvl.09.55

O'Reilly, K. M., Auzenbergs, M., Jafari, Y., Liu, Y., Flasche, S., & Lowe, R. (2020). Effective transmission across the globe: the role of climate in COVID-19 mitigation strategies. *The Lancet. Planetary health*, *4*(5), e172. <https://doi.org/10.1016/S2542-5196(20)30106-6>

Otten A., Fazil, A., Chemeris, A., Breadner, P., & Ng, V. (2019). Prioritization of vector-borne diseases in Canada under current climate and projected climate change. Microbial Risk Analysis. <https://doi.org/10.1016/j.mran.2019.100089>

Overy, D. P., McBurney, S., Muckle, A., Lund, L., Lewis, P. J., & Strang, R. (2016). *Cryptococcus gattii* VGIIb-like variant in white-tailed deer, Nova Scotia, Canada. *Emerging Infectious Diseases, 22*(6), 1131-1133. doi:10.3201/eid2206.160081

Paaijmans, K. P., Cator, L. J., & Thomas, M. B. (2013). Temperature-dependent pre-bloodmeal period and temperature-driven asynchrony between parasite development and mosquito biting rate reduce malaria transmission intensity. *PLOS ONE, 8*(1), 1-7. doi: 10.1371/journal.pone.0055777

Paaijmans, K. P., Read, A. F., & Thomas, M. B. (2009). Understanding the link between malaria risk and climate. *Proceedings of the National Academy of Sciences of the United States of America, 106*(33), 13844-13849. doi: 10.1073/pnas.0903423106

Pan-Canadian Public Health Network. (2016) Retrieved from <http://www.phn-rsp.ca/index-eng.php>

Pandemic Influenza Outbreak Research Modelling Team. (2009). Modelling an influenza pandemic: a guide for the perplexed. *CMAJ, 181*(3-4), 171-173. doi: 10.1503/cmaj.090885

Panic, M., & Ford, J. D. (2013). A review of national-level adaptation planning with regards to the risks posed by climate change on infectious diseases in 14 OECD nations. *International Journal of Environmental Research and Public Health, 10*(12), 7083-7109. <https://doi.org/10.3390/ijerph10127083>

Papp, Z., Clark, R. G., Parmley, E. J., Leighton, F. A., Waldner, C., & Soos, C. (2017). The ecology of avian influenza viruses in wild dabbling ducks (*Anas* spp.) in Canada. *PLOS ONE, 12*(5), 1-18. <https://doi.org/10.1371/journal.pone.0176297>

Park, Benjamin J., Sigel, K., Vaz, V., Komatsu, K., McRill, C., Phelan, M., . . . Hajjeh, Rana A. (2005). An epidemic of coccidioidomycosis in Arizona associated with climatic changes, 1998-2001. *The Journal of Infectious Diseases, 191*(11), 1981-1987. <https://doi.org/10.1086/430092>

Parkinson, A. J., Evengard, B., Semenza, J. C., Ogden, N., Børresen, M. L., Berner, J., . . . Albihn, A. (2014). Climate change and infectious diseases in the Arctic: Establishment of a circumpolar working group. *International Journal of Circumpolar Health, 73*(1), 1-7. <https://doi.org/10.3402/ijch.v73.25163>

Pastula, D. M., Hoang Johnson, D. K., White, J. L., Dupuis, A. P., Fischer, M., & Staples, J. E. (2015). Jamestown Canyon virus disease in the United States—2000-2013. *The American Journal of Tropical Medicine and Hygiene, 93*(2), 384-389. <https://doi.org/10.4269/ajtmh.15-0196>

Patel, M. M., Pitzer, V. E., Alonso, W. J., Vera, D., Lopman, B., Tate, J., . . . Parashar, U. D. (2013). Global seasonality of rotavirus disease. *The Pediatric Infectious Disease Journal, 32*(4), e134-e147. <https://doi.org/10.1097/INF.0b013e31827d3b68>

Pathogen Regulation Directorate. (2010). *Pathogen safety data sheets: Infectious substances—West Nile virus (WNV)*. Public Health Agency of Canada Retrieved from <https://www.canada.ca/en/public-health/services/laboratory-biosafety-biosecurity/pathogen-safety-data-sheets-risk-assessment/west-nile-virus.html>

Patz, J. A., Githeko, A. K., McCarty, J. P., Hussein, S., Confalonieri, U., & de Wet, N. (2003). Climate change and infectious diseases. In A. J. McMichael, D. H. Campbell-Lendrum, C. F. Corvalán, K. L. Ebi, A. Githeko, J. D. Scheraga, & A. Woodward (Eds.), *Climate change and human health: Risks and responses* (pp. 103-132). Geneva, Switzerland: World Health Organization.

Patz, J.A., Campbell-Lendrum, D., Holloway, T. & Foley, J.A. (2005). Impact of regional climate change on human health. *Nature*, 438, 310-7. doi: 10.1038/nature04188.

Paz, S. (2015). Climate change impacts on West Nile virus transmission in a global context. *Philosophical Transactions of the Royal Society B: Biological Sciences, 370*(1665), 1-11. <https://doi.org/10.1098/rstb.2013.0561>

Paz, S., & Semenza, J. C. (2016). El Niño and climate change—Contributing factors in the dispersal of Zika virus in the Americas? *The Lancet, 387*(10020), 745. <https://doi.org/10.1016/S0140-6736(16)00256-7>

Pequeno, P., Mendel, B., Rosa, C., Bosholn, M., Souza, J. L., Baccaro, F., Barbosa, R., & Magnusson, W. (2020). Air transportation, population density and temperature predict the spread of COVID-19 in Brazil. *PeerJ*, *8*, e9322. <https://doi.org/10.7717/peerj.9322>

Peters, M., Godfrey, C., McInerney, P., Soares, C. B., Khalil, H., & Parker, D. (2015). *The Joanna Briggs Institute reviewers' manual 2015: Methodology for JBI scoping reviews*. Adelaide, Australia: The Joanna Briggs Institute.

Petersen, L. R., Brault, A. C., & Nasci, R. S. (2013a). West Nile virus: Review of the literature. *JAMA, 310*(3), 308-315. <https://doi.org/10.1001/jama.2013.8042>

Petersen, L. R., Carson, P. J., Biggerstaff, B. J., Custer, B., Borchardt, S. M., & Busch, M. P. (2013b). Estimated cumulative incidence of West Nile virus infection in US adults, 1999–2010. *Epidemiology & Infection, 141*(3), 591-595. <https://doi.org/10.1017/s0950268812001070>

Pfister, J. R., Archer, J. R., Hersil, S., Boers, T., Reed, K. D., Meece, J. K., . . . Davis, J. P. (2011). Non-rural point source blastomycosis outbreak near a yard waste collection site. *Clinical Medicine & Research, 9*(2), 57-65. <https://doi.org/10.3121/cmr.2010.958>

Phillips, P., Galanis, E., MacDougall, L., Chong, M. Y., Balshaw, R., Cook, V. J., . . . Thompson, D. (2015). Longitudinal clinical findings and outcome among patients with *Cryptococcus gattii* infection in British Columbia. *Clinical Infectious Diseases, 60*(9), 1368-1376. <https://doi.org/10.1093/cid/civ041>

Picard-Masson, M., Lajoie, É., Lord, J., Lalancette, C., Marchand, G., Levac, É., . . . Lajoie, L. (2016). Two related occupational cases of *Legionella longbeachae* infection, Quebec, Canada. *Emerging Infectious Diseases, 22*(7), 1289-1291. <https://doi.org/10.3201/eid2207.160184>

Plummer, F. A., Jones, S. M. (2017), The story of Canada's Ebola vaccine. *Canadian Medical Association Journal, 189* (43), E1326-E1327

Plummer, P. J., McClure, J. T., Menzies, P., Morley, P. S., Van den Brom, R., & Van Metre, D. C. (2018). Management of *Coxiella burnetii* infection in livestock populations and the associated zoonotic risk: A consensus statement. *Journal of Veterinary Internal Medicine, 32*(5), 1481-1494. <https://doi.org/10.1111/jvim.15229>

Proctor, M. E., Klein, B. S., Jones, J. M., & Davis, J. P. (2002). Cluster of pulmonary blastomycosis in a rural community: Evidence for multiple high-risk environmental foci following a sustained period of diminished precipitation. *Mycopathologia, 153*(3), 113-120. <https://doi.org/10.1023/A:1014515230994>

Public Health Agency of Canada. (2009). Case definitions for communicable diseases under national surveillance. *Cananda Communicable Disease Report, 35*(Suppl.2).

Rabaan, A. A. (2019). Cholera: An overview with reference to the Yemen epidemic. *Frontiers of Medicine, 13*(2), 213-228. <https://doi.org/10.1007/s11684-018-0631-2>

Raghavan, R. K., Peterson, A. T., Cobos, M. E., Ganta, R., & Foley, D. (2019). Current and future distribution of the lone star tick, *Amblyomma americanum* (L.) (Acari: Ixodidae) in North America. *PLOS ONE, 14*(1), 1-13. <https://doi.org/10.1371/journal.pone.0209082>

Rajagopalan, S., & Yoshikawa, T. T. (2016). Norovirus infections in long-term care facilities. *Journal of the American Geriatrics Society, 64*(5), 1097-1103. <https://doi.org/10.1111/jgs.14085>

Randazzo, W., Truchado, P., Cuevas-Ferrando, E., Simón, P., Allende, A., & Sánchez, G. (2020). SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. *Water research*, *181*, 115942. <https://doi.org/10.1016/j.watres.2020.115942>

Randolph, S. E. (2004). Faune, climat et politique: Causes possibles aux récents accroissements des zoonoses à tiques [Fauna, climate and politics: Possible causes for the recent increases in tick-borne zoonoses]. *Archives de Pédiatrie, 11*(10), 1282-1285. <https://doi.org/10.1016/j.arcped.2003.12.019>

Rausch, R. (1956). Studies on the helminth fauna of Alaska: XXX. The occurrence of *Echinococcus multilocularis* Leuckart, 1863, on the mainland of Alaska. *The American Journal of Tropical Medicine and Hygiene, 5*(6), 1086-1092. <https://doi.org/10.4269/ajtmh.1956.5.1086>

Reed, K. D., Meece, J. K., Archer, J. R., & Peterson, A. T. (2008). Ecologic niche modeling of *Blastomyces dermatitidis* in Wisconsin. *PLOS ONE, 3*(4), 1-7. <https://doi.org/10.1371/journal.pone.0002034>

Reeves, W. C., Hardy, J. L., Reisen, W. K., & Milby, M. M. (1994). Potential effect of global warming on mosquito-borne arboviruses. *Journal of Medical Entomology, 31*(3), 323-332. <https://doi.org/10.1093/jmedent/31.3.323>

Reina Ortiz, M., Le, N. K., Sharma, V., Hoare, I., Quizhpe, E., Teran, E., . . . Izurieta, R. (2017). Post-earthquake Zika virus surge: Disaster and public health threat amid climatic conduciveness. *Scientific Reports, 7*, 1-10. <https://doi.org/10.1038/s41598-017-15706-w>

Reisen, W., & Brault, A. C. (2007). West Nile virus in North America: Perspectives on epidemiology and intervention. *Pest Management Science, 63*(7), 641-646. <https://doi.org/10.1002/ps.1325>

Reisen, W. K. (2013). Ecology of West Nile virus in North America. *Viruses, 5*(9), 2079-2105. <https://doi.org/10.3390/v5092079>

Reiter, P. (2001). Climate change and mosquito-borne disease. *Environmental Health Perspectives*, 109(suppl 1), 141–161.

Reiter, P. (2008). Climate change and mosquito-borne disease: Knowing the horse before hitching the cart. *OIE Scientific and Technical Review, 27*(2), 383-398. <https://doi.org/10.20506/rst.27.2.1804>

Revich, B., Tokarevich, N., & Parkinson, A. J. (2012). Climate change and zoonotic infections in the Russian Arctic. *International Journal of Circumpolar Health, 71*(1), 1-8. <https://doi.org/10.3402/ijch.v71i0.18792>

Reynolds, H. H., & Elston, D. M. (2017). What's eating you? Lone star tick (*Amblyomma americanum*). *Cutis, 99*(2), 111-114. Retrieved from <https://www.mdedge.com/dermatology/article/130759/infectious-diseases/whats-eating-you-lone-star-tick-amblyomma-americanum>

Rezza, G., Nicoletti, L., Angelini, R., Romi, R., Finarelli, A. C., Panning, M., . . . Cassone, A. (2007). Infection with chikungunya virus in Italy: An outbreak in a temperate region. *The Lancet, 370*(9602), 1840-1846. <https://doi.org/10.1016/s0140-6736(07)61779-6>

Ripoche, M., Campagna, C., Ludwig, A., Ogden, N. H., & Leighton, P. A. (2019). Short-term forecasting of daily abundance of West Nile virus vectors *Culex pipiens-restuans* (Diptera: Culicidae) and *Aedes vexans* based on weather conditions in southern Québec (Canada). *Journal of Medical Entomology, 56*(3), 859-872. <https://doi.org/10.1093/jme/tjz002>

Roberts, K. C., Rao, D. P., Bennett, T. L., Loukine, L., Jayaraman, G. C. (2015). Prevalence and patterns of chronic disease multimorbidity and associated determinants in Canada. *Health Promotion and Chronic Disease Prevention Canada, 35*(6), 87-94. doi: 10.24095/hpcdp.35.6.01. PMID: 26302227; PMCID: PMC4910465

Rocheleau, J. P., Michel, P., Lindsay, L. R., Drebot, M., Dibernardo, A., Ogden, N. H., . . . Arsenault, J. (2018). Risk factors associated with seropositivity to California serogroup viruses in humans and pet dogs, Quebec, Canada. *Epidemiology & Infection, 146*(9), 1167-1176. <https://doi.org/10.1017/s0950268818001000>

Rodenhouse, N. L., Christenson, L. M., Parry, D., & Green, L. E. (2009). Climate change effects on native fauna of northeastern forests. *Canadian Journal of Forest Research, 39*(2), 249-263. <https://doi.org/10.1139/X08-160>

Roe, C. C., Bowers, J., Oltean, H., DeBess, E., Dufresne, P. J., McBurney, S., . . . Engelthaler, D. M. (2018). Dating the *Cryptococcus gattii* dispersal to the North American Pacific Northwest. *mSphere, 3*(1), 1-13. <https://doi.org/10.1128/mSphere.00499-17>

Rohr, J. R., Dobson, A. P., Johnson, P. T. J., Kilpatrick, A. M., Paull, S. H., Raffel, T. R., . . . Thomas, M. B. (2011). Frontiers in climate change-disease research. *Trends in Ecology & Evolution, 26*(6), 270-277. <https://doi.org/10.1016/j.tree.2011.03.002>

Romeo-Aznar, V., Paul, R., Telle, O., & Pascual, M. (2018). Mosquito-borne transmission in urban landscapes: The missing link between vector abundance and human density. *Proceedings of the Royal Society B: Biological Sciences, 285*(1884), 1-9. <https://doi.org/10.1098/rspb.2018.0826>

Romero-Lankao, P., Smith, J. B., Davidson, D. J., Diffenbaugh, N. S., Kinney, P. L., Kirshen, P., . . . Villers Ruiz, L. (2014). North America. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1439-1498). Cambridge, England: Cambridge University Press. Retrieved from <https://www.ipcc.ch/report/ar5/wg2/>

Rosas, Á. L., & Casadevall, A. (2006). Melanization affects susceptibility of *Cryptococcus neoformans* to heat and cold. *FEMS Microbiology Letters, 153*(2), 265-272. <https://doi.org/10.1111/j.1574-6968.1997.tb12584.x>

Rosatte, R. C. (1988). Rabies in Canada: History, epidemiology and control. *The Canadian Veterinary Journal, 29*(4), 362-365. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1680921/>

Rosenstein, N. E., Perkins, B. A., Stephens, D. S., Popovic, T., & Hughes, J. M. (2001). Meningococcal disease. *The New England Journal of Medicine, 344*(18), 1378-1388. <https://doi.org/10.1056/NEJM200105033441807>

Roussel, M., Pontier, D., Cohen, J.-M., Lina, B., & Fouchet, D. (2016). Quantifying the role of weather on seasonal influenza. *BMC Public Health, 16*, 1-14. <https://doi.org/10.1186/s12889-016-3114-x>

Rycroft-Malone, J., Burton, C., Wilkinson, J., Harvey, G., McCormack, B., Baker, R., Dopson, S., Graham, I.D., Staniszewska, S., Thompson, C., Ariss, S., Melville-Richards, L., Williams, L. (2015). Collective action for implementation: a realist evaluation of organisational collaboration in healthcare. *Implementation Science, 11*(17). doi:10.1186/s13012-016-0380-z

Safronetz, D., Sloan, A., Stein, D. R., Mendoza, E., Barairo, N., Ranadheera, C., . . . Drebot, M. (2017). Evaluation of 5 commercially available Zika virus immunoassays. *Emerging Infectious Diseases, 23*(9), 1577-1580. <https://doi.org/10.3201/eid2309.162043>

Sage, K. M., Johnson, T. L., Teglas, M. B., Nieto, N. C., & Schwan, T. G. (2017). Ecological niche modeling and distribution of *Ornithodoros hermsi* associated with tick-borne relapsing fever in western North America. *PLOS Neglected Tropical Diseases, 11*(10), 1-18. <https://doi.org/10.1371/journal.pntd.0006047

Sagurova I, Ludwig A, Ogden NH, Pelcat Y, Dueymes G, Gachon P. (2019). Predicted northward expansion of the geographic range of the tick vector *Amblyomma americanum* in North America under future climate conditions. *Environmental Health Perspectives*, *127*(10), 107014. doi: 10.1289/EHP5668

Sakamoto, R., Ohno, A., Nakahara, T., Satomura, K., Iwanaga, S., Kouyama, Y., . . . Yamaguchi, K. (2009). *Legionella pneumophila* in rainwater on roads. *Emerging Infectious Diseases, 15*(8), 1295-1297. <https://doi.org/10.3201/eid1508.090317>

Salb, A. L., Barkema, H. W., Elkin, B. T., Thompson, R. C. A., Whiteside, D. P., Black, S. R., . . . Kutz, S. J. (2008). Dogs as sources and sentinels of parasites in humans and wildlife, northern Canada. *Emerging Infectious Diseases, 14*(1), 60-63. <https://doi.org/10.3201/eid1401.071113>

Salkeld DJ, Padgett KA, Jones JH. (2013). A meta-analysis suggesting that the relationship between biodiversity and risk of zoonotic pathogen transmission is idiosyncratic. *Ecology Letters*, 16(5), 679-686

Samia, N. I., Kausrud, K. L., Heesterbeek, H., Ageyev, V., Begon, M., Chan, K. S., Stenseth, N. C. (2011) Dynamics of the plague-wildlife-human system in Central Asia are controlled by two epidemiological thresholds. *Proceedings of the National Academies of Science of the U S A, 108*(35), 14527-14532.

Samy, A. M., Elaagip, A. H., Kenawy, M. A., Ayres, C. F., Peterson, A. T., & Soliman, D. E. (2016). Climate change influences on the global potential distribution of the mosquito *Culex quinquefasciatus*, vector of West Nile virus and lymphatic filariasis. *PLOS ONE, 11*(10), 1-13. <https://doi.org/10.1371/journal.pone.0163863>

Sapp, S. G. H., Rascoe, L. N., Wilkins, P. P., Handali, S., Gray, E. B., Eberhard, M. L., . . . Yabsley, M. J. (2016). *Baylisascaris procyonis* roundworm seroprevalence among wildlife rehabilitators, United States and Canada, 2012–2015. *Emerging Infectious Diseases, 22*(12), 2128-2131. <https://doi.org/10.3201/eid2212.160467>

Schanzer, D. L., Langley, J. M., & Tam, T. W. S. (2006). Hospitalization attributable to influenza and other viral respiratory illnesses in Canadian children. *The Pediatric Infectious Disease Journal, 25*(9), 795-800. <https://doi.org/10.1097/01.inf.0000232632.86800.8c>

Schanzer, D. L., Langley, J. M., & Tam, T. W. S. (2008). Role of influenza and other respiratory viruses in admissions of adults to Canadian hospitals. *Influenza and Other Respiratory Viruses, 2*(1), 1-8. <https://doi.org/10.1111/j.1750-2659.2008.00035.x>

Schanzer, D. L., McGeer, A., & Morris, K. (2013a). Statistical estimates of respiratory admissions attributable to seasonal and pandemic influenza for Canada. *Influenza and Other Respiratory Viruses, 7*(5), 799-808. <https://doi.org/10.1111/irv.12011>

Schanzer, D. L., Sevenhuysen, C., Winchester, B., & Mersereau, T. (2013b). Estimating influenza deaths in Canada, 1992-2009. *PLOS ONE, 8*(11), 1-11. <https://doi.org/10.1371/journal.pone.0080481>

Schneeberger, P. M., Wintenberger, C., van der Hoek, W., & Stahl, J. P. (2014). Q fever in the Netherlands 2007-2010: What we learned from the largest outbreak ever. *Médecine et Maladies Infectieuses, 44*(8), 339-353. <https://doi.org/10.1016/j.medmal.2014.02.006>

Schultz-Cherry, S., Olsen, C. W., & Easterday, B. C. (2011). History of swine influenza. *Current Topics in Microbiology and Immunology, 370*, 21-28. <https://doi.org/10.1007/82_2011_197>

Seitz, A. E., Adjemian, J., Steiner, C. A., & Prevots, D. R. (2015). Spatial epidemiology of blastomycosis hospitalizations: Detecting clusters and identifying environmental risk factors. *Medical Mycology, 53*(5), 447-454. <https://doi.org/10.1093/mmy/myv014>

Sejvar, J. J. (2014). Clinical manifestations and outcomes of West Nile virus infection. *Viruses, 6*(2), 606-623. <https://doi.org/10.3390/v6020606>

Semenza, J. C., Lindgren, E., Balkanyi, L., Espinosa, L., Almqvist, M. S., Penttinen, P., & Rocklöv, J. (2016). Determinants and drivers of infectious disease threat events in Europe. *Emerging Infectious Diseases, 22*(4), 581-589. <https://doi.org/10.3201/eid2204>

Septfons, A., Leparc-Goffart, I., Couturier, E., Franke, F., Deniau, J., Balestier, A., . . . De Valk, H. (2016). Travel-associated and autochthonous Zika virus infection in mainland France, 1 January to 15 July 2016. *Eurosurveillance, 21*(32), 1-7. <https://doi.org/10.2807/1560-7917.Es.2016.21.32.30315>

Shafir, S. C., Sorvillo, F. J., Sorvillo, T., & Eberhard, M. L. (2011). Viability of *Baylisascaris procyonis* eggs. *Emerging Infectious Diseases, 17*(7), 1293-1295. <https://doi.org/10.3201/eid1707.101774>

Shaman, J., Day, J. F., & Stieglitz, M. (2005). Drought-induced amplification and epidemic transmission of West Nile virus in southern Florida. *Journal of Medical Entomology, 42*(2), 134-141. <https://doi.org/10.1093/jmedent/42.2.134>

Shaman, J., Pitzer, V. E., Viboud, C., Grenfell, B. T., & Lipsitch, M. (2010). Absolute humidity and the seasonal onset of influenza in the continental United States. *PLOS Biology, 8*(2), 1-13. <https://doi.org/10.1371/journal.pbio.1000316>

Shapiro, L. L. M., Whitehead, S. A., & Thomas, M. B. (2017). Quantifying the effects of temperature on mosquito and parasite traits that determine the transmission potential of human malaria. *PLOS Biology, 15*(10), 1-21. <https://doi.org/10.1371/journal.pbio.2003489>

Silk, B. J., Foltz, J. L., Ngamsnga, K., Brown, E., Muñoz, M. G., Hampton, L. M., . . . Hicks, L. A. (2013). Legionnaires' disease case-finding algorithm, attack rates, and risk factors during a residential outbreak among older adults: An environmental and cohort study. *BMC Infectious Diseases, 13*, 1-8. <https://doi.org/10.1186/1471-2334-13-291>

Simmering, J. E., Polgreen, L. A., Hornick, D. B., Sewell, D. K., & Polgreen, P. M. (2017). Weather-dependent risk for Legionnaires' disease, United States. *Emerging Infectious Diseases, 23*(11), 1843-1851. <https://doi.org/10.3201/eid2311.170137>

Simon, A., Tardy, O., Hurford, A., Lecomte, N., Bélanger, D., & Leighton, P. (2019). Dynamics and persistence of rabies in the Arctic. *Polar Research, 38*, 1-14.

Simon, J. A., Marrotte, R. R., Desrosiers, N., Fiset, J., Gaitan, J., Gonzalez, A., . . . Millien, V. (2014). Climate change and habitat fragmentation drive the occurrence of *Borrelia burgdorferi*, the agent of Lyme disease, at the northeastern limit of its distribution. *Evolutionary Applications, 7*(7), 750-764. <https://doi.org/10.1111/eva.12165>

Sivabalan, P., Saboo, A., Yew, J., & Norton, R. (2017). Q fever in an endemic region of North Queensland, Australia: A 10 year review. *One Health, 3*, 51-55. <https://doi.org/10.1016/J.ONEHLT.2017.03.002>

Skog, L., Linde, A., Palmgren, H., Hauska, H., & Elgh, F. (2014). Spatiotemporal characteristics of pandemic influenza. *BMC Infectious Diseases, 14*, 1-14. <https://doi.org/10.1186/1471-2334-14-378>

Skowronski, D. M., Li, Y., Tweed, S. A., Tam, T. W. S., Petric, M., David, S. T., . . . Brunham, R. C. (2007). Protective measures and human antibody response during an avian influenza H7N3 outbreak in poultry in British Columbia, Canada. *CMAJ, 176*(1), 47-53. <https://doi.org/10.1503/cmaj.060204>

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., . . . Sauerborn, R. (2014). Human health: Impacts, adaptation, and co-benefits. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 709-754). Cambridge, England: Cambridge University Press. Retrieved from <https://www.ipcc.ch/report/ar5/wg2/>

Sonenshine, D. E. (2018). Range expansion of tick disease vectors in North America: Implications for spread of tick-borne disease. *International Journal of Environmental Research and Public Health, 15*(3), 1-9. <https://doi.org/10.3390/ijerph15030478>

Souto, A. C. P., Bonfietti, L. X., Ferreira-Paim, K., Trilles, L., Martins, M., Ribeiro-Alves, M., . . . Meyer, W. (2016). Population genetic analysis reveals a high genetic diversity in the Brazilian *Cryptococcus gattii* VGII population and shifts the global origin from the Amazon rainforest to the semi-arid desert in the northeast of Brazil. *PLOS Neglected Tropical Diseases, 10*(8), 1-19. <https://doi.org/10.1371/journal.pntd.0004885>

Spence, L., Artsob, H., Grant, L., & Th'Ng, C. (1977). St. Louis encephalitis in southern Ontario: Laboratory studies for arboviruses. *CMAJ, 116*(1), 35-37. Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1879132/>

St-Germain, G., Murray, G., & Duperval, R. (1993). Blastomycosis in Quebec (1981-90): Report of 23 cases and review of published cases from Quebec. *Canadian Journal of Infectious Diseases, 4*(2), 89-94. <https://doi.org/10.1155/1993/249823>

St-Pierre, J., Dufresne, P. J., Carignan, A., Lévesque, É., Bernard, F., Longtin, J., & LeBlanc, L. (2018). Case series: Report of the first two human indigenous cases of *Cryptococcus gattii* infection in eastern Canada. *Mycopathologia, 183*(2), 399-406. <https://doi.org/10.1007/s11046-017-0215-8>

Stafford, K. C., III., Molaei, G., Little, E. A. H., Paddock, C. D., Karpathy, S. E., & Labonte, A. M. (2018). Distribution and establishment of the lone star tick in Connecticut and implications for range expansion and public health. *Journal of Medical Entomology, 55*(6), 1561-1568. <https://doi.org/10.1093/jme/tjy115>

Statistics Canada. (2016). A portrait of the population aged 85 and older in 2016 in Canada. Retrieved from <https://www12.statcan.gc.ca/census-recensement/2016/as-sa/98-200-x/2016004/98-200-x2016004-eng.cfm>

Statistics Canada. (2019). Table 24-10-0041-01 International travellers entering or returning to Canada, by type of transport. Retrieved from <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2410004101>

Steverding, D. (2014). The history of Chagas disease. *Parasites & Vectors, 7*, 1-8. <https://doi.org/10.1186/1756-3305-7-317>

Stout, J. E., & Yu, V. L. (1997). Legionellosis. *The New England Journal of Medicine, 337*(10), 682-687. <https://doi.org/10.1056/NEJM199709043371006>

Sultan, B., Labadi, K., Guégan, J.-F., & Janicot, S. (2005). Climate drives the meningitis epidemics onset in West Africa. *PLOS Medicine, 2*(1), 0043-0049. <https://doi.org/10.1371/journal.pmed.0020006>

Sumi, A., Toyoda, S., Kanou, K., Fujimoto, T., Mise, K., Kohei, Y., . . . Kobayashi, N. (2017). Association between meteorological factors and reported cases of hand, foot, and mouth disease from 2000 to 2015 in Japan. *Epidemiology & Infection, 145*(14), 2896-2911. <https://doi.org/10.1017/S0950268817001820>

Sunenshine, R. H., Anderson, S., Erhart, L., Vossbrink, A., Kelly, P. C., Engelthaler, D., & Komatsu, K. (2007). Public health surveillance for coccidioidomycosis in Arizona. *Annals of the New York Academy of Sciences, 1111*(1), 96-102. <https://doi.org/10.1196/annals.1406.045>

Suresh, S., Forgie, S., & Robinson, J. (2018). Non-polio *Enterovirus* detection with acute flaccid paralysis: A systematic review. *Journal of Medical Virology, 90*(1), 3-7. <https://doi.org/10.1002/jmv.24933>

Tabachnick, W. J. (2016). Climate change and the arboviruses: Lessons from the evolution of the dengue and yellow fever viruses. *Annual Review of Virology, 3*, 125-145. <https://doi.org/10.1146/annurev-virology-110615-035630>

Takeuchi-Storm, N., Woolsey, I. D., Jensen, P. M., Fredensborg, B. L., Pipper, C. B., & Kapel, C. M. O. (2015). Predictors of *Echinococcus multilocularis* prevalence in definitive and intermediate hosts: A meta-analysis approach. *Journal of Parasitology, 101*(3), 297-303. <https://doi.org/10.1645/14-645.1>

Tam, B. Y., Martin, I., & Tsuji, L. J. S. (2014). Geospatial analysis between the environment and past incidences of West Nile virus in bird specimens in Ontario, Canada. *GeoJournal, 79*(6), 805-817. <https://doi.org/10.1007/s10708-014-9526-1>

Tamerius, J. D., & Comrie, A. C. (2011). Coccidioidomycosis incidence in Arizona predicted by seasonal precipitation. *PLOS ONE, 6*(6), 1-7. <https://doi.org/10.1371/journal.pone.0021009>

Tang, J. W., Lai, F. Y. L., Nymadawa, P., Deng, Y. M., Ratnamohan, M., Petric, M., . . . Wong, F. Y. W. (2010). Comparison of the incidence of influenza in relation to climate factors during 2000–2007 in five countries. *Journal of Medical Virology, 82*(11), 1958-1965. <https://doi.org/10.1002/jmv.21892>

Tasanee, A., Chayanit, L., & Agsornpien, N. (2015). Does the correlation between rainfall vs dengue hemorrhagic fever incidence always exist? Case study in Phuket, Thailand. *Journal of Environmental Research and Development, 9*(3), 509-513. Retrieved from <http://jerad.org/archiveabstract.php?vol=9&issue=3>

Tatem, A. J., Hay, S. I., & Rogers, D. J. (2006). Global traffic and disease vector dispersal. *Proceedings of the National Academy of Sciences of the United States of America, 103*(16), 6242-6247. <https://doi.org/10.1073/pnas.0508391103>

Tatem, A. J., Huang, Z., Das, A., Qi, Q., Roth, J., & Qiu, Y. (2012). Air travel and vector-borne disease movement. *Parasitology, 139*(14), 1816-1830. <https://doi.org/10.1017/S0031182012000352>

Teixeira, M. de M., Patan, J. S., Taylor, M. L., Gómez, B. L., Theodoro, R. C., de Hoog, S., Engelthaler, D. M., Zancopé-Oliveira, R. M., Felipe, M. S., Barker, B. M. (2016). Worldwide phylogenetic distributions and population dynamics of the genus *Histoplasma*. *PLoS Neglected Tropical Diseases 10*, e0004732. doi: 10.1371/journal.pntd.0004732.

Thielman, A. C., & Hunter, F. F. (2007). Photographic key to the adult female mosquitoes (Diptera: Culicidae) of Canada. *Canadian Journal of Arthropod Identification, 04*. <https://doi.org/10.3752/cjai.2007.04>

Thomas-Bachli, A. L., Pearl, D. L., Berke, O., Parmley, E. J., & Barker, I. K. (2015). A comparison of West Nile virus surveillance using survival analyses of dead corvid and mosquito pool data in Ontario, 2002–2008. *Preventive Veterinary Medicine, 122*(3), 363-370. <https://doi.org/10.1016/j.prevetmed.2015.10.007>

Thompson, W. W., Comanor, L., & Shay, D. K. (2006). Epidemiology of seasonal influenza: Use of surveillance data and statistical models to estimate the burden of disease. *The Journal of Infectious Diseases, 194*(Suppl. 2), S82-S91. <https://doi.org/10.1086/507558>

Tinline, R., & Gregory, D. (i2020). *Taking the bite out of rabies: The evolution of rabies management in Canada*. Toronto, ON: University of Toronto Press.

Tomaselli, M., Kutz, S., Gerlach, C., & Checkley, S. (2017). Local knowledge to enhance wildlife population health surveillance: Conserving muskoxen and caribou in the Canadian Arctic. Biological Conservation, 217, 337-48.

Tomasello, D., & Schlagenhauf, P. (2013). Chikungunya and dengue autochthonous cases in Europe, 2007-2012. *Travel Medicine and Infectious Disease, 11*(5), 274-284. <https://doi.org/10.1016/j.tmaid.2013.07.006>

Tong, D. Q., Wang, J. X. L., Gill, T. E., Lei, H., & Wang, B. (2017). Intensified dust storm activity and valley fever infection in the southwestern United States. *Geophysical Research Letters, 44*(9), 4304-4312. <https://doi.org/10.1002/2017GL073524>

Tossa, P., Deloge-Abarkan, M., Zmirou-Navier, D., Hartemann, P., & Mathieu, L. (2006). Pontiac fever: An operational definition for epidemiological studies. *BMC Public Health, 6*, 112. 10.1186/1471-2458-6-112

Towers, S., Chowell, G., Hameed, R., Jastrebski, M., Khan, M., Meeks, J., . . . Harris, G. (2013). Climate change and influenza: The likelihood of early and severe influenza seasons following warmer than average winters. *PLOS Currents: Influenza, 1*. <https://doi.org/10.1371/currents.flu.3679b56a3a5313dc7c043fb944c6f138>

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K., Colquhoun, H., Kastner, M., . . . Straus, S. E. (2016). A scoping review on the conduct and reporting of scoping reviews. *BMC Medical Research Methodology, 16*, 1-10. <https://doi.org/10.1186/s12874-016-0116-4>

Trudel, L., Veillette, M., Bonifait, L., & Duchaine, C. (2014). Management of the 2012 *Legionella* crisis in Quebec City: Need for a better communication between resources and knowledge transfer. *Frontiers in Microbiology, 5*, 1-4. <https://doi.org/10.3389/fmicb.2014.00182>

Tsetsarkin, K. A., Vanlandingham, D. L., McGee, C. E., & Higgs, S. (2007). A single mutation in chikungunya virus affects vector specificity and epidemic potential. *PLOS Pathogens, 3*(12), 1895-1906. <https://doi.org/10.1371/journal.ppat.0030201>

Tuite, A. R., Kinlin, L. M., Kuster, S. P., Jamieson, F., Kwong, J. C., McGeer, A., & Fisman, D. N. (2010). Respiratory virus infection and risk of invasive meningococcal disease in central Ontario, Canada. *PLOS ONE, 5*(11), 1-7. <https://doi.org/10.1371/journal.pone.0015493>

Turell, M. J., Britch, S. C., Aldridge, R. L., Kline, D. L., Boohene, C., & Linthicum, K. J. (2013). Potential for mosquitoes (Diptera: Culicidae) from Florida to transmit Rift Valley fever virus. *Journal of Medical Entomology, 50*(5), 1111-1117. <https://doi.org/10.1603/ME13049>

Turell, M. J., Byrd, B. D., & Harrison, B. A. (2013). Potential for populations of *Aedes j. japonicus* to transmit Rift Valley fever virus in the USA. *Journal of the American Mosquito Control Association, 29*(2), 133-137. <https://doi.org/10.2987/12-6316r.1>

Turell, M. J., Dohm, D. J., & Fonseca, D. M. (2014). Comparison of the potential for different genetic forms in the *Culex pipiens* complex in North America to transmit Rift Valley fever virus. *Journal of the American Mosquito Control Association, 30*(4), 253-259. <https://doi.org/10.2987/14-6441R.1>

Turell, M. J., Wilson, W. C., & Bennett, K. E. (2010). Potential for North American mosquitoes (Diptera: Culicidae) to transmit Rift Valley fever virus. *Journal of Medical Entomology, 47*(5), 884-889. <https://doi.org/10.1603/ME10007>

Uejio, C. K., Mak, S., Manangan, A., Luber, G., & Bartlett, K. H. (2015). Climatic influences on *Cryptococcus gattii* populations, Vancouver Island, Canada, 2002-2004. *Emerging Infectious Diseases, 21*(11), 1989-1996. <https://doi.org/10.3201/eid2111.141161>

Valseth, K., Nesbø, C. L., Easterday, W. R., Turner, W. C., Olsen, J. S., Stenseth, N. C., & Haverkamp, T. H. A. (2017). Temporal dynamics in microbial soil communities at anthrax carcass sites. *BMC Microbiology, 17*, 1-15. <https://doi.org/10.1186/s12866-017-1111-6>

van Leuken, J. P. G., Swart, A. N., Droogers, P., van Pul, A., Heederik, D., & Havelaar, A. H. (2016). Climate change effects on airborne pathogenic bioaerosol concentrations: A scenario analysis. *Aerobiologia, 32*(4), 607-617. <https://doi.org/10.1007/s10453-016-9435-5>

Vander Kelen, P., Downs, J. A., Unnasch, T., & Stark, L. (2014). A risk index model for predicting eastern equine encephalitis virus transmission to horses in Florida. *Applied Geography, 48*, 79-86. <https://doi.org/10.1016/j.apgeog.2014.01.012>

Varia, M., Wilson, S., Sarwal, S., McGeer, A., Gournis, E., Galanis, E., & Henry, B. (2003). Investigation of a nosocomial outbreak of severe acute respiratory syndrome (SARS) in Toronto, Canada. *CMAJ, 169*(4), 285-292. Retrieved from <http://www.cmaj.ca/content/169/4/285.long>

Varrin, R., Bowman, J., & Gray, P. A. (2007). *The known and potential impacts of climate change on biodiversity in Ontario's terrestrial ecosystems: Case studies and recommendations for adaptation.* (Climate Change Research Report CCRR-09). Sault Ste. Marie, ON: Ontario Ministry of Natural Resources Retrieved from <http://www.climateontario.ca/MNR_Publications/276927.pdf>

Venturi, G., Di Luca, M., Fortuna, C., Remoli, M. E., Riccardo, F., Severini, F., . . . Rizzo, C. (2017). Detection of a chikungunya outbreak in Central Italy, August to September 2017. *Eurosurveillance, 22*(39), 1-4. <https://doi.org/10.2807/1560-7917.ES.2017.22.39.17-00646>

Viboud, C., Pakdaman, K., Boëlle, P.-Y., Wilson, M. L., Myers, M. F., Valleron, A.-J., & Flahault, A. (2004). Association of influenza epidemics with global climate variability. *European Journal of Epidemiology, 19*(11), 1055-1059. <https://doi.org/10.1007/s10654-004-2450-9>

Villeneuve, A., Polley, L., Jenkins, E., Schurer, J., Gilleard, J., Kutz, S., . . . Gagné, F. (2015). Parasite prevalence in fecal samples from shelter dogs and cats across the Canadian provinces. *Parasites & Vectors, 8*, 1-10. <https://doi.org/10.1186/s13071-015-0870-x>

Vugia, D. J., Wheeler, C., Cummings, K. C., & Karon, A. (2009). Increase in coccidioidomycosis—California, 2000-2007. *MMWR Morbidity and Mortality Weekly Report, 58*(5), 105-109. Retrieved from <https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5805a1.htm>

Walsh, M. G., de Smalen, A. W., & Mor, S. M. (2018). Climatic influence on anthrax suitability in warming northern latitudes. *Scientific Reports, 8*, 1-9. <https://doi.org/10.1038/s41598-018-27604-w>

Wang, C., Liu, L., Hao, X., Guo, H., Wang, Q., Huang, J., He, N., Yu, H., Lin, X., Pan, A., Wei, S., Wu, T. (2020). Evolving Epidemiology and Impact of Non-pharmaceutical Interventions on the Outbreak of Coronavirus Disease 2019 in Wuhan, China. *JAMA*. doi:10.1101/2020.03.03.20030593

Wang, G., Minnis, R. B., Belant, J. L., & Wax, C. L. (2010). Dry weather induces outbreaks of human West Nile virus infections. *BMC Infectious Diseases, 10*, 1-7. <https://doi.org/10.1186/1471-2334-10-38>

Wang, J., Ogden, N. H., & Zhu, H. (2011). The impact of weather conditions on *Culex pipiens* and *Culex restuans* (Diptera: Culicidae) abundance: A case study in Peel Region. *Journal of Medical Entomology, 48*(2), 468-475. <https://doi.org/10.1603/ME10117>

Wang, P., Goggins, W. B., & Chan, E. Y. Y. (2016). Hand, foot and mouth disease in Hong Kong: A time-series analysis on its relationship with weather. *PLOS ONE, 11*(8), 1-12. <https://doi.org/10.1371/journal.pone.0161006>

Warren, F. J., & Lemmen, D. S. (2014). *Canada in a changing climate: Sector perspectives on impacts and adaptation*. Ottawa, ON: Government of Canada. Retrieved from <https://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2014/16309>

Washington State Department of Health. (2021). Coccidioidomycosis (Valley Fever). Retrieved from <https://www.doh.wa.gov/ForPublicHealthandHealthcareProviders/NotifiableConditions/Coccidioidomycosis#:~:text=Sources%3A%20*Coccidioides*%20sp.,There%20are%20no%20specific%20precautions>

Webster, D., Dimitrova, K., Holloway, K., Makowski, K., Safronetz, D., & Drebot, M. A. (2017). California serogroup virus infection associated with encephalitis and cognitive decline, Canada, 2015. *Emerging Infectious Diseases, 23*(8), 1423-1424. <https://doi.org/10.3201/eid2308.170239>

Weir, E. (2005). Hantavirus: 'Tis the season. *CMAJ, 173*(2), 147. <https://doi.org/10.1503/cmaj.050690>

Weissenböck, H., Kolodziejek, J., Url, A., Lussy, H., Rebel-Bauder, B., & Nowotny, N. (2002). Emergence of Usutu virus, an African mosquito-borne *Flavivirus* of the Japanese encephalitis virus group, central Europe. *Emerging Infectious Diseases, 8*(7), 652-656. <https://doi.org/10.3201/eid0807.020094>

White, A. N. J., Ng, V., Spain, C. V., Johnson, C. C., Kinlin, L. M., & Fisman, D. N. (2009). Let the sun shine in: Effects of ultraviolet radiation on invasive pneumococcal disease risk in Philadelphia, Pennsylvania. *BMC Infectious Diseases, 9*. <https://doi.org/10.1186/1471-2334-9-196>

Williams, C. R., Mincham, G., Faddy, H., Viennet, E., Ritchie, S. A., & Harley, D. (2016). Projections of increased and decreased dengue incidence under climate change. *Epidemiology & Infection, 144*(14), 3091-3100. <https://doi.org/10.1017/s095026881600162x>

Wilson, W. C., Kim, I. J., Trujillo, J. D., Sunwoo, S. Y., Noronha, L. E., Urbaniak, K., . . . Richt, J. A. (2018). Susceptibility of white-tailed deer to Rift Valley fever virus. *Emerging Infectious Diseases, 24*(9), 1717-1719. <https://doi.org/10.3201/eid2409.180265>

Windsor-Essex County Health Unit. (2019a). *Aedes aegypti* mosquito. Retrieved from <https://www.wechu.org/z-health-topics/aedes-aegypti-mosquito>

Windsor-Essex County Health Unit. (2019b). *Aedes **albopictus*** mosquito. Retrieved from <https://www.wechu.org/z-health-topics/aedes-albopictus-mosquito>

Wong, S.S.Y., Yip, C.C.Y., Lau, S.K.P. & Yuen, K.Y. (2010). Human enterovirus 71 and hand, foot and mouth disease. *Epidemiology & Infection*, 13, 1071-89. doi: 10.1017/S0950268809991555.

Wood, D. M., Dang, P. T., & Ellis, R. A. (1979). Part 6 The mosquitoes of Canada—Diptera: Culicidae. In *The insects and arachnids of Canada*. Ottawa, ON: Government of Canada. Retrieved from <http://publications.gc.ca/pub?id=9.811351&sl=0>

World Health Organization. (2007). *Legionella and the prevention of legionellosis*. Geneva, Switzerland: WHO Press. Retrieved from <https://www.who.int/water_sanitation_health/emerging/legionella.pdf>

World Health Organization. (2013). *WHO expert consultation on rabies: Second report* (WHO Technical Report Series 982). Geneva, Switzerland: WHO Press. Retrieved from <https://apps.who.int/iris/handle/10665/85346>

World Health Organization Global Malaria Programme. (2018). *Global report on insecticide resistance in malaria vectors: 2010-2016*. Geneva, Switzerland: World Health Organization. Retrieved from <https://apps.who.int/iris/bitstream/handle/10665/272533/9789241514057-eng.pdf?ua=1>

World Health Organization (WHO). (2019a). *Mosquito-borne diseases.* Retrieved from <https://www.who.int/neglected_diseases/vector_ecology/mosquito-borne-diseases/en/>

World Health Organization (WHO). (2019b). *Rift Valley Fever*. Retrieved from <https://www.who.int/news-room/fact-sheets/detail/rift-valley-fever>

World Health Organization (WHO). (2019c). Strengthening health security by implementing the International Health Regulations (2005). Retrieved from <https://www.who.int/ihr/en/>

World Health Organization (WHO). (2019d). Strengthening Global Outbreak Alert and Response Network (GOARN). Retrieved from <https://www.who.int/ihr/alert_and_response/outbreak-network/en/>

World Health Organization (WHO). (2019e). Rapid risk assessment of acute public health events. Retrieved from <https://www.who.int/csr/resources/publications/HSE_GAR_ARO_2012_1/en/>

World Health Organization (WHO). (2019f). Antimicrobial resistance. Retrieved from <https://www.who.int/antimicrobial-resistance/en/>

World Health Organization (WHO). (2019g). Prioritizing diseases for research and development in emergency contexts. Retrieved from <https://www.who.int/activities/prioritizing-diseases-for-research-and-development-in-emergency-context>

World Health Organization (WHO). (2020). WHO Timeline – COVID-19. Retrieved from <https://www.who.int/news-room/detail/08-04-2020-who-timeline---covid-19>

World Tourism Organization, & United Nations Environment Programme. (Eds.). (2008). *Climate change and tourism—Responding to global challenges*. Madrid, Spain: World Tourism Organization.

Wormser, G. P., Dattwyler, R. J., Shapiro, E. D., Halperin, J. J., Steere, A. C., Klempner, M. S., . . . Nadelman, R. B. (2006). The clinical assessment, treatment, and prevention of Lyme disease, human granulocytic anaplasmosis, and babesiosis: Clinical practice guidelines by the Infectious Diseases Society of America. *Clinical Infectious Diseases, 43*(9), 1089-1134. <https://doi.org/10.1086/508667>

Wu, J. T., Leung, K., & Leung, G. M. (2020). Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: A modelling study. *The Lancet, 395*(10225), 689-697. doi:10.1016/s0140-6736(20)30260-9

Xiao, F.-Z., Zhang, Y., Deng, Y.-Q., He, S., Xie, H.-G., Zhou, X.-N., & Yan, Y.-S. (2014). The effect of temperature on the extrinsic incubation period and infection rate of dengue virus serotype 2 infection in Aedes *albopictus*. *Archives of Virology, 159*(11), 3053-3057. <https://doi.org/10.1007/s00705-014-2051-1>

Yang, H. M., Macoris, M. L. G., Galvani, K. C., Andrighetti, M. T. M., & Wanderley, D. M. V. (2009). Assessing the effects of temperature on the population of *Aedes aegypti*, the vector of dengue. *Epidemiology & Infection, 137*(8), 1188-1202. <https://doi.org/10.1017/s0950268809002040>

Yansouni, C.P., Pernica, J.M., & Goldfarb, D. (2016). Enteric parasites in Arctic communities: Tip of the iceberg? *Trends in Parasitology, 32*(11), 834-38.

Yoo, E. H., Chen, D., Diao, C., & Russell, C. (2016). The effects of weather and environmental factors on West Nile virus mosquito abundance in Greater Toronto Area. *Earth Interactions, 20*(3), 1-22. <https://doi.org/10.1175/ei-d-15-0003.1>

Yu, G., Li, Y., Cai, J., Yu, D., Tang, J., Zhai, W., . . . Qin, J. (2019). Short-term effects of meteorological factors and air pollution on childhood hand-foot-mouth disease in Guilin, China. *Science of the Total Environment, 646*, 460-470. <https://doi.org/10.1016/j.scitotenv.2018.07.329>

Yue, R. P. H., & Lee, H. F. (2018). Pre-industrial plague transmission is mediated by the synergistic effect of temperature and aridity index. *BMC Infectious Diseases, 18*(1), 134. doi: 10.1186/s12879-018-3045-5

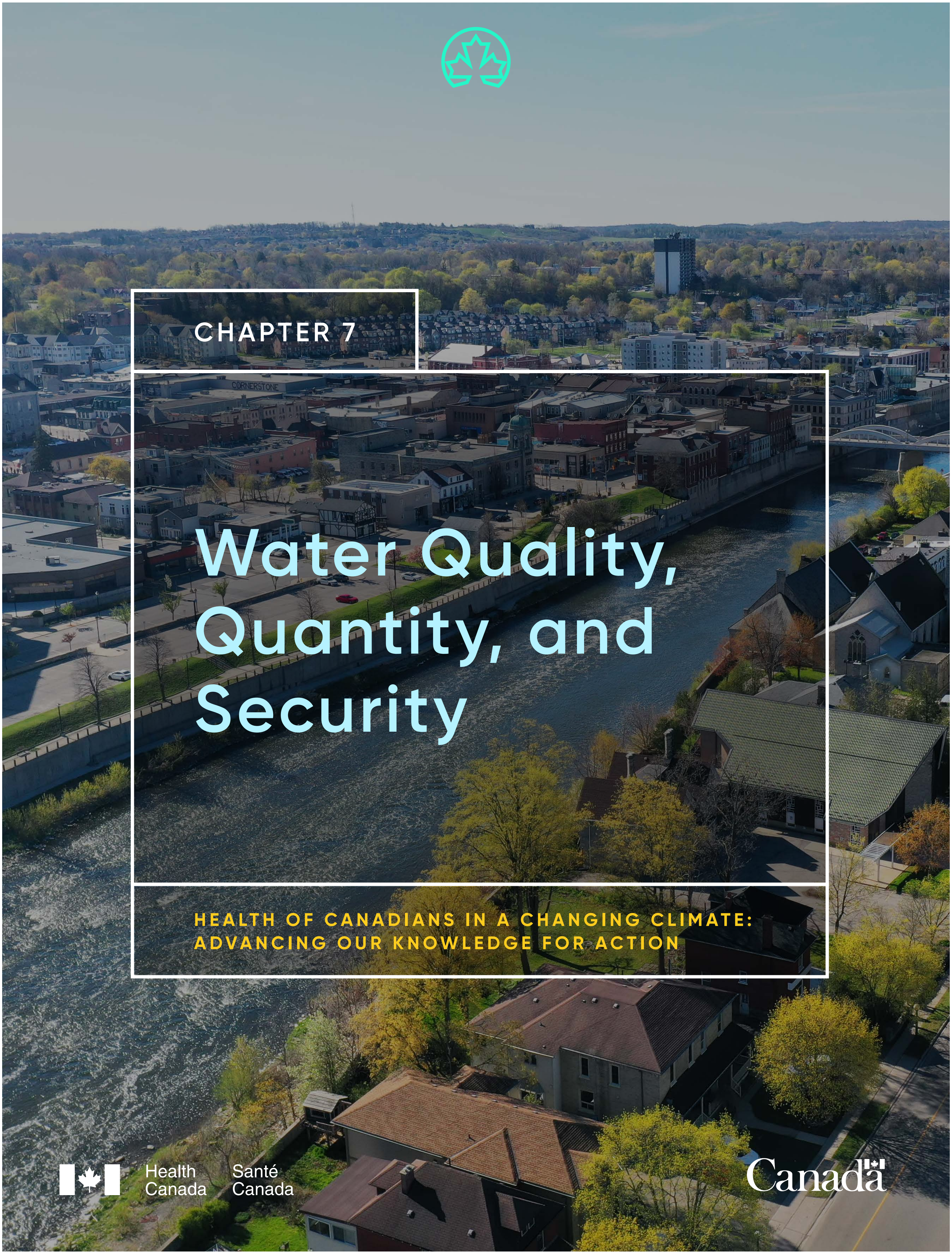
Zhang, T., Wu, Q., & Zhang, Z. (2020). Probable Pangolin Origin of SARS-CoV-2 Associated with the COVID-19 Outbreak. *Current biology : CB*, 30(8), 1578. <https://doi.org/10.1016/j.cub.2020.03.063>

Zhao, D., Wang, L., Cheng, J., Xu, J., Xu, Z., Xie, M., . . . Su, H. (2017). Impact of weather factors on hand, foot and mouth disease, and its role in short-term incidence trend forecast in Huainan City, Anhui province. *International Journal of Biometeorology, 61*(3), 453-461. <https://doi.org/10.1007/s00484-016-1225-9>

Zhao, Q., Li, S., Cao, W., Liu, D.-L., Qian, Q., Ren, H., . . . Guo, Y. (2018). Modeling the present and future incidence of pediatric hand, foot, and mouth disease associated with ambient temperature in mainland China. *Environmental Health Perspectives, 126*(4), 1-11. <https://doi.org/10.1289/EHP3062>

Zheng, H., Drebot, M. A., & Coulthart, M. B. (2014). West Nile virus in Canada: Ever-changing, but here to stay. *Canada Communicable Disease Report, 40*(10), 173-177. <https://doi.org/10.14745/ccdr.v40i10a01>

Zhu, F., Xu, W., Xia, J., Liang, Z., Liu, Y., Zhang, X., . . . Wang, N. (2014). Efficacy, safety, and immunogenicity of an enterovirus 71 vaccine in China. *The New England Journal of Medicine, 370*(9), 818-828. <https://doi.org/10.1056/NEJMoa1304923>



CHAPTER 7

Water Quality, Quantity, and Security

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada   Santé Canada

Canada

Lead Authors

Tim Takaro, Simon Fraser University

Paddy Enright, Health Canada and University of Waterloo

Contributing Authors

Shannon Waters, Vancouver Coastal Health

Lindsay Galway, Lakehead University

Jordan Brubacher, Simon Fraser University

Eleni Galanis, British Columbia Centre for Disease Control

Lorraine McIntyre, British Columbia Centre for Disease Control

Christina Cook, University of British Columbia

Gemma Dunn, Uisce (Ishka) Consulting International

Manon D. Fleury, Public Health Agency of Canada

Ben Smith, Public Health Agency of Canada

Tom Kosatsky, British Columbia Centre for Disease Control

Suggested Citation

Takaro, T., Enright, P., Waters, S., Galway, L., Brubacher, J., Galanis, E., McIntyre, L., Cook, C., Dunn, G., Fleury, M. D., Smith, B., & Kosatsky, T. (2022). Water Quality, Quantity, and Security. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada

Table of Contents

Summary

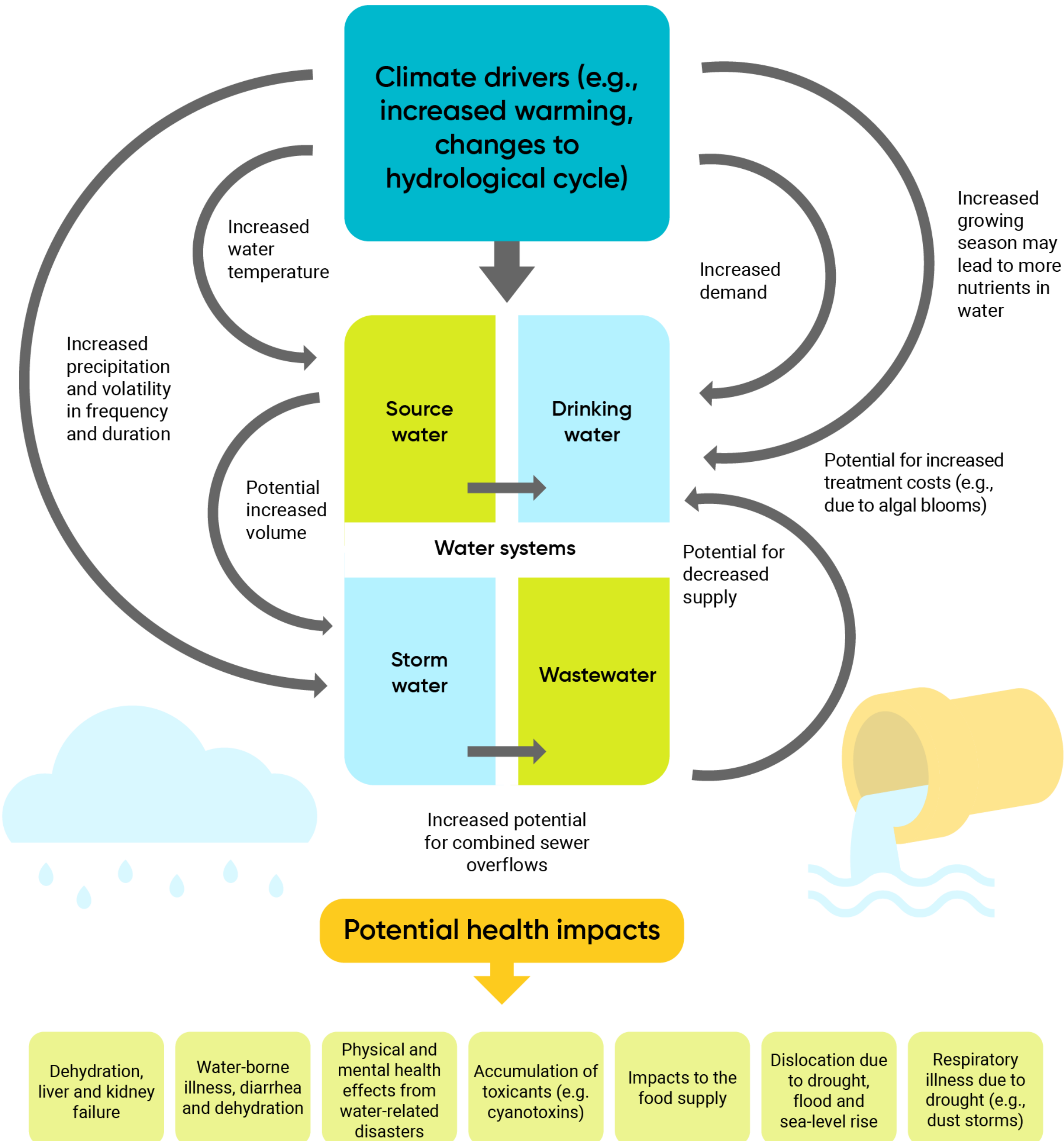
Climate change is expected to result in fluctuations in water quantity, degraded water quality, increased flood and drought risks, as well as a greater burden of climate-related water-borne disease. The impacts of sea-level rise and loss of ice in Canada are likely to be significant. Not all Canadians will experience these impacts equally. First Nations, Métis, and Inuit communities, many of which already face water insecurity, are expected to be disproportionately affected, as are rural and remote communities that have only basic water and sewage infrastructure.

The health impacts associated with climate change effects on water quality and quantity are not inevitable. Through effective mitigation and adaptation, they can be reduced. Canadians can better adapt to these anticipated impacts and protect health by assessing local climate risks and vulnerabilities, developing adaptation plans, improving surveillance systems, building climate-resilient water systems, and promoting intersectoral collaboration to protect water resources and address climate-related risks.

Key Messages

- Changes in precipitation and temperature due to climate change will result in impacts on water quality and quantity and disrupt both natural water systems (rivers, lakes, oceans) and human drinking water and wastewater systems, thereby increasing risks to the health of Canadians. The extent and intensity of these changes will vary by region and season.
- Water-related health risks associated with climate change include threats to drinking water and irrigation supplies; increases in water-borne diseases (e.g., cryptosporidiosis, giardiasis, campylobacteriosis); physical injuries and mental health impacts from extreme weather events such as floods and droughts; and threats to health and well-being due to the socio-economic and environmental consequences of water insecurity.
- Climate change-related water and food shortages, coupled with increasing population growth in climate vulnerable regions of the world with fewer resources, could affect Canada through regional and international migration.
- Adaptation to the anticipated impacts of climate change on water resources and human health can help protect Canadians from future risks. Adaptation will require broad multi-sectoral action and coordination among, for example, public health practitioners and service providers, and water and wastewater managers.
- Indigenous Peoples are among those most affected by the degradation of water resources, but they also possess countless generations of accumulated knowledge, which can be applied to protect health. Partnerships among Indigenous communities, health authorities, and water managers are needed to identify the population-specific health impacts of climate change impacts on water resources and to implement effective adaptation options informed by traditional knowledges and cultural needs.

- More information is required on the current burden of disease in Canada related to climate change impacts on water resources and related hazards, and on the projected health risks from further warming. Research is also needed on the most effective ways to adapt to increasing stresses on drinking water systems and on needed public health interventions, including the communication of risks to the public. Better models for regional drought and flood prediction are needed.
- Health authorities can increase understanding of climate change impacts on water resources and health, as well as potential adaptation options, by conducting local and regional vulnerability and adaptation assessments related to climate change and health. By doing so, health authorities can improve their preparedness, maximize the health benefits of cross-sector collaboration, and build climate resilience within their communities.



Examples of the direct and indirect ways climate change can alter water quality and quantity and affect health.

Overview of the Health Impacts of Water Quality, Quantity, and Security in the Context of Climate Change

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS

Water quality, quantity, and security	• Increased precipitation and flooding causing dangerous evacuations, drinking water shortages, disruptions
	• Increased drought leading to regional water shortages, diminished food security, dust storms and habitat loss
	• Increased permafrost melt affecting water accessibility
	• Increased salt-water infiltration affecting water accessibility
	• Increased frequency of harmful algal blooms
	• Higher water temperatures increasing the prevelance of water-borne pathogens
	• Water shortages causing or contributing to international conflict and forced migration
	• Wildfire degrading watersheds
		• Water-borne and food-borne infections, illnesses and deaths
		• Water-borne infections and illnesses:
		  ◦ Acute gastrointestinal illness
		  ◦ Infant mortality
		  ◦ Birth defects
		  ◦ Exacerbation of chronic diseases
		  ◦ Skin diseases
		• Food-borne illnesses:
		  ◦ Food poisoning
		  ◦ Paralytic seafood poisoning
		• Kidney failure
		• Stress and other mental health impacts
		• Respiratory illness
		• Liver failure
		• Injuries, illness, and deaths from flooding and extreme precipitation events
		• Destruction or damage of health infrastructure
		• Health and social services disruptions
		• Disruptions to water systems and water management resulting in impacts such as degraded source water quality
		• Failure of drinking water systems during extreme weather events

7.1 Introduction

Climate change will reduce the quantity and quality of water in all Canadian regions on a seasonal basis (Andrey et al., 2014). The health of Canadians can be affected by climate change effects on water in a number of ways: by an increasing frequency and severity of extreme weather events, such as floods and droughts, as well as the degradation of drinking and recreational water quality due to longer-term warming. These effects may arise because of shifts in ecological boundaries and changes to the cryosphere, and to the freshwater–saltwater interface. Health may also suffer from climate change impacts on water that affect food safety and security, for example, through the contamination of fish and shellfish (see Chapter 8: Food Safety and Security). Both extreme events and longer-term warming can increase pressures on water systems, which are integral to efforts to keep people healthy and safe.

Health outcomes can include both physical and mental health impacts, for example, in the aftermath of a flood or during a drought. Such events can increase health impacts associated with chemical and biological contamination of water supplies such as water-borne illnesses. Illness caused by contamination may be acute, infectious, and restricted to the gastrointestinal tract, or chronic and associated with multiple systemic effects. Changes in water quality and quantity affect different exposure pathways that can interact with multiple social and behavioural factors, leading to negative health outcomes (Trtanj et al., 2016). For example, climate change effects on water can cause the loss of cultural and societal stabilizing factors that affect various determinants of health (e.g., loss of employment in industries that rely on a predictable water supply), which also have longer-term effects on mental health (see Chapter 4: Mental Health and Well-Being).

This chapter outlines the current and possible future health impacts of climate change in Canada related to effects on freshwater, marine, and coastal systems, with a specific focus on the importance of drinking water, wastewater, and stormwater infrastructure in reducing risks. It includes discussion of how climate change affects the sources of contaminants and exposure pathways, including projections of increased health risks, where data are available. Current evidence of climate impacts on fish and shellfish illnesses that affect Canadians is reviewed, and broader climate change implications for water security are explored. The chapter identifies adaptation options that public health authorities can take to protect health, in collaboration with decision makers outside of the health sector. It also identfies important knowledge gaps that would benefit from future research to support actions that help prepare for climate change.

7.2 Methods and Approach

This chapter used a narrative scoping approach to identify information related to the current and projected water-related health impacts of climate change and possible adaptations in Canada. Systematic searches of the Agricola, Medline, and Embase databases were conducted for publications up to January 2019. Systematic searches targeted seven subject areas to support the broader narrative review, including:

- climate change and drinking water;
- climate change, water, and adaptation;
- climate change, water, and algal blooms;
- climate change and water in Canada;
- climate change, water, and extreme weather;
- climate change, water, and the food system; and
- climate change, water, and traditional indigenous uses.

A number of search terms were employed for each subject. Some common search terms included variations of climate change; drinking water; water supply; human(s); health; public health; environmental exposure; diseases; mental health; mortality; morbidity; flood; safety; adaptation; infection; bacteria; pathogen; infectious; parasitic; water-borne; and others.

Additional peer-reviewed and grey literature was identified from the authors' knowledge, reviewers' comments, and targeted searches. Author knowledge and targeted searches were used to incorporate relevant literature published after the completion of systematic searches. Estimates of future trends in streamflow, surface water levels, soil moisture, and groundwater draw on *Canada's Changing Climate Report* (Bush & Lemmen, 2019).

Some degree of caution is warranted when interpreting studies on climate change and water-borne disease. For example, publication bias may affect the evidence base (Levy et al., 2016). Additionally, due to constraints associated with using secondary data sources, studies are often limited in what covariates can be included, which may introduce uncertainty in the estimates. Moreover, pathogens can be transmitted by multiple agents and via multiple pathways (Semenza et al., 2012), and some health outcomes, such as acute gastrointestinal illness (AGI), are known to be under-reported (Thomas et al., 2013).

7.3 Climate Change, Water, and Health

Water quality and quantity are intricately linked and vary depending on geophysical, biological, and social contexts. Water quantity refers to the abundance of water available in an ecosystem or community. Water quality refers to the suitability of available water for a given task (e.g., drinking). Water security is a measure of access to water of a sufficient quantity and quality to protect and promote health and well-being. Hydrogeological factors, including soil, slope, and aquifer composition, as well as climatological factors, such as temperature and precipitation, all influence water quality and quantity via complex and interconnected pathways. Source water quality and quantity are the predominant factors that affect drinking water and drive water treatment requirements (Boholm & Prutzer, 2017). The most significant determinant of water quality is human activity (Trtanj et al., 2016). In most cases of water supply contamination, human activity is the source of contamination, either directly, via human waste entering the water supply, or indirectly, through land-use change, industry, or agriculture (Trtanj et al., 2016).

Climate change-related stressors, such as extreme rain events or rapid spring snowmelts, are increasing the risks of water-borne disease. Generally, floods and high river flows dilute dissolved substances and transport pathogens, while droughts and low river flows concentrate them (Delpla et al., 2009) with health implications for populations using the water source. Healthy natural ecosystems are often able to filter biological and chemical contaminants (e.g., through wetlands), highlighting the value of source water protection to drinking water systems (DWSs) and health protection.

Climate change can affect water resources through multiple pathways, but water resources are principally impacted by climate-driven changes to precipitation and temperature. In addition to an appropriate volume of water, which may be affected by flood or droughts, many human health impacts are mediated by biological or chemical agents in water that humans use, or come in contact with, through drinking water, bathing, recreation, or ceremonial use. The primary implications for human health are illustrated in Figure 7.1. From a Canadian perspective, the negative health effects associated with climate change impacts on water include physical impacts (e.g., physical trauma) from floods, mental health impacts (e.g., due to exposure to extreme weather events such as floods or droughts), and water-borne infectious diseases and other illnesses caused by gradual warming and by chemical and biological contamination. Indirect impacts (e.g., to personal hygiene or food security) are largely driven by limited access to water of a sufficient quantity or quality.

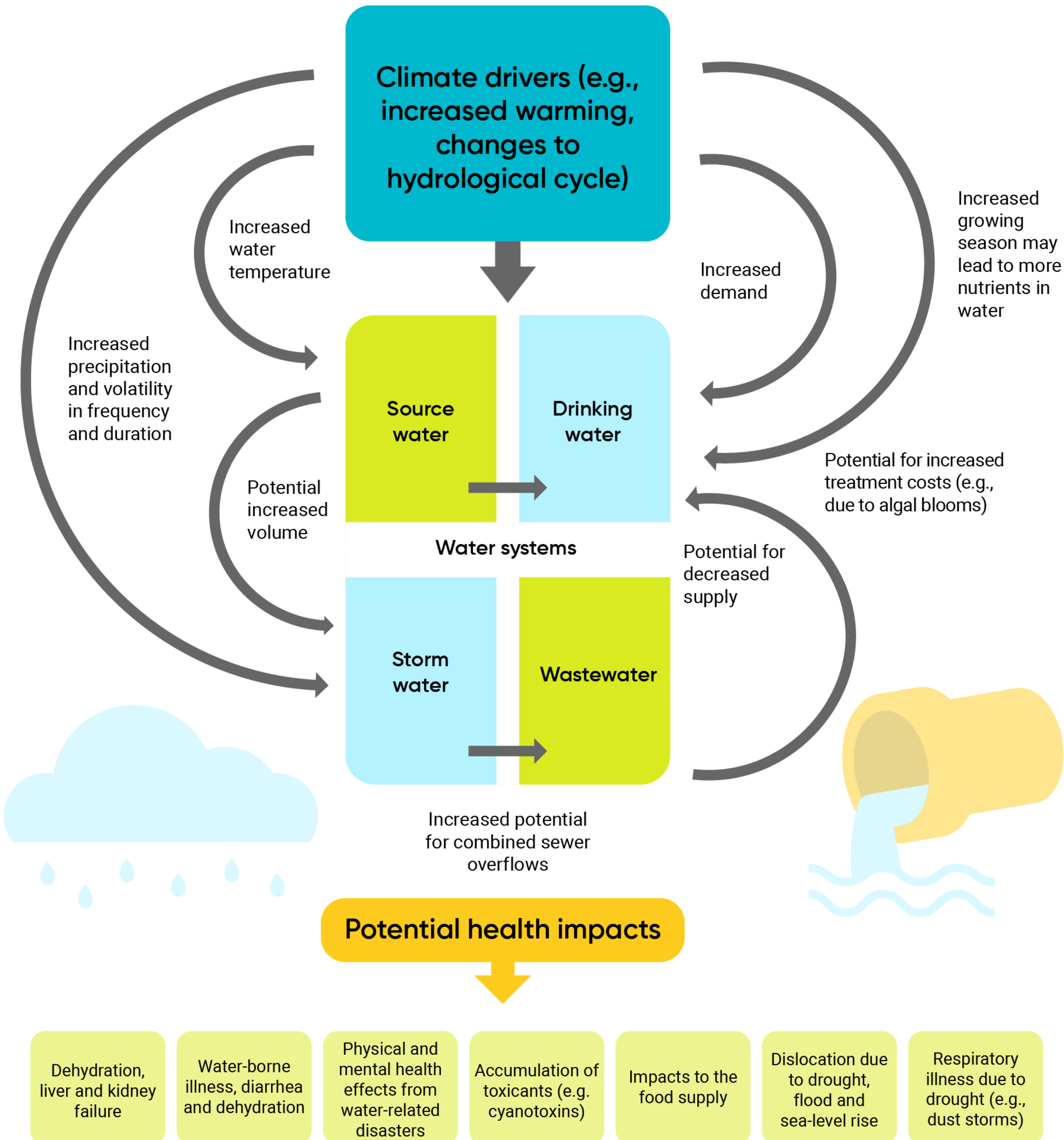


Figure 7.1 Examples of the direct and indirect ways climate change can alter water quality and quantity and affect health.

7.3.1 Indigenous Peoples — Water is Life

First Nations, Inuit, and Métis peoples are diverse, with equally diverse beliefs, views, and experiences; however, water is an area where views are widely shared (McGregor, 2012). Within many Indigenous teachings, water has a variety of meanings, but underpinning all these is that "water is life" (AFN, 2013; Bharadwaj & Bradford, 2018). Water is part of creation stories that many Indigenous Peoples[1] identify with, and because water is considered "life" itself, Indigenous Peoples often feel that they have a sacred connection to water and a responsibility to protect it, now and for future generations (McGregor, 2012; Sanderson et al., 2015). The Assembly of First Nations speaks of this responsibility as a never-ending circle from the "tiny droplets of water falling from the skies to the continuation of its journey to the lakes and rivers and the ground where it is stored" (AFN, 2013, p. 1). Inuit Elders speak of the healing quality of water gathered from the land when compared with municipally treated water, "I feel more alive when I'm drinking river water. More alive. Active." (Watson, 2017, p. 123).

To many Indigenous Peoples, water is sacred and has power, playing roles in their lives beyond hydration — for its aesthetics; as medicine; as a symbol of fertility, purity, strength, and softness; as a home for living beings (some of which are sources of traditional food); as a life-enriching cleansing agent; and an element of interconnectedness (McGregor, 2012; Sanderson et al., 2015; Bharadwaj & Bradford, 2018). Water is not viewed as a discrete aspect of the environment but as part of a holistic system. When considering the role of water, many Indigenous Peoples account for its value beyond that for humans, for example, the plants that water nourishes, the fish that live in water, the traditional medicines that grow in or around water, and the animals that drink water. Water is critical to life and to the physical, emotional, mental, and spiritual well-being of many Indigenous Peoples (McGregor, 2012). Climate-related changes in freshwater availability in the North has had impacts on subsistence food supplies and connection to the land (Goldhar et al., 2013a).

To many Indigenous Peoples, water has a spirit and is to be respected as a living being. Water is considered by many as a relative, or a participant in a caring and compassionate relationship. Many Indigenous Peoples view various water bodies as having different personalities, and water is understood to have feelings and can be sad and/or angry if it is not respected or treated properly. As with all relationships, there are responsibilities on both sides, and water must be respected and allowed to perform its life-giving duties. Across Canada, there are local protocols and ceremonies for giving thanks and for maintaining and establishing a spiritual connection to water (McGregor, 2012).

Indigenous Peoples, along with all plants and animals, have the right to clean and healthy water and have the responsibility to make informed decisions that affect the waters, planning at least seven generations ahead (McGregor, 2012; Sanderson et al., 2015; CWB, 2018). Indigenous Peoples have sovereign, inherent, and treaty rights over the land and waters in their traditional territories and continue to assert and exercise their rights and responsibilities through ceremony and management practices, as traditional stewards of watersheds (AFN, 2013). The *United Nations Declaration on the Rights of Indigenous Peoples*, adopted by Canada, affirms the work needed to achieve reconciliation, including in areas regarding water. Articles 25 and 32 of the declaration support

1 The term Indigenous is used in this chapter to refer collectively to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples, as defined under Section 35 of the *Constitution Act, 1982*. Wherever possible, clear distinctions are made between these three distinct, constitutionally recognized groups. Indigenous Peoples outside of Canada are also referenced in some instances – particularly with respect to international climate policy, processes, and rights – and are identified as such.

the right of Indigenous Peoples to their special relationship with water and to act on their responsibilities to future generations. The declaration calls for states to obtain free and informed consent before approving any project affecting lands or territories and other resources, particularly in connection with the development, use, or exploitation of mineral, water, or other resources (McGregor, 2012). This special relationship with water is important context for considering the impacts of climate change on Indigenous Peoples for the rest of this chapter.

7.3.2 Water Quality

7.3.2.1 Drinking Water Systems and Health

Drinking water systems are designed to provide safe drinking water, and, by extension, to protect and promote human health. Most of Canada's population is serviced by large municipal DWSs, while approximately 15% of the population is serviced by smaller non-municipal systems (Pons et al., 2015). Some Canadians, particularly those living in rural areas, access their drinking water through private water systems (i.e., privately owned systems that provide drinking water to individuals and households that own the systems) such as wells, springs, or surface water (Statistics Canada, 2011). In the Canadian context, there is no universally agreed-upon definition of a small DWS, and there are important differences with regard to the definition and regulation of small systems across provinces and territories (Charrois, 2010; Pons et al., 2015). For this report, large DWSs are defined as those serving populations of 5000 or more, and small systems are those serving populations of less than 5000 (Health Canada, 2005). Some DWS are supplied by surface water, some by groundwater, and others use a mix of surface and groundwater sources. Approximately 10% of the population relies on a groundwater source, and the majority of Canadians with private water supply use groundwater sources (Statistics Canada, 2011; Murphy et al., 2016a).

The most studied health outcomes related to drinking water are AGI and other water-borne diseases. Small and private DWSs across Canada are more vulnerable to contamination and AGI outbreaks than larger municipally managed systems (Hrudey & Hrudey, 2004; Schuster et al., 2005; Uhlmann et al., 2009; Wilson et al., 2009; Charrois, 2010). Investigations of past water-borne disease outbreaks in Canadian DWSs have shown that a high proportion of outbreaks occurred in small DWSs (Moffatt & Struck, 2011), and are most often the result of multiple risk factors such as system failures, lack of treatment, limited monitoring, resource constraints, operator knowledge, or poor-quality source waters (Schuster et al., 2005; Wilson et al., 2009). Private DWSs are commonly untreated and vulnerable to contamination (Schuster et al., 2005), particularly surface water and groundwater under the direct influence of surface water sources (Murphy et al., 2016b). Nevertheless, water-borne disease has been associated with DWSs of all sizes and sources, including the largest recorded outbreak in the United States in Milwaukee, Wisconsin, in 1993 with 403,000 AGI cases (Corso et al., 2003). Although large municipal systems have multiple barriers in place to prevent contamination and reduce the risk of both sporadic and outbreak-related illness, a range of pressures, such as population growth, aging infrastructure, resource constraints, and climate change, are placing unprecedented pressures on these systems (Sharma et al., 2010). Due to these pressures, there is a growing risk that it may become more difficult for large municipal DWSs to reliably provide clean and dependable drinking water supplies to Canadians (Shuster-Wallace et al., 2019; Shuster-Wallace et al., 2020).

Although much of Canada benefits from reliable access to quality drinking water, many Indigenous communities face long-standing challenges to accessing safe drinking water, including long-term drinking water advisories and limited access to quality water or safe DWSs. In Canada's North, Inuit and other northerners often rely on trucked water systems, where water is delivered to individual homes or distribution centres and stored in tanks until it is used (Daley et al., 2018). This system can adversely affect health due to inadequate supply (e.g., tanks do not hold enough water to meet household needs) and quality (e.g., water may be contaminated during storage) (Daley et al., 2014). Water management issues in Indigenous communities are discussed further in section 7.3.4.2 Impacts on Infrastructure.

Contamination of water destined for human consumption (e.g., drinking, cooking, and washing) or recreation (e.g., swimming in open waters) is typically categorized as biological, chemical, or radioactive. Biological contamination is microbial, from either bacteria, protozoa, viruses, or algae, and is usually managed by municipal systems that combine filtration and disinfection (Ashbolt, 2015). Chemical contamination threats are varied and include arsenic, lead, microplastics, and pharmaceuticals (i.e., synthetic hormones) (Kleywegt et al., 2011; Uslu et al., 2013). Many of these contaminants require sophisticated treatment (Kim et al., 2018), which is a challenge for many of Canada's DWSs. Radioactive contamination (e.g., isotopes of radium, uranium, and radon) must be removed by filtration.

Many Canadian DWSs continue to face challenges with their drinking water. For example, between 2011 and 2017, on average, 10% of Canadian households on a municipal DWS reported being subject to a boil water advisory at some point over the past year (Statistics Canada, 2021). A significant proportion (close to 50%) of boil water advisories are issued as a result of drinking water distribution system problems such as line breaks, pressure losses, or planned maintenance work. Most of these boil water advisories were precautionary, and were rescinded when repairs or maintenance was completed (Health Canada, 2015).

Climate change can increase challenges to DWSs, through gradual warming, extreme weather events (e.g., floods, droughts, wildfires), and saltwater intrusion, all of which can increase contamination of waters and the need for treatment. The application of a risk-based approach to monitoring for potential contamination will be necessary as climate change exacerbates current risks to water quality and creates unfamiliar risks in the future.

7.3.2.1.1 Mechanisms Through Which Climate Change Impacts Water Quality

There is a well-documented seasonality to many infectious diseases, including sporadic cases (Lake et al., 2005; Britton et al., 2010; Lal et al., 2013) and outbreaks of water-borne AGI. Outbreaks are considered to occur if two or more epidemiologically linked people have a similar illness after exposure to the same water source (Curriero et al., 2001; Auld et al., 2004). The level of exposure required to experience health impacts differs according to the pathogen and, in many cases, the individual (e.g., less exposure may be required in children than in adults). An overview of climate-sensitive biological agents of water-related illnesses is provided in Table 7.1.

Table 7.1 Climate-sensitive biological agents of water-related illness

PATHOGEN OR TOXIN PRODUCER	EXPOSURE PATHWAY	SELECTED HEALTH OUTCOMES AND SYMPTOMS	MAJOR CLIMATE CORRELATION OR DRIVER (STRONGEST DRIVER(S) LISTED FIRST)
Algae: Toxigenic marine species of *Alexandrium, Pseudo-nitzschia, Dinophysis, Gambierdiscus;* and *Karenia brevis*	Shellfish and fish consumption Recreational waters (including aerosolized toxins) Drinking water	Gastrointestinal and neurological illness caused by shellfish poisoning (paralytic, amnesic, diarrhetic, neurotoxic) or fish poisoning (ciguatera) Asthma exacerbations, eye irritations caused by contact with aerosolized toxins (*K. brevis*)	Increased water temperature, ocean surface currents, ocean acidification, hurricanes (*Gambierdiscus* spp. *and K. brevis*)
Cyanobacteria (multiple freshwater species producing toxins, including microcystin)	Drinking water Recreational waters	Liver and kidney damage, gastroenteritis (diarrhea and vomiting), neurological disorders, and respiratory arrest	Increased water temperature, precipitation patterns
Enteric bacteria and protozoan parasites, including *Salmonella enterica, Campylobacter* spp., toxigenic *Escherichia coli, Cryptosporidium, Giardia*	Drinking water Recreational waters Shellfish consumption	Enteric pathogens generally cause gastroenteritis; some cases may be severe and may be associated with long-term and recurring effects	Changes in air and water temperature, heavy precipitation (especially when preceded by a dry period), and flooding
Enteric viruses, including enteroviruses, rotaviruses, noroviruses, hepatitis A and E	Drinking water Recreational waters Shellfish consumption	Most cases result in gastrointestinal illness; severe outcomes may include paralysis and infection of the heart or other organs	Heavy precipitation, flooding, and changes in air and water temperature

PATHOGEN OR TOXIN PRODUCER	EXPOSURE PATHWAY	SELECTED HEALTH OUTCOMES AND SYMPTOMS	MAJOR CLIMATE CORRELATION OR DRIVER (STRONGEST DRIVER(S) LISTED FIRST)
Leptospira and Leptonema bacteria	Recreational waters Indoor cooling systems that use water	Mild to severe influenza-like illness (with or without fever) to severe cases of meningitis, kidney, and liver failure	Flooding, increased water temperature, heavy precipitation
Vibrio bacteria species	Recreational waters Shellfish consumption	Varies by species but includes gastroenteritis (*V. parahaemolyticus, V. cholerae*), septicemia (bloodstream infection) through ingestion or wounds (*V. vulnificus*), skin, eye, and ear infections (*V. alginolyticus*)	Increased water temperature, sea-level rise, precipitation patterns (as they affect coastal salinity)
Legionella bacteria species, non-tuberculous mycobacteria (suggestive evidence)	Indoor cooling systems that use water	Pneumonia	Air temperature, extreme weather events, proliferation of air conditioning use

Source: Trtanj et al., 2016

Distinct seasonality of water-borne diseases across different hydroclimatic systems has been observed, both in Canada and elsewhere (Bertuzzo et al., 2012; Galway et al., 2014). A number of epidemiological studies have observed a positive association of AGI with ambient air temperature, as well as with flooding and heavy rainfall events, explaining part of these seasonal patterns (Levy et al., 2016). For example, AGI rates in selected watersheds in British Columbia (bacterial and protozoan combined) peak in the early summer among snow-dominated watersheds and in the fall for rain-dominated ones, which roughly corresponds to when each of the two different hydroclimatic regimes experience most surface runoff and groundwater recharge (Galway et al., 2014). Extreme rain events increase this discharge, often measured as turbidity in source water, particularly after a dry period (Chhetri et al., 2017). By understanding hydroclimatic factors, including seasonal changes related to climate change and underlying seasonal AGI trends, DWS designers and operators can take measures to improve filtration and treatment efficiency and reduce contamination and risks of AGI during expected seasonal peaks in disease (Galway et al., 2014).

Box 7.1 Water, watersheds, and health

The watershed represents more than just a drainage basin; it describes a complex socio-ecological system, evolved over millennia, that is connected by water, which all life depends on (Parkes et al., 2010). Watersheds encompass the land contained within the drainage basin and are linked systems, with small streams forming their own watersheds nested within ever-larger catchment areas, up to the global scale (e.g., the Ottawa River is itself a large watershed, which is part of the even larger St. Lawrence River watershed). Watersheds can be described physically as a basin, in which gravity acts upon the water, that enables downstream exposures to upstream pathogen sources.

Increasingly, water management and other natural resources and ecosystem management initiatives are being undertaken at the watershed scale, such as by Ontario's conservation authorities (Conservation Ontario, n.d.). Nationally, watershed-based approaches to ecosystem management have emerged as galvanizing forces for participatory or community-driven action (Bakker & Cook, 2011; Guehlstorf & Hallstrom, 2012; Morris & Brandes, 2013; Gérin-Lajoie et al., 2018). British Columbia alone has more than 230 community-based groups working to protect water quality, many of which are volunteer-driven.

This growing interest in water resources management and environmental protection at the watershed scale creates opportunity for citizen-led efforts to monitor, report on, and respond to health-relevant climate change impacts on water resources. For example, many Indigenous communities have been developing watershed strategies as a means of governance over their resources. Engagement of youth has been pursued by many to create the next generation of "watershed warriors" (AFN, 2013). Numerous First Nations communities in the Prairies have completed source water protection plans (Patrick, 2018) that will benefit human health. Indigenous Peoples are faced with long-standing issues and challenges in reacting or responding to the many competing pressures to protect their watersheds (AFN, 2013; Goldhar et al., 2013a). Organizations focused on governance and management at the watershed scale are critical components of protecting watersheds as social-ecological systems (Canadian Council of Ministers for the Environment, 2016; Picketts et al., 2017).

The patterns, frequency, and intensity of precipitation may influence water-borne AGI through several mechanisms. Precipitation patterns can influence overland flow, runoff, and erosion, and lead to re-suspension of particles and pathogens, increasing the potential for surface and groundwater contamination by pathogens and affecting the effectiveness of DWSs (Semenza et al., 2012). Some research indicates that heavy rain following a period of drought can lead to overland flow events with particularly high pathogen loads and increased risk of surface water contamination (Levy et al., 2016). Additionally, extreme rainfall events may increase microbial concentrations in drinking water supplies due, in part, to increased particulate matter following surface runoff and re-suspension of river bottom sediment by increasing turbidity (Mann et al., 2007; De Roos et al., 2017). Turbidity refers to the cloudiness of water or undissolved solids and is a proxy indicator of water quality. High turbidity has been shown to reduce the effectiveness of water treatment in DWSs and may also provide a medium for microbial growth in source waters (Mann et al., 2007). The influence of snow-related precipitation (e.g., rain-on-snow events, snowmelt, or spring thaws) could also affect the risk of AGI but remains largely unstudied (Jagai et al., 2012).

Nearly 70% of all water-borne disease outbreaks in the United States from 1948 to 1994 occurred after a heavy rain event (Curriero et al., 2001). Heavy rain has also been identified as a contributing factor in Canada's Walkerton, Ontario, tragedy (Auld et al., 2004) and the largest outbreak of AGI in the United States in Milwaukee in 1993. In Milwaukee, a heavy precipitation event quickly saturated the soil, causing surface runoff and associated turbidity, resulting in a compromised water treatment process (Curriero et al., 2001). Unlike the Milwaukee event that was associated with a single large rain event, the Walkerton event followed multiple days of heavy rain that saturated the soil, leading to the contamination of a drinking water production well. The water supply was contaminated with multiple pathogens (Auld et al., 2004) reaching consumers after additional failures in the water treatment process (Hrudey et al., 2003). These examples highlight some of the similarities and differences among DWSs concerning how extreme precipitation can affect water quality under various hydrological conditions and possible implications of future climate change.

In Canada, sporadic AGI cases are likely responsible for a greater burden of illness than AGI outbreaks, but are more challenging to study. Two relatively large 10-year studies in British Columbia recorded an average 19 cases/100,000 and 26.9 cases/100,000, respectively. There were no outbreaks during the two study periods (Uhlmann et al., 2009; Chhetri et al., 2017). Identifying transmission pathways and under-reporting, including the possibility of unreported outbreaks, presents challenges (Hunter & Thompson, 2005). However, emerging evidence suggests that heavy precipitation events can be associated with increases in sporadic AGI in municipal DWSs (Chhetri et al., 2017). While the risk to specific indviduals is small, due to the large populations exposed, the number of cases or population attributable risk is significant. Considering that most AGI cases go unreported, AGI estimates are likely to be quite conservative. In a representative survey in British Columbia, it was estimated that only once in 48.5 cases of cryptosporidiosis and once in 40.7 cases of giardiasis are reported (MacDougall et al., 2008).

Before a membrane-filtration drinking water treatment plant was installed for much of Metro Vancouver in 2010, a significant increase in water-borne disease two to four weeks after heavy rain events (defined as above the 90th percentile) was observed (Chhetri et al., 2017). Using identical methods, another study by the International Joint Commission found similar associations in three municipal DWSs sourcing water from the Great Lakes region (Mezzacapo et al., 2018). In both studies, a dry period, defined as at least 30 days of the previous 60 without precipitation, was a significant mediating factor increasing risk. A preceding dry period of some length has also been observed in other studies (Levy et al., 2016). It is hypothesized that a dry period, or drought, allows for accumulation of pathogens in the environment and source waters, increasing the risk of drinking water contamination (Levy et al., 2016). While these studies cannot be extrapolated to other watersheds across Canada, they do highlight the vulnerability to sporadic illness due to heavy rain events in some municipal systems, independent of outbreaks due to DWS failures. For many regions in Canada, climate change is expected to increase extreme rain events (Chhetri et al., 2017; Bush & Lemmen, 2019). More studies are needed to examine the effects of extreme rain following dry periods on the various types of water treatment available and how each performs in the many types of watershed-level hydroclimatic systems across Canada.

7.3.2.2 Saltwater Intrusion

In coastal regions of Canada, the intrusion of saltwater from the ocean into coastal aquifers is a growing concern, as the saltwater can contaminate the groundwater, making it unusable for drinking or irrigation. Population increases, accompanied by increased groundwater demands, as well as rising sea levels and storm surges, are all driving factors of this phenomenon (Klassen & Allen, 2017). The complex interactions between fresh and saline coastal aquifers make it difficult to study these changes. As saltwater intrusions may last years and even decades, their impacts on water and food security, and implications for human health, can be long-lasting and severe (Luh et al., 2017). Contamination of groundwater by ocean water leads to increased demand on surface water sources and uncontaminated groundwater sources. Small islands with growing populations, such as British Columbia's Gulf Islands, are particularly vulnerable. The increased density of coastal wells on some Gulf Islands has resulted in a depressed water table, resulting in saltwater intrusion and possible contamination of wells located nearest to the coast (Klassen & Allen, 2017). Saltwater intrusion events have also occurred in the Canadian Arctic and Atlantic Canada (Somers & Nishimura, 2012; Thienpont et al., 2012).

7.3.2.3 Pathogens in Sewage Found in Ocean Water

Pathogens found in sewage can end up in ocean water and bioaccumulate in shellfish, particularly filter-feeding bivalves such as oysters, mussels, and clams (Le Guyader et al., 2000), which, when consumed raw or undercooked, can cause sporadic illness and disease outbreaks (Bellou et al., 2013). The pathogens of main concern include norovirus and hepatitis A, both viruses. Norovirus is a very common cause of gastroenteritis, causing symptoms such as nausea, vomiting, diarrhea, and low-grade fever, lasting one to three days. It occurs primarily in the winter months and causes numerous community and facility disease outbreaks. It is usually self-limiting; a small proportion of patients require hospitalization for dehydration (Heymann, 2015). Hepatitis A causes liver infection and manifests as fever, nausea, abdominal pain, and jaundice. Most people recover without treatment, but adults can experience a more serious course with chronic liver disease, and 1% to 2% of cases are fatal (Heymann, 2015). These pathogens can contaminate food through contact with an infected food handler or from direct contact with human sewage.

Vibrio spp. are the most common form of bacteria to affect human health in Canada following the consumption of fish and shellfish (see section 7.3.4 Water Security and Society). However, bacteria other than *Vibrio spp*. are occasionally found in fish and shellfish and have caused outbreaks (Burkhardt & Calci, 2000; Feldhusen, 2000: DePaola et al., 2010). *Salmonella* is the most common cause of such bacterial contamination in Canada, although, on occasion, *Escherichia coli*, *Campylobacter*, and *Shigella* have contaminated fish or shellfish. These bacteria are introduced into the marine environment from animal or human feces or during processing. Agricultural runoff is another possible source of marine contamination and disease outbreaks, although it is uncommon. Although *V. cholerae* are naturally occurring marine bacteria, illness risk is amplified in areas where sewage is not controlled.

Direct contact with human sewage is commonly how shellfish become contaminated (Campos & Lees, 2014). Climatically driven increases in extreme precipitation events may result in an increased number of sewage water releases, particularly in combined stormwater and sewage water systems. Overflows occur when raw sewage enters the environment via accidental or planned discharges from municipal sewer systems, storm drains, or septic systems, or seepage from damaged sewage pipes (Cook et al., 2009; Miller et al., 2018). Numerous shellfish-related disease outbreaks have been reported in association with overflow events (Maalouf et al., 2010). Some studies have linked heavy rainfall to overflows, oyster contamination, and norovirus outbreaks in Canada (Doyle et al., 2004; CBC, 2012). Extreme rainfall also reduces marine water salinity, which enhances norovirus survival (Wang & Deng, 2016).

7.3.2.4 Phytoplankton and Algal Blooms

Phytoplankton are microscopic organisms found in both fresh and marine waters and are sensitive to climate. Two common forms include algae and cyanobacteria (Zimmerman, 2015). Phytoplankton growth is determined by temperature, light, freshwater discharge, salinity, upwelling, and the availability of nutrients (Moore et al., 2008; Finnis et al., 2017; Vandersea et al., 2018). Climate change is providing favourable conditions for algae and cyanobacteria in ocean and freshwaters globally. Reports of blooms are becoming increasingly common in lakes across Canada (Pick, 2016). Some species of freshwater cyanobacteria produce toxins (cyanotoxins) that are harmful to human health when ingested, leading to liver, skin, and nervous system toxicity (Hilborn & Beasley, 2015). Cyanobacteria should not be confused with the toxic marine algae that contaminate shellfish and cause gastrointestinal neurological disease; however, together they are commonly known as "harmful algal blooms" (Carmichael & Boyer, 2016).

Marine biotoxins are produced by phytoplankton found in ocean waters. They accumulate in shellfish or fish and can cause human illness when ingested raw or cooked. Three toxin groups of concern have been found off both the Pacific and Atlantic coasts of Canada and can accumulate in bivalve and invertebrate shellfish. Other marine biotoxins, such as ciguatoxin, occur in tropical waters and can be found in fish imported to Canada (Visciano et al., 2016).

Diarrhetic shellfish poisoning (DSP), characterized by nausea, vomiting, and diarrhea, can last one to three days and is caused by okadaic acid group and *dinophysis* toxins produced by several species of *Dinophysis* and *Prorocentrum* (Taylor et al., 2013a). Saxitoxin describes a group of more than 30 toxins and derivatives produced mainly by *Alexandrium* ssp., causing paralytic shellfish poisoning. This illness is characterized by diarrhea, numbness, tingling, paralysis of the mouth and extremities, headache, and difficulty walking and swallowing, and it can also be fatal (Alexander et al., 2009; Etheridge, 2010). Domoic acid (DA), produced by diatoms called *Pseudo-nitzschia*, causes amnesic shellfish poisoning (ASP), characterized by diarrhea, headache, dizziness, confusion, permanent or short-term memory loss, and seizures. It can also be fatal (Perl et al., 1990; Grattan et al., 2018).

The first reported ASP outbreak was associated with mussels from North American Atlantic waters in 1987 (Perl et al., 1990). In 2011, an outbreak of DSP was associated with the consumption of mussels from British Columbia (Taylor et al., 2013a). Paralytic shellfish poisoning cases are routinely reported in British Columbia and the Atlantic provinces (Prakash et al., 1971; Finnis et al., 2017). On the Pacific Coast of the United States, DA has been found in traditional marine foods, such as razor clams (Grattan et al., 2018). The US Food and Drug Administration has established a regulatory safety level of 20 parts per million of DA for human shellfish consumption. However, a study with coastal Indigenous Peoples who consumed clams from Washington

State showed deficits in memory and recall capacity with repeated DA exposures below this level (Grattan et al., 2018). Health Canada has also established regulatory safety levels for various contaminants, some of which are currently under review. Currently, Health Canada (2020) has established a limit of:

- 20 mg/kg of DA for human shellfish consumption;
- 0.2 mg/kg of DSP toxins in edible shellfish tissue for human consumption; and
- 0.8 mg/kg of paralytic shellfish poisoning toxins in edible shellfish tissue for human consumption.

Temperature and nutrient loading are major determinants of harmful algal blooms and are influenced by temperature and extreme precipitation in both freshwater (IJC, 2017) and oceans, although few studies have directly assessed the link between climate change and marine biotoxins. Gobler et al. (2017) showed that, from 1982 to 2016, increasing ocean temperatures led to an increase in *Alexandrium* and *Dinophysis* bloom season duration and growth rates. Other researchers projected an increase in algal blooms in response to climate change–driven changes to marine ecosystems, particularly warming ocean temperatures in Canada (Glibert et al., 2014; Moore et al., 2015; DFO, 2020).

An increasing number of marine harmful algal blooms and biotoxin outbreaks are being reported worldwide. This is likely due to a combination of climate change, increased nutrient load in coastal waters, heightened awareness, and improved diagnostic capacity (Botana, 2016; Gobler et al., 2017). Harmful algal blooms and disease outbreaks are being reported from new or expanding geographical areas. DSP outbreaks are being reported in new areas of North America and Europe, and cases have been reported in British Columbia, Nova Scotia, and Newfoundland (Todd, 1997; Deeds et al., 2010; Taylor et al., 2013a; Gobler et al., 2017). Paralytic shellfish poisoning has appeared in new areas, such as Iceland (Gobler et al., 2017), and saxitoxin-producing planktons are expanding in other Arctic regions, such as Alaska (Anderson et al., 2019). Ciguatoxins are spreading northward and southward and have now been found in the Canary Islands, Crete, Madeira, and Southern Australia (Botana, 2016).

Harmful algal blooms and disease outbreaks usually occur during summer months, when the temperature is higher and more light is available (Moore et al., 2008). Climate change is increasing both ocean and freshwater temperatures, and this could increase the range, growing season, and growth rate of certain phytoplankton (Moore et al., 2008; Gobler et al., 2017). While some harmful algal blooms occur without anthropogenic inputs, others are caused by large external inputs of nitrogen and phosphorus (e.g., from chemical or manure-based agricultural fertilizers). These nutrients end up in the waterways adjacent to agricultural land, resulting in explosive growth, particularly following a dry spring coupled with an extended warm period (Pick, 2016). This has been observed, for example, in British Columbia freshwater, with the first heavy rains of the fall (Galanis et al., 2014). Cyanobacterial blooms most often occur in warm, nutrient-rich waters with low amounts of mixing among its layers (Hilborn & Beasley, 2015). In addition to more favourable conditions with warming waters, the increased surface runoff associated with extreme precipitation events can transport biological pathogens, as outlined above, and also transfer nutrients into source water, promoting algal growth (Delpla et al., 2009). Lake Erie, the shallowest of the Great Lakes, frequently experiences cyanobacteria blooms, while blooms in the other Great Lakes occur much less frequently (Carmichael & Boyer, 2016). Harmful algal blooms have increased across Canada over the past few decades (DFO, 2020).

The efficacy of water treatment for cyanotoxins ranges from 60% to 99.9% (Zamyadi et al., 2013). Efficacy of treatment varies because each species of cyanobacteria responds to treatment options differently. Monitoring and correctly identifying the species is an important component of treatment; however, this often requires time-consuming analysis by highly qualified personnel. Next-generation gene sequencing is currently being explored as an alternative approach to cyanobacteria identification and screening (Zamyadi et al., 2019), which may reduce barriers to enhanced monitoring. In regions where lake and streamflow rates are projected to decrease in the summer months, the nutrients may become more concentrated. The increased water temperatures that result from this low flow will further promote growth.

Warming may also lead to growth of toxigenic plankton able to survive in low-nutrient conditions, leading to greater risk of ASP in warmer waters (McCabe et al., 2016). Areas of a watershed that have been recently burned by wildfire can cause an increased nutrient load into a water source through depositions of ash (Emelko et al., 2011; Emelko et al., 2016) and may increase the risk of such blooms, at least in freshwater (Martin, 2016). Whether wildfire-derived nutrient loads have an impact in coastal waters is unknown. However, given that nutrient availability is a key determinant of phytoplankton growth, this is a realistic scenario (Sundarambal et al., 2010; Morrison & Kolden, 2015). The number of wildfires in Canada is increasing, highlighting the importance of this nutrient source (Wang et al., 2015). The relationships between wildfires, nutrient loading, algal blooms, and human health warrants further study (Wang et al., 2015; Wotton et al., 2017; Hallema et al., 2018).

7.3.3 Water Quantity

While the demand for water in many Canadian communities is increasing due to growing populations, industry, and agricultural needs, climate change has reduced the availability of water in some locations, with the greatest vulnerability being in Southern Ontario, the Southern Prairies, and the Southern Interior of British Columbia (Andrey et al., 2014). Climate change will continue to cause fluctuations in water quantity across Canada; some locations may experience both reductions and increases, but at different times (Bush & Lemmen, 2019). Indigenous communities, often located in low-lying and flood-prone areas, are particularly vulnerable to these fluctuations (ISC, 2020b; Thistlethwaite et al., 2020). In Canada, mean annual precipitation has increased, on average, with the greatest percentage increases occurring at more northern latitudes (Bush & Lemmen, 2019). Normalized precipitation (precipitation expressed as a percentage) has, on average, increased by 20% across Canada from 1948 to 2012 (Vincent et al., 2015). Despite absolute precipitation typically being lower in Canada's North, from 1948 to 2012, precipitation in that region increased by 30% (Vincent et al., 2015). However, due to a low density of meteorological stations and the associated paucity of data, there is low confidence in this estimate. Smaller increases in normalized precipitation have been observed in some regions of Southern Canada. Additionally, some seasonal differences have been observed. For instance, precipitation has increased in all four seasons in Northern Canada, while in Southern Canada, although it has increased in most seasons, these increases were rarely statistically significant (Bush & Lemmen, 2019).

Due to limited data availability, long-term precipitation trends (greater than 100 years) are available only for Southern Canada. Since 1900, a 5% increase in precipitation has been observed in Southern Canada, while the ratio of snowfall to total precipitation has decreased; this pattern is most pronounced in spring and autumn (Vincent et al., 2015). These shifts toward precipitation falling as rain instead of snow have led to earlier spring melts and increased streamflow in many areas (Vincent et al., 2015).

Table 7.2 Health impacts of drought

PRIMARY IMPACTS

Impact	Cause
Water- and food-borne diseases	Reduced water availability concentrates pathogens, and associated warmer temperatures may contribute to pathogen prevalence Greater erosion and compacting of soil so that rainfall events lead to increased runoff and associated point and/or non-point sources of pollution
Water-related illness	In coastal communities, groundwater sources may become infiltrated by saltwater in drought or water-scarce conditions, causing hypertension (Naser et al., 2019) and reducing available water for drinking and washing Increase in harmful algal blooms and illness related to harmful algal bloom toxins Inadequate access to water supplies affect hygiene, increasing susceptibility to disease Reduced access to potable water may lead to dehydration and failure of liver, kidney, and other organs after a matter of a few days, or approximately 10% body loss; in the presence of AGI with severe diarrhea, the margin of time to more severe illness or death without water can be only hours
Infectious diseases	Increased abundance of disease-carrying vectors (e.g., mosquitos) due to changes in reservoir species behaviour, impacts on mosquito predators, and reduced flushing of mosquito larvae in urban and suburban environments (see Chapter 6: Infectious Diseases) Increased growth of harmful fungi which may be of increasing importance due to emerging anti-fungicidal resistance (see Chapter 6: Infectious Diseases)
Respiratory impairments	Increased dust storms and an increased concentration of fine particulate matter in the air

SECONDARY IMPACTS	
Impact	Cause
Malnutrition and food security	Reduced agricultural outputs and/or negative economic impacts, reducing the ability of Canadians, particularly those with low incomes, to purchase nutritious foods (see Chapter 8: Food Safety and Security)
Mental health	Impacts on Indigenous Peoples who depend upon sometimes transient water sources that sustain them physically, culturally, and spiritually, along with agricultural workers whose families and livelihoods may be threatened (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada and Chapter 4: Mental Health and Well-Being)
Recreational exposure and injury	Increased recreational water use during warm and dry weather heightens exposure to increased concentration of pathogens in the available water, leading to more illness (e.g., leptospirosis, AGI) Low water levels may increase the likelihood of recreational injuries (e.g., spinal injuries resulting from diving or jumping into bodies of water)
Respiratory impairments	Increased concentration of particulate matter and allergens in the air; smoke from wildfires, in part driven by drought conditions, reduces air quality (see Chapter 5: Air Quality)

Source: Adapted from Yusa et al., 2015

7.3.3.1 Drought

Drought is "a prolonged period of abnormally dry weather that depletes water resources for human and environmental needs" (Yusa et al., 2015, p. 8360). Water scarcity associated with drought is linked to hydrometeorological conditions; other factors, such as human impacts on water resources and increased demand, can exacerbate the effects of drought (Yusa et al., 2015; Cook et al., 2017). The most immediate impact of drought is on availability of water for both humans and the environment, but quantity concerns will progress to quality concerns as drought persists. Lower river flows mean that point sources of pollution could have a higher impact on ecological systems, communities, and health. Drought periods followed by precipitation increase the risk of water-borne disease (Whitehead et al., 2009; Chhetri et al., 2017) (see Chapter 3: Natural Hazards). During drought, pathogens may accumulate in the environment (e.g., in riparian zones); when precipitation returns, heavy loads of contamination are flushed from the landscape into water sources (Whitehead et al., 2009). A Canadian study examining the risk of cryptosporidiosis and giardiasis found risk increased after extreme rain events — events in which rainfalls exceeded the 90th percentile of weekly average precipitation — and that this risk further increased if 30 of the previous 60 days had had no precipitation (Chhetri et al., 2017). Additionally, increased temperatures associated with drought may increase the speed of many chemical processes, lower the amount of dissolved oxygen available for aquatic fauna, and affect growth of micro-organisms (Cook et al., 2017). All of these factors put increased treatment demand on municipal water supply systems and could have implications for human health.

The possible health impacts of drought are presented in Table 7.2. The impacts of drought can be far-reaching and include, for example, the mental health impacts of coping with drought while depending upon non-irrigated agriculture (Edwards et al., 2015).

Concerns about the effects of drought on water security are increasing around the world and across Canada. Extreme temperatures associated with climate change are expected to increase drought risk in Canada at the end of the century under a high emissions scenario, particularly in the southern Canadian Prairies and British Columbia interior (Bush & Lemmen, 2019). Some Canadian cities have had to develop drought preparedness plans, including Tofino, British Columbia, a small coastal tourist town that sources water from a nearby lake (Lloyd, 2017). Tofino's watershed experiences no snowpack, making it entirely dependent on rain that falls during the rainy season to last through the summer months (Lloyd, 2017). In the summer of 2006, Tofino was forced to implement severe water restrictions and rely on imported potable water and a backup unpotable source to allow local businesses to continue to operate (Lloyd, 2017). While smaller island watersheds are notably at a higher drought risk, aquifer-dependent communities can also be at risk. Such is the case with Merritt, British Columbia, a hot and arid inland community that is solely dependent on an aquifer that is slowly depleting (Lloyd, 2017). These realities are leading some regions to weigh the costs of using alternative water sources, such as desalinated sea water, recycled potable water, inter-basin water transfers, and decentralized water sources (Lam et al., 2017).

7.3.3.2 Streamflow and Snowmelt

Streamflow has been correlated with pathogenic contamination of source waters and with turbidity and may therefore influence drinking water contamination and AGI risk (Lake et al., 2005; Jagai et al., 2012). Both high and low flows have been identified as risk factors for degraded water quality (Jalliffier-Verne et al., 2015). As average temperatures rise as a result of climate change, spring snowmelts are projected to occur earlier in many locations throughout Canada, resulting in increased spring flows that may be followed by decreased flows throughout the summer (Bush & Lemmen, 2019). Snowmelt can act on AGI transmission pathways in similar ways to rain events (Jagai et al., 2012), for example, by driving increased contamination of source water, contributing to flood risk, and potentially overwhelming water treatment measures (Chhetri et al., 2017).

7.3.3.3 Extreme Precipitation

Changes in extreme precipitation (measured by a period of a day or less) due to warming have not yet been observed at Canadian weather stations at a national scale but have been observed on much larger scales globally, where more data are available (Westra et al., 2013). Extreme precipitation trends are difficult to observe on a smaller scale because of natural variability. However, Environment and Climate Change Canada projects with high confidence that daily extreme precipitation will increase in Canada, with the return periods — the time between events — projected to decrease (Bush & Lemmen, 2019). Globally, the median increase in extreme precipitation is approximately 7% per 1°C increase in global mean temperature (Westra et al., 2013). Extreme precipitation can affect human health by driving flood events, contributing to source water contamination through runoff, stressing the capacity of DWSs, and other impacts (see Chapter 3: Natural Hazards).

7.3.3.4 Flooding

Flooding is the most frequent and costly natural hazard globally (CRED & UNISDR, 2015; Henstra & Thistlethwaite, 2017) and in Canada (Kovacs & Sandink, 2013). Climate change is anticipated to contribute to an increase in flood events worldwide (IPCC, 2014). In Canada more precipitation will fall as rain rather than snow in the coming decades (Bush & Lemmen, 2019), and regional climate models have projected an increase in rain-on-snow events across North America (Il Jeong & Sushama, 2018). It is unclear what the combined impacts of warm temperatures and reduced snowpack will have on snowmelt-related flooding events (Bush & Lemmen, 2019). Streamflow-related flooding events are also complex, making it difficult to project changes in flood frequency and intensity (Bush & Lemmen, 2019).

Although climate change may not increase flooding in all areas of Canada, a general increase in flood risk is likely in urban areas, where land-use patterns may exacerbate flooding, and in coastal areas where flooding is driven by sea-level rise (Bush & Lemmen, 2019). Many Canadian dams and dikes are vulnerable to failure, and these risks will rise as extreme rain events and flooding increase with climate change (McClearn, 2020). Record-keeping is often sparse and poorly regulated for the country's 14,000 dams (McClearn, 2020). A report issued following the 2017 failure of the Gorie Dam on the North Maitland River in Southwestern Ontario due to heavy rains, noted that, in Ontario, many dams and weirs "are approaching or have exceeded their normal life expectancy" (Greck and Associates Limited, 2018, p. 5).

In Canada, floods are often caused by heavy rain and/or the fast melting of snow and ice due to rapidly rising temperatures in the spring. During these conditions, overland flow of water can transport biological and chemical contaminants from surrounding areas into adjacent surface water bodies or unprotected wells. Abandoned wells can provide a conduit for contaminants to enter an aquifer used by other adjacent, properly sealed wells. Common contaminants are bacteria, viruses, and parasites, or chemical pollution from industrial, agricultural, or residential waste systems. Inundation and increased turbidity can overwhelm drinking water and wastewater treatment systems and are a significant health risk during these events (Hrudey et al., 2003). Globally, floods in coastal areas and riverine estuaries are increasing due to sea-level rise and storm surge from extreme weather events (IPCC, 2014; Kinney et al., 2015). Health risks from flooding can include mortality directly associated with flooding, such as drowning (Lowe et al., 2013); hypothermia (Lowe et al., 2013); injuries, such as broken bones (Doocy et al., 2013); gastrointestinal illness (Vollaard et al., 2004); zoonotic diseases such as hookworm (Kovats & Akhtar, 2008); vector-borne illnesses (Ahern et al., 2005); respiratory issues from exposure to bio-contaminants following a flood (Hulin et al., 2012) (see Chapter 5: Air Quality); mental health impacts (Azuma et al., 2014); and pediatric conditions, such as childhood obesity (Dancause et al., 2013). Health risks from flooding are also discussed in Chapter 3: Natural Hazards, Chapter 4: Mental Health and Well-Being, and Chapter 6: Infectious Diseases. Table 7.3 provides information on the primary and secondary health impacts of floods. Many impacts can be addressed or reduced with adequate warning and preparation, along with adherence to basic safety precautions related to the operation of motor vehicles, the use of combustible fuels in closed spaces, the use and management of electrical infrastructure and equipment, and the proper management and oversight of drinking water supply and treatment systems.

Table 7.3 Health impacts of floods

PRIMARY IMPACTS	
Impact	Cause
Mortality	Drowning or acute trauma (e.g., from debris or building collapse) usually attributable to motor vehicle accidents or high-risk behaviours in flooded areas (e.g., swimming, wading through flood waters, etc.)
Hypothermia	Exposure to floodwater causing a drop in core body temperature
Cardiovascular stress	Exertion and stress related to the event, leading to high blood pressure, heart attacks, and strokes
Physical injuries	Direct contact with floodwater, causing lacerations, skin irritations, bruises, and wound infections
Mental health	Adverse psychological responses to flood events, associated damage, and emergency situations, such as depression, anxiety, and post-traumatic stress disorder; these impacts may be particularly severe for those who face evacuations due to flood events – these impacts may be both a primary and seconday effect of flooding
Infection	Aspiration of water into the lungs, causing pulmonary swelling, lung irritation, and fungal infection
Orthopedic injuries	Contact with water-borne debris, attempts to escape from collapsed structures, falls from ladders, and attempts to rescue people or possessions can cause sprains, strains, and other orthopedic injuries

SECONDARY IMPACTS	
Impact	Cause
Electrocution	Contact with downed power cables/lines, circuits, and electrical equipment in contact with standing water
Burns and explosion-related injuries	Disturbed propane and natural gas lines, tanks, power lines, and chemical storage tanks; toxic gas emissions; rescue boats coming into contact with power lines, leading to fire, chemical, or explosion-related burns
Vector-borne illness	The creation of pools of stagnant water may result in increased mosquito breeding and an associated increase in mosquito-borne illnesses
Impacts to the health system	Disruption or decreased availability of emergency and ongoing health services, because of damage to health infrastructure; decreased ability to provide/access care; displacement of patients and staff; impaired surveillance of illness, injury, or toxic exposure to health care staff; loss of medical records; and loss/impairment of medication and medical devices
Mental health	Adverse psychological responses to flood events, associated damage, and emergency situations, such as depression, anxiety, and post-traumatic stress disorder; these impacts may be particularly severe for those who face evacuations due to flood events – these impacts may be both a primary and seconday effect of flooding
Carbon monoxide poisoning	Health impacts associated with inappropriate use of unventilated cooking tanks (e.g., barbeques), pressure washers, and gas-powered generators
Burns/smoke inhalation	House fires started by candles used during power outages that can be associated with flood events
Dehydration and environmental exposure	Exposure of vulnerable populations to environmental stresses in days following the event, leading to heat exhaustion, heat stroke, heart attack, and stroke

SECONDARY IMPACTS	
Water- and food-borne diseases	Contaminated food and water from sewage overflows; flooding of agricultural areas; transport of sediment, fertilizers, and pesticides into waterways; damage and disruption of drinking water system operations; leakage of toxic materials from industrial sites into waterways Health risks include gastrointestinal issues, infectious diseases such as *Legionella pneumophila*, norovirus, rotavirus, and hepatitis A and C
Respiratory issues	Respiratory contaminants from mould, bacterial, and other fungal growth on damp structures

Source: Adapted from Berry et al., 2014a

7.3.3.5 Projected Sea-Level Rise

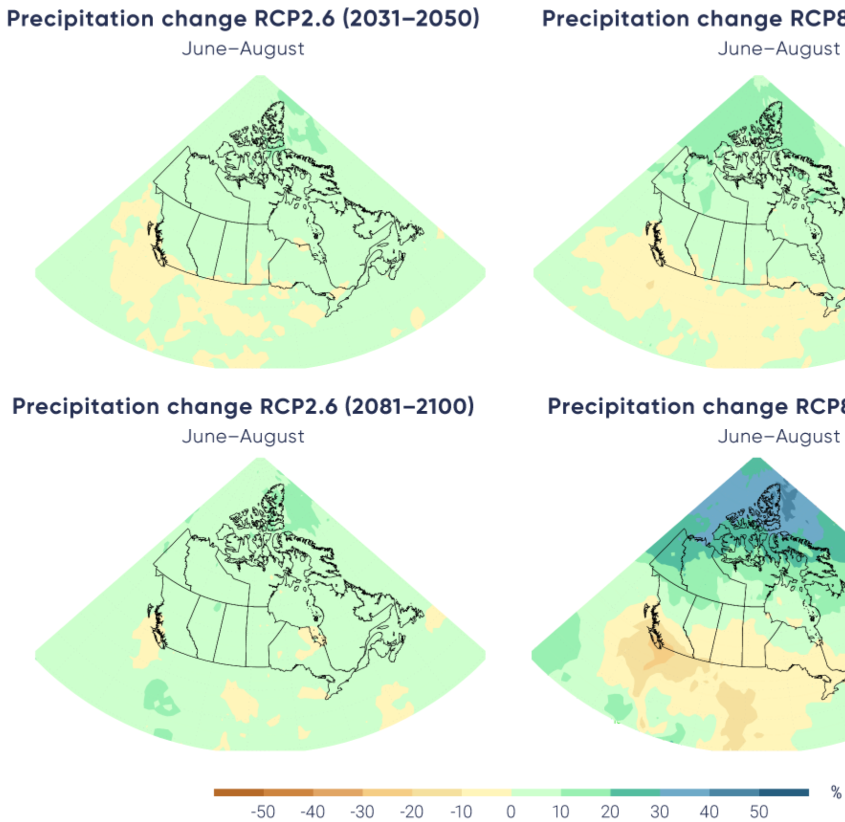
Sea-level rise contributes to flooding and coastal erosion and is important to consider during infrastructure planning and maintenance, as well as for the protection of human and ecosystem health (see Chapter 3: Natural Hazards). Warm water expands; therefore, as oceans absorb heat from the atmosphere, sea-level will rise. Global sea levels may rise by up to 1 metre by 2100 (Bush & Lemmen, 2019). However, because landmasses are slowly moving vertically through uplift and subsidence, the relative sea-level rise experienced on land is variable. In Canada, sea-level change by 2100 will range from −0.9 metre to 1 metre (Bush & Lemmen, 2019). Larger storm surges are projected for Canada's Arctic and Atlantic coasts, which will cause additional coastal flooding in some regions. Storm surges and rising sea levels could place additional pressures on water and wastewater infrastructure located along the coast, in addition to contributing to saltwater intrusion of coastal aquifers, which is already occurring in some regions of Canada, such as the Gulf Islands in British Columbia (Klassen & Allen, 2017).

7.3.3.6 Projected Precipitation

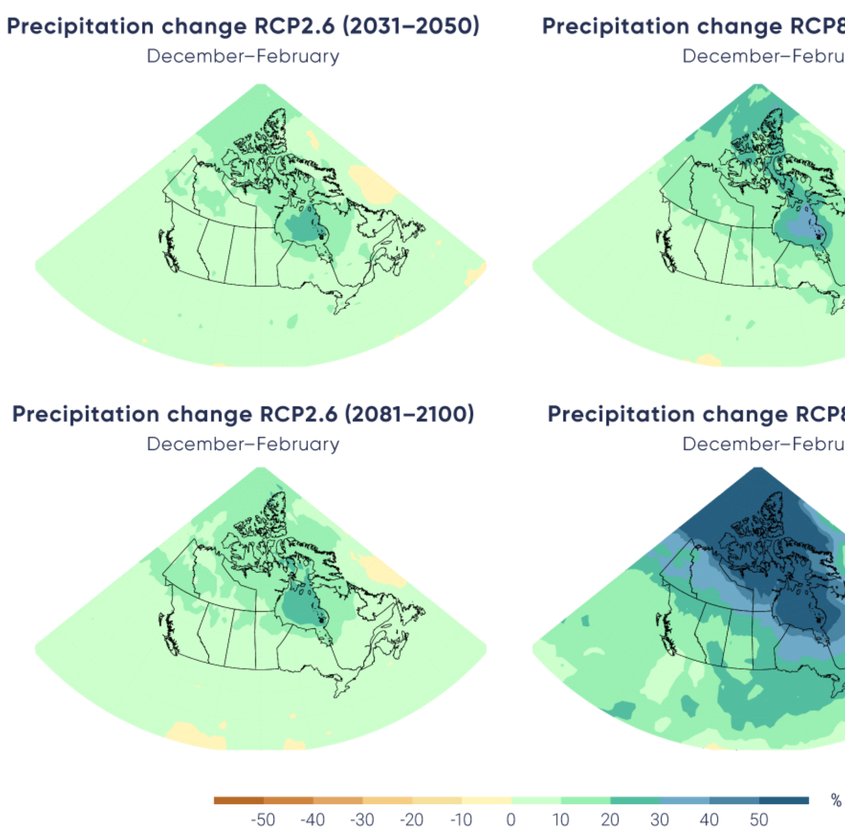
Mean precipitation in Canada is projected to increase or decrease, depending on season and location (Figure 7.2). By mid-century, depending on the emissions scenario used, Canada is projected to experience an increase of around 5.5% to 7% mean precipitation in all seasons nationally. Under a high emissions scenario (Representative Concentration Pathway [RCP]8.5), by the year 2100, this projected increase reaches 24%, with some Arctic regions increasing by more than 30%. Under a low emissions scenario (RCP2.6), a 7% increase is projected nationally (Zhang et al., 2019).

However, under a high emissions scenario (RCP8.5), precipitation is projected to decrease in some regions of Southern Canada during summer months, with much smaller summer decreases projected under a low emissions scenario (RCP2.6). Decreases of mean precipitation of around 30% are projected for Southwestern British Columbia during summer, under a high emissions scenario (Zhang et al., 2019).

a)


Precipitation change RCP2.6 (2031–2050)
June–August
Precipitation change RCP8.5 (2031–2050)
June–August
Precipitation change RCP2.6 (2081–2100)
June–August
Precipitation change RCP8.5 (2081–2100)
June–August
%
-50 -40 -30 -20 -10 0 10 20 30 40 50

b)


Precipitation change RCP2.6 (2031–2050)
December–February
Precipitation change RCP8.5 (2031–2050)
December–February
Precipitation change RCP2.6 (2081–2100)
December–February
Precipitation change RCP8.5 (2081–2100)
December–February
%
-50 -40 -30 -20 -10 0 10 20 30 40 50

c)

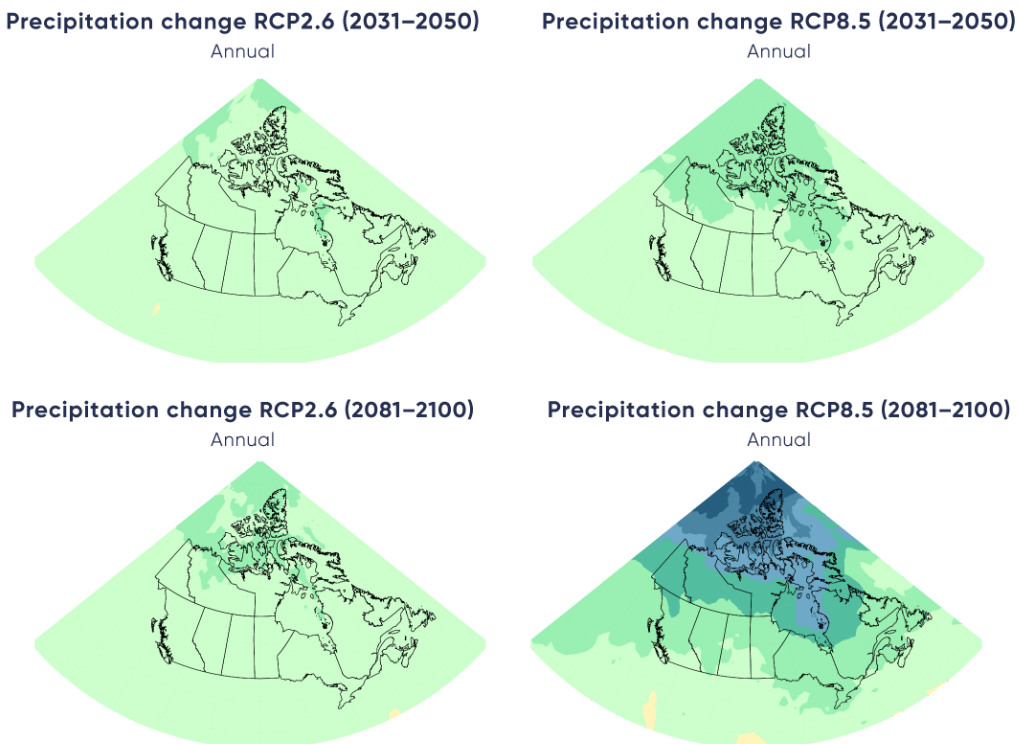


Figure 7.2 Projected precipitation changes for summer (A), winter (B), and annually (C) for two emissions scenarios (RCP2.6 and RCP8.5) by mid and late 21st century. Source: Zhang et al., 2019.

7.3.3.7 Projected Extreme Precipitation

Overall, Canada is expected to experience an increase in precipitation over the next 80 years, with greater intensity in the fall, winter, and spring. The frequency of extreme precipitation events is likely to increase across Canada, and their magnitude is projected to increase in proportion to the amount of warming. For example, under a high emissions scenario (RCP8.5) and averaged across Canada, a rare once in 20-year one-day precipitation event is projected to occur once in 10 years by 2031 to 2050, and once in five years by 2100 (i.e., a four-fold increase in frequency) (Zhang et al., 2019). Under a low emissions scenario (RCP2.6), once in 20-year one-day events are projected to become once in 15-year events by 2031 to 2050, with little additional increase in frequency beyond mid-century. Importantly, larger changes in the frequency of even rarer events is projected. For example, a once in 50-year one-day event is projected to become a once in 10-year event by 2031 to 2050 and a once in five-year event by 2100 under a high emissions scenario (i.e., a five-fold increase in frequency) (Zhang et al., 2019).

7.3.3.8 Projected Freshwater Availability and Scarcity

Canada's Changing Climate Report assessed available literature on observed and projected changes in Canada's cryosphere (snow, ice, and permafrost) (Derksen et al., 2019), including resulting impacts on freshwater availability (Bonsal et al., 2019). Climate-driven changes to streamflow seasonality have already been observed in Canada: for example, earlier spring freshet due to earlier spring snowmelt, higher winter streamflows, and, for many regions, reduced summer flows (Bonsal et al., 2019). A lack of observations (especially in Northern Canada) limits the confidence in trend detection for many freshwater-related variables, but the available measurements indicate that annual streamflow magnitude, surface water, and shallow groundwater levels, droughts, and soil moisture have been highly variable over the past 30 to 100 years and have not exhibited increasing or decreasing trends connected to climate change (Bonsal et al., 2019).

Warming temperatures are expected to decrease the proportion of total precipitation falling as snow, with a shift to increased rain, especially in spring and autumn (Zhang et al., 2019). This will have direct impacts on the flow regime for many streams across the country. For example, Canada's largest Pacific watershed, the Fraser River Basin, is projected to shift from a watershed where peak streamflow is generated by spring snowmelt (nival regime) to a watershed where peak flow will instead be dominated by rainfall-generated flows (pluvial regime) (Curry et al., 2019). Understanding how such changes will influence fisheries and other human uses of the watershed, including those that impact health (e.g., drinking water infrastructure, freshwater quantity, and quality), requires further study.

Ongoing changes to snow cover across Canada driven by a warming climate (Mudryk et al., 2018; Derksen et al., 2019) will contribute to changes in streamflow magnitude, seasonality, and corresponding freshwater availability. Observed declines in mountain glacier mass have, to date, had a limited impact on freshwater availability. However, climate models project that glacier mass could shrink by 85% across western Canada by 2100 under a medium emissions scenario (Derksen et al., 2019). In coming decades, glacier-fed rivers will experience periods of increased summer discharge due to greater meltwater contributions from enhanced glacier melt, but this is a short-term response to melting ice and is unsustainable once ice mass declines past a critical level. The rate and timing of this transition will have important consequences for stream and river water quality and temperature, and for the availability of water for human uses, such as hydroelectricity generation and agriculture (Derksen et al., 2019). Permafrost warming and thaw will result in changes to surface hydrology, which are not yet fully understood, including regionally variable wetting or drying of the landscape, changes to freshwater quantity and quality, and landscape changes due to subsidence and thermokarst events. As a result of increased temperature and evaporation, lower surface water levels of wetlands and lakes are projected in many regions toward the end of the century under a high emissions scenario. It is uncertain to what degree increases in precipitation will offset lower surface water levels (Bonsal et al., 2019).

Annual streamflow is projected to decrease in some southern interior regions in Canada, while increasing in others (mostly northern regions). In some areas where increased evapotranspiration is expected to outweigh increases in precipitation, there is an increased risk of drought and decreased soil moisture (such as in the Southern Prairies and British Columbia Interior). This risk is greater under higher levels of climate warming (Bonsal et al., 2019).

Due to the close link between surface temperature and groundwater recharge, projected changes to temperature and precipitation are expected to influence future groundwater levels. However, given the complexity of groundwater systems and a lack of information, the magnitude and even direction of change is not clear (Bonsal et al., 2019). For example, a major challenge when researching climate change impacts on groundwater is distinguishing effects of climate change from those due to land-use change, such as agriculture. Agricultural irrigation from groundwater sources has the potential to deplete aquifers, particularly in arid environments (Taylor et al., 2013b). More research is needed on groundwater trends and potential impacts due to climate change, particularly in areas that rely on groundwater for drinking water and irrigation.

Soil moisture refers to the water stored in the unsaturated upper layer of soil, and it is an important component of the land energy and water balances that affect agricultural production. Soil moisture is involved in complex feedbacks with both temperature and precipitation. It has a direct impact on plants' transpiration, which is the largest component of total land evapotranspiration (Seneviratne et al., 2010). Therefore, in certain regions where soil moisture becomes limited, evapotranspiration can decrease and may lead to reduced precipitation (Seneviratne et al., 2010). Reduced soil moisture can also increase near-surface air temperature by limiting the amount of energy used by latent heat flux, a process that has been identified as a contributing factor for extreme heat events (Seneviratne et al., 2010), which have substantial impacts on human health (see Chapter 3: Natural Hazards).

Indigenous communities are among those disproportionately affected by decreased precipitation and related effects on water sources. For example, communities along the Yukon River reported changes to traditional drinking water resources, with impacts on their subsistence activities as well. In Pond Inlet, Nunavut, community members reported concerns about water quality due to observed changes in water taste and colour during the summer (ISC, 2019).

In the Fraser River Basin in Northern British Columbia, the snow-dominated system is shifting to a rain-dominated one (Kang et al., 2014; Picketts et al., 2017). In some parts of the basin, such as its tributary the Nechako River, there are projected changes to annual discharge, with earlier peak flows and lower low flows in late summer. Climate change projections indicate that the spring freshet will arrive earlier, and summer flows may decrease (Kang et al., 2014; Picketts et al., 2017). Decreases in snow accumulations will alter water quality, and decreases in flow can have major negative effects on migrating salmon, which have cultural significance for many First Nations Peoples. These changes will affect First Nations and their cultural relationship to water, food security, and the state of drinking water on many reserves, with concurrent implications for health. In many cases, these health impacts may be compounded by a variety of challenges unrelated to climate change (e.g., social issues rooted in colonization) (Berner et al., 2016).

7.3.4 Water Security and Society

Water security has direct implications for drinking water and water systems, food and food systems, cultural and spiritual practices, and recreation. Access to drinking water of a suitable quality and in sufficient supply to sustain health and well-being is a core component of water security. Similarly, water is fundamental to both food production (e.g., crop irrigation, maintaining healthy fish stocks, etc.) and food processing (e.g., manufacturing processed foods, cleaning vegetables before distribution for sale, cooking, etc.). Air temperature, water temperature, and precipitation are the most important climatic variables influencing the occurrence of food-borne disease (Smith & Fazil, 2019) (see Chapter 8: Food Safety and Security). Of the 11 key food-borne pathogens identified by Smith and Fazil (2019) to examine in the context of climate change in Canada, six are influenced, in part, by precipitation, drought, and/or water temperature.

Parts of Canada already face periods of water insecurity, due to impacts on water quality and shortages in water supply. For example, in 2019, Iqaluit, Nunavut, faced an unprecedented shortage of source water after a summer of historically low precipitation (Bell, 2019). As the climate continues to warm, and in the absence of effective adaptation measures, concerns related to water security and human health may increase. Public health and water management practitioners, researchers, and decision makers all have a role to play in protecting and promoting health by working to attain and/or maintain water security.

7.3.4.1 Water and the Food System

Water, in a sufficient supply and of a sufficient quality, is critical to food production and is also used for cleaning, sanitation, and manufacturing activities in the food system (Kirby et al., 2003). Food processing operations require very large amounts of water (Compton et al., 2018). Variability in water supply could disrupt food-processing activities, with long-term disruptions affecting food security. Water may also serve as a vehicle for transmission of chemical and/or microbial contamination of foods during processing (Kirby et al., 2003). Key pathways by which climate change can affect food processing via water impacts include increasing frequency and length of drought periods, which may result in reduced access to water required for processing activities; flooding agricultural fields with contaminated water; and contaminating water used in food processing, such as through floodwater washing contaminants into water sources (Delpla et al., 2009; Schnitter & Berry, 2019). Impacts through any of these routes would necessitate alterations to current Hazard Analysis Critical Control Point (HACCP) steps used to prevent food-borne illness in Canada (CFIA, 2012). Food businesses in Canada are required to have a food safety plan, and the HACCP is a key tool for developing one. In the HACCP approach, water is used for food processing and cleaning, and removing chemical and microbial contaminants on meat, produce, or other raw ingredients.

Water serves as a potential vehicle for the direct transmission of chemical and microbial contaminants to foods during processing. Chemical contaminants can include heavy metals, household and industrial pollutants, pesticides, and nitrates. Microbial contaminants can include pathogenic bacteria, such as verotoxigenic *Escherichia coli*, parasites such as *Toxoplasma gondii*, protozoa such as *Cryptosporidium*, and viruses such as norovirus. As noted in previous sections, extreme weather events associated with climate change can promote the movement of chemicals and pathogens from the surrounding environment into source water at higher levels than usual, potentially overwhelming existing treatment methods.

Both municipally treated and privately sourced water are used in food processing. Such water sources are generally treated for selected chemical and microbial hazards but are not risk-free (Kirby et al., 2003). Water that is untreated or ineffectively treated before use in food processing can transmit contaminants directly to foods. Food-borne disease outbreaks have been traced back to use of contaminated water during food processing (Kirby et al., 2003). Even water containing extremely low levels of a pathogen could result in hazardous exposures to humans via food. Given optimal conditions, transfer of just one pathogen cell to food could result in an infectious dose reaching the consumer, as the pathogen can grow from the period of food processing through distribution, retail, and storage to consumption (see Chapter 8: Food Safety and Security). Using common food processing methods, it is very difficult to completely inactivate all possible pathogens. Some food products, such as leafy greens, are more likely to cause illness, because of the minimal processing involved and the increased likelihood that they will be eaten raw (Jung et al., 2014). Given that small and private DWSs are already associated with water-borne disease outbreaks to a greater extent than larger systems, food processors serviced by such systems are at greater risk (Moffatt & Struck, 2011).

In addition to food contamination from use of water containing harmful pathogens, water shortages may also affect the processing of foods such as meat and produce, both of which have been linked to microbial food-borne disease outbreaks in Canada (Ravel et al., 2009). Water shortages can affect human health through compromised ability to remove contaminants from food; for example, limitations to the use of water for cleaning and sanitizing could result in less efficient removal of contaminants. During periods of low water availability, if alternative interventions or procedures to process foods are unavailable, reduced access to safe, nutritious food could compromise food security and affect human health.

The risk to food processing from water shortages has a seasonal component and is highest during the summer, when water demand for all purposes is greatest (Wiener et al., 2016). This time of year is also optimal for survival of many pathogens in the environment, as higher temperatures support and encourage growth (Smith & Fazil, 2019). While risks to food processing are highest in Southern Canada, depending on food exportation and supply chains, local or regional impacts on food processing from water shortages may be felt nationally.

Nearly 30% of food consumed in Canada is imported from other countries, with the majority of imported food coming from the United States (Statistics Canada, 2009). Climate change impacts on water availability and quality can also affect processing of foods in other countries that export food to Canada. These impacts are specific to the region, commodity, and possible contaminants and could ultimately have an impact on public health in Canada.

7.3.4.1.1 Fishing and Seafood

Climate change is expected to affect marine food sources, through temperature effects on marine ecosystems (e.g., changes in micro-biota and other species higher in the food web), ocean acidification, extreme precipitation events, and subsequent agricultural runoff linked to nutrient loading. The consumption of contaminated raw or undercooked fish and shellfish carries the risk of infection from viruses, bacteria, parasites, and toxins.

Vibrio species are naturally occurring bacteria found in ocean water worldwide, including Canada's Pacific and Atlantic coastal waters. Common species on the Pacific and Atlantic coasts include *V. parahaemolyticus (Vp), V. vulnificus, V. fluvialis, V. alginolyticus* and non-toxigenic *V. cholerae* (Banerjee et al., 2018). *Vp* is the most common species linked to shellfish-related illness in Canada. If ingested, *Vp* can lead to diarrhea, vomiting, nausea, and fever lasting one to seven days, and, in rare cases, to death (BC CDC, 2020). The majority of *Vp* infections are caused by the consumption of raw oysters obtained from commercial fisheries or self-harvested. Other routes of exposure include inadvertently or submerging wounds or ears in contaminated ocean water or swallowing it.

Vp and other *Vibrio* species in bivalve shellfish on the Pacific and Atlantic coasts of Canada increased between 2006 to 2009 and 2010 to 2013 (Banerjee et al., 2018). Every year, 30 to 70 human infections are reported in British Columbia, as are a small number from other parts of the country (BC CDC, 2020). For every case of *Vp* reported in Canada, 92 additional cases are believed to have occurred in the affected community (Thomas et al., 2013). *V. fluvialis* and *V. alginolyticus* each result in zero to four locally acquired cases per year in British Columbia (Khaira & Galanis, 2007; BC CDC, 2020) which typically present as acute gastrointestinal illness. *V. vulnificus* can cause severe infection, including primary septicemia and necrotizing soft-tissue infections. Locally acquired *V. vulnificus* infection is extremely rare in Canada; only five case reports have been published (Abbott, 1986; Kelly, 1991; Vinh et al., 2006; Bigham et al., 2008).

Large *Vp* outbreaks in British Columbia have led to closures of shellfish harvest areas and bans on the sale of raw oysters in restaurants. These measures can threaten both the economic viability of the shellfish harvesting industry and the continued use of the food source (Fyfe et al., 1997; Taylor et al., 2018). Other *Vibrio* species are pathogenic to shellfish and fish and can also cause major economic impacts (Paillard et al., 2004).

Vibrio species are thermophilic, meaning they prefer higher temperatures; therefore, sea surface temperature (SST) is the most important environmental predictor of *Vibrio* concentrations. Higher temperatures lead to higher *Vibrio* concentrations in ocean water and oysters, and, by extension, increased rates of human illness (Cook et al., 2002; Parveen et al., 2008; Haley et al., 2014; Konrad et al., 2017). The SST threshold for *Vp* growth is approximately 15°C (Khaira & Galanis, 2007; Konrad et al., 2017), which means the majority of locally acquired *Vibrio* infections in Canada occur during the summer months.

Although the biologic cycle of *Vibrio* species, with the exception of toxigenic cholera, is not well understood, it is known that *Vibrio* species attach to chitin-containing organisms, particularly zooplanktons, which are considered their natural reservoir (Vezulli et al., 2010). The seasonal variation in *Vibrio* concentrations depends on both SST and the composition of the plankton reservoir (Turner et al., 2009). *Vibrio* concentration is directly related to certain growth stages of zooplankton following phytoplankton blooms, which occur in warmer temperatures (Turner et al., 2009).

The ongoing warming of ocean temperatures and associated extension of summer conditions, driven by climate change, increases the risk of *Vibrio* proliferation in ocean waters. This can result in increased accumulation in bivalve shellfish and, subsequent increased risk to humans. The rate of *Vp* illness has increased over many years, in association with slowly increasing SST; there have also been large outbreaks that occur over a few months following short-term anomalies in SST (Martinez-Urtaza et al., 2010). In the North Atlantic Ocean, both the warming of the Northern Hemisphere and the Atlantic Multidecadal Oscillation are associated with increasing *Vibrio* presence in the water over the last 50 years (Vezzulli et al., 2016). A more rapid increase in *Vibrio* incidence has been observed at higher latitudes (Logar-Henderson et al., 2019). This may be due to ballast water discharge during a period of warmer-than-usual weather (McLaughlin et al., 2005) or the introduction of new strains of *Vp* in warm water transported from other regions during large climatic events such as El Niño (Martinez-Urtaza et al., 2010).

Non-toxigenic *V. cholerae* is emerging in Canada in bivalve shellfish. On the Atlantic coast, it was found in 1% of samples taken between 2006 and 2013 and in 20% of samples taken between 2014 and 2016; on the Pacific coast, it increased from 1% in 2006 to 2009 to 5% in 2010 to 2013 (Banerjee et al., 2018). Human illness caused by locally acquired non-toxigenic *V. cholerae* is rare: in 2018, three confirmed cases were reported on Vancouver Island (CBC, 2019). Increasing incidence of *Vibrio*-related illness has also been noted in Europe and the United States (Newton et al., 2012; Baker-Austin et al., 2013). It is possible that, with increased warming, the incidence of *Vibrio*-related illness will continue to increase (see Chapter 8: Food Safety and Security).

7.3.4.2 Impacts on Infrastructure

The reliable operation of water infrastructure is critical to health. Drinking water, wastewater, and stormwater systems are interdependent and can be affected by climate change impacts, with cascading effects from one to the other. For the purposes of this chapter, DWSs include drinking and wastewater treatment facilities and the infrastructure required to transport water from source, to treatment, to users, to waste treatment, and to discharge point. If DWSs are rendered inoperable or ineffective, water security, and by extension human health, can suffer. Contaminated drinking water or ineffective water systems increase the risk of communicable diseases (Alderman et al., 2012). For example, extreme rainfall events may affect the ability of water system operators to reduce turbidity, which has been associated with health impacts, such as non-specific gastroenteritis (Aramini et al., 2000; Schwartz et al., 2000; Charron et al., 2004). DWSs are therefore a primary defence against water insecurity and associated health outcomes.

The Canadian Infrastructure Report Card 2019 found that, overall in Canada, approximately 70% of potable water infrastructure (i.e., local water and transmission pipes, water treatment facilities, water pumping stations, water reservoirs) is in very good (30%) or good (40%) condition, and 25% is in fair, poor, or very poor condition. In addition, approximately 55% to 65% of wastewater infrastructure is in very good or good condition. For approximately 15% of linear wastewater assets (i.e., sewer pipes and sanitary force mains) the condition is unknown, as they are underground. Regarding stormwater infrastructure, it is estimated that approximately 40% to 60% is in good or very good condition, but large data gaps exist because of limited data collection about condition (BluePlan Engineering, 2019).

DWSs across Canada were not designed with the impacts of climate change in mind and are considered among the infrastructure most vulnerable to climate hazards such as extreme events (flooding, droughts, and storms), permafrost degradation in northern regions, and lower water levels in many parts of the country associated with higher temperatures and saltwater intrusion (Lemmen & Warren, 2004; Moffat & Struck, 2011; Luh et al., 2017). A 2012 survey of 53 Canadian water utilities, conducted by the Canadian Water and Wastewater Association, found that only 30% of respondents were aware of the potential impacts of climate change, and over half (56%) did not have operational plans to address the impacts of climate change (Brettle et al., 2015).

Drinking water infrastructure can be affected, or overwhelmed, by climate change hazards in many ways. For example, the quality of water entering a water treatment system can be affected by a flood (e.g., contaminants from rural or urban areas) or by a wildfire (e.g., organic carbon and nitrogen runoff); these events could directly affect the physical infrastructure itself. If water treatment and infrastructure upgrades are required (e.g., use of more chemicals like chlorine), costs will increase for municipalities (Andrey et al., 2014). Case studies in Manitoba (Genivar, 2007) and Newfoundland (CCPE, 2008) identified potential risks to water treatment system functions (pre-treatment, softening and clarification, disinfection, storage, chemical storage, and valves and pipes) from climate hazards such as flooding, high temperatures, intense rain, drought, ice storms, and intense wind.

Many older cities still use a “combined sewer overflow” design that integrates stormwater and sanitary sewage systems. An increase in heavy precipitation events and/or rain-on-snow or frozen ground events will increase risks of stormwater impacts on sanitary systems, potentially overwhelming systems (Andrey et al., 2014) and heightening the risk of untreated sewage being discharged into adjacent streams and lakes (Madoux-Humery et al., 2016). This can cause contamination of the municipal DWS itself, if an intake is located nearby, and it can also lead to contamination of water bodies used for recreational activities. In Montréal, Quebec, a 10-year study found that 80% of all peak *E. coli* measurements at two municipal drinking water intakes along the St. Lawrence River were linked to combined sewer overflow events that were driven by either 10 mm of rain or snowmelt (Madoux-Humery et al., 2016). The investigators were able to demonstrate a human origin of the fecal contamination. Modern-day sewer designs segregate stormwater from the sanitary sewage in order to avoid this issue, but, even so, stormwater alone can be a source of pathogens due to pathogen reservoirs that exist in the built environment (Turgeon et al., 2011).

Rising sea levels associated with climate change have also been observed to alter groundwater flows in coastal cities in the United States, resulting in an increased likelihood of sewer overflow events as rising groundwater enters aging sewer infrastructure or builds up in areas of high permeability (e.g., in fill materials used during construction) (Rossi & Toran, 2019). In addition to rain events, combined sewer overflows are also affected by land-use change and by changes to local hydrology due to urban growth (Jalliffier-Verne et al., 2015). Opportunities to reduce the likelihood of overflow events include city planning that decreases the area of impervious surfaces and overall demands on aging stormwater systems by reducing the amount of water they need to transport to river systems. This practice would help all cities, with or without combined sewer overflows, to reduce the transfer of biological and chemical contaminants from the city into adjacent waterways, as well as to increase groundwater recharge.

Even after water has been treated to drinking water standards, it may still become contaminated after it leaves the treatment facility and travels through the system. In large systems, this risk is commonly reduced by post-treatment disinfection. Low water pressure events have been associated with elevated AGI in older DWSs that contain cracked and damaged water lines, which may travel adjacent to sewage lines (Gargano et al., 2015). In places where sewage lines run alongside water lines, if leaks form on both lines, the only barrier of protection is to maintain high pressure in the water line relative to that of the sewage line. Heavy precipitation associated with climate change may place added stress on aging infrastructure and make it more prone to failure, thereby increasing the likelihood of these low pressure events (Luh et al., 2017). DWSs generally alleviate some pressures associated with drought, decreased streamflow, and aquifer depletion by making better use of available water sources (e.g., water conservation). Broader source water protection initiatives for both surface and groundwater support such efforts.

Small communities may be more vulnerable to impacts on water security from climate change because of deficits in water system infrastructure, as well as fewer technological, training, and financial resources (Moffat & Struck, 2011). Exacerbating the water security implications of climate change, 8.7% of DWSs, serving in total approximately 4 million Canadians, employed no treatment at all (as of 2006–2007), relying primarily on groundwater (Statistics Canada, 2013). This reliance on groundwater sources may put increased pressure on these systems during times of prolonged water scarcity and, particularly for systems that rely on single sources, increases the urgency for source water protection. Many of these DWSs serve small communities.

7.3.4.2.1 Water Systems in Indigenous Communities

Access to safe drinking water is a challenge for many Indigenous communities in Canada. For example, as of February 15, 2020, 61 First Nations communities were under long-term (greater than one-year) drinking water advisories (ISC, 2020a). The Multi-Barrier Approach to Safe Drinking Water is designed for municipal water service systems with a central water treatment plant, piped distribution system, and coordinated monitoring oversight. In many Indigenous communities, particularly those that are small, remote, and isolated, the water distribution system is unlike traditional municipal water service systems, and often features a mix of private wells, trucked water, piped water, and few or no household water services (Daley et al., 2014; Patrick, 2018). Many Indigenous communities face challenges, including poor source water quality, insufficient water treatment technology, inadequate water distribution systems, as well as local and regional water contamination caused by local industry. Institutional disadvantages, such as inadequate design standards for wastewater disposal, difficulty retaining qualified water treatment plant operators, insufficient funding for water system upgrades, and limits on the capacity of trucked systems to deliver water in the quantity residents require it, also contribute to these challenges (Daley et al., 2014; Patrick, 2018). For some people, a lack of trust in water systems, existence of chemical and biological hazards, cultural preference, taste, or other reasons, lead them to, at times, rely on water gathered from the land (Harper et al. 2011; Goldhar et al., 2013b). This gathered and untreated water may be at increased risk of contamination, including as a result of risks from climate change. Any pathogen found in the water (e.g., vector-borne infectious agents, chemical contamination from nearby pollution sources, or pathogens associated with faulty treatment) may be directly consumed by water users (Martin et al., 2007; Harper et al., 2011), causing negative health outcomes.

Climate change is exacerbating the current water challenges facing Indigenous communities (Ford et al., 2010; Andrey et al., 2014; Patrick, 2018; ISC, 2019). Changing temperatures can directly affect water and sewage treatment facilities, as well as food and drinking water security. Small, rural, and circumpolar communities are particularly vulnerable, having to navigate multiple interacting risks (Berner et al., 2016). Many Indigenous communities have recognized this risk; are concerned about climate change impacts on their water quality, quantity, and security (Picketts et al., 2017; ISC, 2019); and recognize the need for action. For example, the Inuit Tapiriit Kanatami's *National Inuit Climate Change Strategy* (2019) identified the need to adapt to climate change–driven impacts on health, including those related to water, as a priority for climate action. Information on how Indigenous Peoples are adapting to climatic impacts on water quality, quantity, and security is provided in section 7.5 Adaptation to Reduce Risks as well as in Chapter 2: Climate Change and Indigenous Peoples' Health in Canada.

7.3.4.3 Cryosphere

The cryosphere includes all places where water is frozen, including snow, ice, permafrost, and seasonally frozen ground. At lower latitudes and elevations in Canada, this state exists for part of the year, and at higher latitudes and elevations, it lasts year-round (Bush & Lemmen, 2019). The cryosphere, and Arctic regions in particular, are dramatically affected by changes in temperature and precipitation driven by climate change

(Overland et al., 2018). The timing, duration, and intensity of melt periods, as well as the likelihood of precipitation being rain or snow, are all affected by temperature. Snow reflects a large amount of incoming solar radiation back into the atmosphere, and changes in snow depth have impacts on ground temperature and lake and sea ice thickness (Bush & Lemmen, 2019). In Canada, it appears that the length of the year with snow cover declined across the majority of the country, and seasonal snow accumulation has likely declined by 5% to 10% since 1981. Climate models project that snow cover duration will continue to decrease across Canada by mid-century, regardless of the emissions scenario (Bush & Lemmen, 2019).

Changes in the cryosphere are likely to affect the health and well-being of Canadians, particularly those in Northern and Arctic regions, in several ways, including impacts on food security, damage to infrastructure, release of legacy pollutants, impacts on transportation networks, and others (Hovelsrud et al., 2011; AMAP, 2015). Although the processes behind these impacts are complex, in Northern Canada, they can generally be linked to two primary issues: changes in ice conditions and changes to permafrost.

Changes in the quantity and quality of sea ice have wide-ranging impacts on Arctic food systems and navigation (Ford et al., 2009). Reduced sea ice quantity and quality impacts the variety of sea life and their migratory patterns, as well as the overall biodiversity of the region (AMAP, 2017). These changes may, in turn, affect access to traditional food sources for Northern communities (see Chapter 8: Food Safety and Security). In addition to impacts on sea life, changes in the quantity and quality of sea ice also affect the ability of Inuit and other Northern hunters to harvest food, because of reduced ability to travel safely on the ice. Less access to the land also inhibits the ability to pass on traditional knowledge to future generations (ISC, 2019).

The annual development of ice roads relies upon sea ice and ice on rivers and lakes. The use of these roads dramatically reduces shipping costs and transportation time, and they are central to sustaining Northern communities. Climate change is affecting the use of these roads, for example, in Ontario's Far North (Hori et al., 2018), and continued warming will have wide-ranging ramifications for daily life in Northern communities, including by affecting health facility supply chains and access to market foods.

Changes to the natural environment also have direct impacts on other types of built infrastructure across the Arctic. Much existing infrastructure has been built with the expectation of continual permafrost. Changes to permafrost threaten the structural integrity of buildings and roads, including health facilities, and water and wastewater treatment facilities. The degradation of permafrost has resulted in impacts on some DWSs by breaking both drinking water and sewage pipes, which could allow potential contaminants to enter drinking water (Lemmen & Warren, 2004). For example, the City of Iqaluit, Nunavut, has been affected by climate change-related permafrost thaw causing extensive damage to municipal water and wastewater pipes (George, 2019). In addition to risks to infrastructure, legacy contaminants currently stored in the permafrost may be released during permafrost melt (AMAP, 2015) (see Chapter 3: Natural Hazards). Warmer water in freshwater lakes, tundra ponds, and streams may also result in greater bacterial methylation of mercury and increased release of mercury from thawing permafrost (Berner et al., 2016), with potential implications for human health.

7.4 Projected Health Security Risks and Impacts

Projecting future impacts of water scarcity and flooding on global health security is challenging because of our limited ability to model events and responses that are subject to current and future adaptation and greenhouse gas (GHG) mitigation policies, which can change. Although significant progress has been made toward understanding the health impacts of climate change and identifying ways to adapt to them, the complexity of the relationships among water, food, and other social and environmental determinants of health requires a broader understanding of compounding and cascading climatic impacts that can amplify harm (Pescaroli & Alexander, 2018).

Local and regional conflicts in other parts of the world, driven by or exacerbated by water insecurity, may have implications for Canadians and Canadian interests. Water has been a source of conflict throughout history, and many scholars consider this risk to be increasing with population growth, rapid economic development, and climate-induced changes in the hydrologic cycle (Levy & Sidel, 2011; Gleick et al., 2020). The risk of forced migration as a result of climate change may also be increasing, particularly for less developed countries (Rigaud et al., 2018). Water-related impacts that contribute to migration pressure and population displacement include rising sea levels, desertification, floods, monsoons, hurricanes, and cyclones (Dickson et al., 2014; McLeman, 2019).

Future scenarios that could spark international conflict affecting Canada include drought-driven reversal of peace-building efforts in Africa, international conflict over the Indus River, and further instability in the Middle East (McLeman, 2011; McLeman, 2019). Refugee surges and maintenance of refugee camps along borders can provide cover for insurgent groups, and reductions in water security can lead to internal conflicts, both of which destabilize governments and can lead to deployment of Canadian peacekeeping forces (Canadian Parliament Standing Committee on National Defence, 2019; Gleick et al., 2020).

Domestically, increasing water temperatures, driven by climate change, may allow for the successful northern expansion of novel contaminants, such as *Naegleria fowleri*. This pathogen can cause primary amebic meningitis, a very rare but almost always fatal disease of the central nervous system (Health Canada, 2012). No cases of illness associated with *N. fowleri* have yet been reported in Canada. The most northerly known case to date was reported in Minnesota (Gompf & Garcia, 2019).

Climate change is anticipated to increase the frequency and severity of wildfires, primarily due to changes in temperature and precipitation, causing decreases of precipitation in some areas and insufficient increases of precipitation in others to offset the effects of rising temperatures (Wotton et al., 2017). Hot, dry, and strong winds are conditions that produce high risk of extreme wildfire (Bush & Lemmen, 2019). Risk of extreme fire conditions, an increase in fire-spread days, and a lengthened fire season are projected for Canada as a whole, and the Western Prairies in particular (Wang et al., 2015).

In addition to the more commonly discussed health impacts of wildfires (e.g., burns, respiratory effects, mental health impacts), watersheds may be severely affected through effects on water flows and water quality. Long-term (multi-year) effects of wildfires include increased stormwater runoff, increased nutrient (mainly nitrogen and phosphorus) and contaminant loads, increased organic carbon, elevated risks of algal and cyanobacterial blooms, elevated microbial activity, dissolved organic carbon transformation, and presence of fire-fighting chemicals (Khan et al., 2015; Harper et al., 2018; Robinne et al., 2019) (see Chapter 3: Natural Hazards), with implications for human health. Water flows may be affected by changes to vegetation, as well as topographic changes caused by flash floods and landslides associated with wildfires. Changes in water flows may affect the reliability of inflow forecasting methods used by drinking water managers to project the quantity of available water for treatment.

Although municipal DWSs may remain capable of adequately treating source water in environments recently affected by wildfire, the added stress of increased wildfire activity may increase operating costs and strain treatment capacity (Robinne et al., 2019). For example, in the aftermath of the 2016 Fort McMurray wildfire, out of an abundance of caution, the water utility chose to issue a precautionary boil water advisory for three months and saw its annual costs for treatment chemicals increase by 50% (Curtis & Gillis, 2016; Thurton, 2017; Robinne et al., 2019). Recent research has identified communities in Alberta whose source water may be at risk due to wildfires (see Figure 7.3) (Robinne et al., 2019), a situation that will likely worsen due to climate change. To prepare communities and drinking water providers for the impacts of climate change, increased research into the impacts of wildfires on water quality is needed.

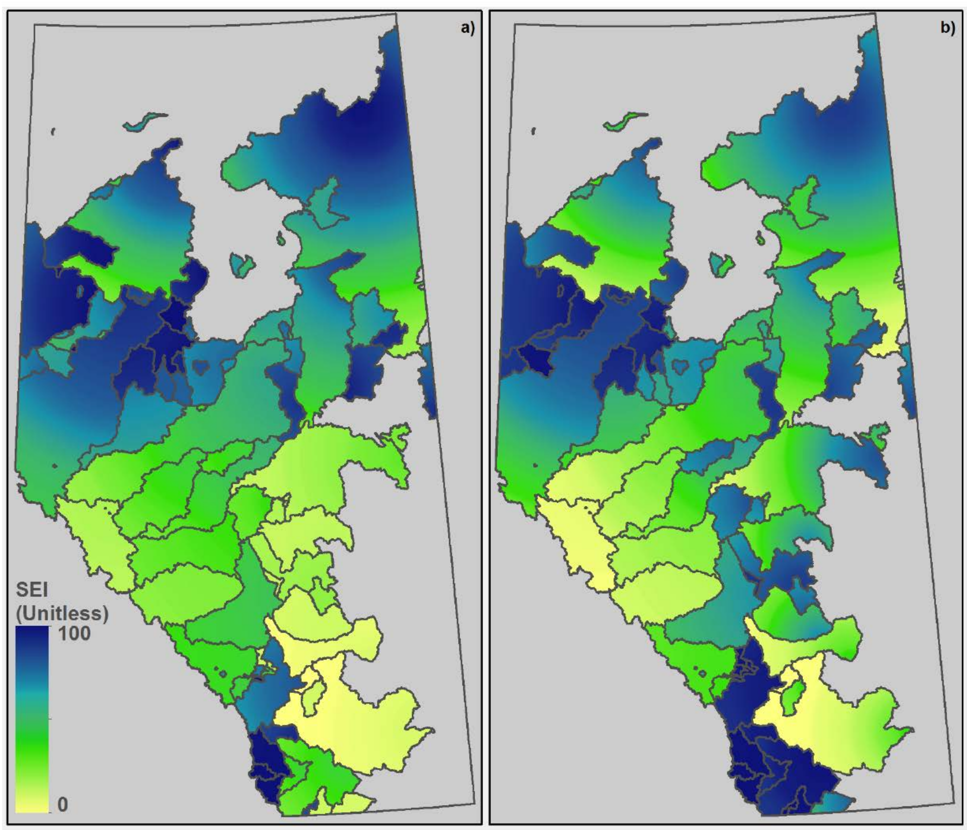


Figure 7.3 Source Exposure Index (SEI) for Alberta and wildfire exposure index for forested watersheds. This figure shows Robinne et al.'s (2019) Source Exposure Index (SEI) for Alberta (a) and wildfire exposure index for forested watersheds (b). In both figures, a higher value indicates higher exposure. The SEI is a spatial index that assesses source exposure based on the availability and demand for water in a watershed, the watershed's forest cover, and the danger of a fire occurring in that area.

7.5 Adaptation to Reduce Risks

To reduce the health impacts of climate change, reducing GHGs is the most important preventative measure. However, regardless of near-term GHG emissions reductions, climate change will continue to pose risks to water quality, quantity, and security in Canada for the foreseeable future. Therefore, there is a pressing need to identify further adaptive actions to reduce or eliminate the anticipated health impacts of climate change. Adapting to the health impacts of climate change involves actions taken by health officials, in collaboration with those in other fields, to understand, assess, prepare for, and help prevent the health impacts of climate change. Adaptive actions often emphasis supporting those most at-risk in society (see Chapter 10: Adaptation and Health System Resilience). It includes the design, implementation, monitoring, and evaluation of specific measures, for example, health and health supporting infrastructures, to reduce health risks. The responsibility for adapting to climate change impacts on water and health is diffuse. Many important health-related adaptation options (e.g., upgrading or replacing water and wastewater systems, flood and drought risk reduction, adaptive agricultural practices, and water storage) are under the purview of decision makers outside of the health sector (e.g., drinking water management, public works and infrastructure, emergency management, civil society) and at different levels of government (municipal, Indigenous, regional, provincial/territorial, or federal).

The federal government has varying levels of responsibility for water governance and management, related to fish habitat, navigation, transboundary waters, water monitoring, and water on federal lands (Zubrycki et al., 2011). To support the reduction of health risks related to water, the federal role is often centred on research, coordination, facilitation of inter-jurisdictional collaboration, education, and outreach. In collaboration with key provincial/territorial, Indigenous, and academic stakeholders, the federal government develops water quality guidance for drinking water (Health Canada, 2019a) and recreational waters (Health Canada, 2012). In Indigenous communities, the federal government generally plays a larger role, due to its responsibility for federal lands (Zubrycki et al., 2011).

Primary responsibility for water governance and management in Canada lies with provincial/territorial governments, with municipalities (ECCC, 2016; Health Canada, 2019b), or with municipal/provincial agencies and corporations, which often take the lead on drinking and wastewater treatment operations. This shared jurisdictional responsibility for water issues, and hence climate change adaptation, is also characterized by participation by a multitude of disciplines and sectors (e.g., DWSs, urban design, agriculture, health, energy), involving diverse risk management methods and terminologies.

Although progress has been made toward improving the uptake of integrated, multisectoral approaches to water management, challenges remain (Shrubsole et al., 2017). Despite human health being a central consideration in almost all water management and governance frameworks, the role of health decision makers is often not explicitly articulated in water management planning and, in practice, is often focused on developing guidelines or standards, monitoring and surveillance, and health communications and response. Through collaboration with health sector officials, decision makers in other sectors have a significant opportunity to reduce health risks from climate change impacts on water through adaptation. Successful health adaptation will require significant intersectoral and intergovernmental coordination. Although not exhaustive, the following section identifies possible adaptive approaches that can reduce the human health consequences of climate change impacts on water quality, quantity, and security.

7.5.1 Climate-Resilient Water Systems

Water systems and water management practices have traditionally been developed with the understanding that past experience was the best indicator of future conditions for the delivery of services. Climate change upends this notion; design parameters of systems built to withstand past climate conditions may not meet future needs (Milly et al., 2008). Past approaches to water management and governance have not adequately incorporated either novel or existing pressures likely to be introduced or exacerbated by climate change. A national survey conducted in 2017 of officials responsible for municipal asset management revealed that information and data about climate change impacts are either unavailable, or poorly integrated into local infrastructure (e.g., water infrastructure) decision making (PSD et al., 2019). Water management planning and water system design should incorporate climate change information (Milly et al., 2008), and water managers, health authorities, and allied professions and sectors should work collaboratively to advance progress toward climate-resilient water systems (Smith et al., 2019).

Resilience is the ability of a system to cope with, respond to, and recover from a shock or stressor in order to continue providing key functions (e.g., a water system can withstand a climate-driven shock without failing to adequately treat water). Climate-resilient water management identifies and implements flexible actions that reduce risks to water quality, quantity, and security in a range of possible future climates to a variety of potential climate shocks and stressors (Smith et al., 2019). Efforts to build climate-resilient water systems have been ongoing since 2007 in Canada. Examples of initiatives to develop new information and tools to support climate-resilient water management to support health include the following:

- The *Northwest Territories Water Stewardship Strategy: A Plan for Action 2016-2020* builds on the momentum of the *Northwest Territories Water Stewardship: A Plan for Action 2011-2015* and aims to ensure the maintenance of the quantity and quality of water resources in the Northwest Territories, secure water supply, and ensure the resilience of freshwater ecosystems (GNWT, 2016).
- The Saskatchewan Water Security Agency is undertaking the project Building Capacity for Community Hydrologic Drought Response, which will increase the ability of municipalities in Saskatchewan to reduce the impacts of drought exacerbated by climate change, including impacts on water supply and quality (NRCan, 2021).
- The Atlantic Canada Water and Wastewater Association is undertaking a project called Incorporating Climate Resilience for Municipal Infrastructure into the Updates of Existing Atlantic Canada Water and Wastewater Design Guidelines (NRCan, 2021).
- The Government of Manitoba, through the project Climate Resiliency: Capacity Building for Manitoba Decision Makers, is increasing the capacity and expertise of professionals (including engineers and planners), the business community in Northern Manitoba, and Indigenous organizations and communities, to reduce climate change impacts, including through adaptations related to land use, water management, and infrastructure (NRCan, 2021).

- The Federation of Canadian Municipalities has developed guides and disseminated information through webinars and networks to support municipalities in efforts to integrate climate change considerations into asset management programs, including those related to water. Key grant programs include the Municipal Asset Management Program, Municipalities for Climate Innovation Program, and Climate and Asset Management Network (PSD et al., 2019).

Many opportunities exist to further integrate climate resilience into water management activities (Smith et al., 2019). The World Health Organization has developed guidance for climate-resilient water safety planning to aid water system decision makers and health authorities in building climate change resilience in water systems and reducing health risks associated with climatic impacts on water resources. This process builds on and leverages the success of existing approaches to water resources management, such as integrated water risk management and climate change adaptation, to ensure that health and climate considerations are adequately captured in water management (WHO, 2017).

Across Canada and internationally, health authorities are increasingly recognizing the need to assess their vulnerability and identify adaptations to reduce the health impacts of climate change, including those related to water issues (Berry et al., 2018) (see Chapter 10: Adaptation and Health System Resilience). Guidance documents and toolkits have been developed to facilitate the completion of vulnerability and adaptation assessments (V&As) related to climate change and health (WHO, 2013; Ebi et al., 2016).

The opportunity exists to increase the understanding of climate change impacts on health through effects on water quality, quantity, and security by conducting V&As at local to regional levels in Canada. A number of previous assessments conducted by health authorities in Canada (Berry et al., 2014b; Grey Bruce Health Unit, 2017; Levison et al., 2017) have included examination of water issues, and many of the 10 projects funded through Health Canada's HealthADAPT initiative also address these issues (Government of Canada, 2020). The participation of health sector officials in broader climate change impact and adaptation assessments, which are often led by the environment department or ministry of the government involved, is also important for increasing understanding of existing and projected impacts of climate change and options for reducing risks to Canadians and for facilitating needed intersectoral collaboration, to make progress in building resilience.

Climate change adaptation actions to reduce risks from impacts related to water often require collaboration with decision makers in other health-relevant sectors. For example, a V&A conducted by the Middlesex-London Public Health Unit in Ontario identified enhanced source water protection as a potential climate change adaptation (Berry et al., 2014b). By working with other sectors to integrate V&A findings into water management processes, the health sector can help to address key upstream determinants of health that help prevent dangerous exposures before illness and injury can affect populations.

Box 7.2 Indigenous water co-governance as a way to address climate change

In the Cowichan Valley, British Columbia, the Cowichan Watershed Board (CWB) undertakes governance and management activities at the watershed scale. The CWB was created after a severe summer drought in 2007 amid stakeholder recognition that a more formal and proactive approach to water management was needed in the face of continued population growth, climate change, and the cumulative impacts of past uncoordinated decision making in the Cowichan-Koksilah watershed. The CWB draws its strength from its governance model, with officials from Cowichan Tribes and the Cowichan Valley Regional District participating as equal partners and co-chairs steering the Board. This partnership, to advance whole-of-watershed health, supports the local recognition of Indigenous rights and is also a deep commitment to moving down the path of reconciliation (CWB, 2018).

Effective water management in watersheds such as the Cowichan-Koksilah watershed has been hampered because the legislative authority and responsibility for water is complex and spread among federal, provincial, and local governments and agencies and because of unextinguished Indigenous rights. Leadership and coordinated decision making are central to the CWB's purpose and structure. The CWB currently does not hold any statutory decision-making powers, although it is anticipated that the CWB may evolve to acquire some form of delegated authority to make local water management decisions. In the meantime, the CWB has endorsed "watershed targets," including ensuring sustainable fish populations, ensuring clean water and adequate summer flow, protecting and preserving riparian and estuarine habitats, conserving water, and increasing local residents' "watershed IQ." To attain these targets, it is necessary to follow the ancient Cowichan Tribes principle, adopted by the CWB, of "Nutsumaat kws yaay'us tthqa" – coming together as a whole to work together to be stronger as partners for the watershed (CWB, 2018).

7.5.2 Adaptation Options to Protect Water Quality, Quantity, and Security

A number of adaptation measures, including new or enhanced policies and programs, are available to reduce health risks from climate change impacts on water quality, quantity, and security (Table 7.4). Many of these actions are most effective when they are tailored to the local or regional context, based on information about climate change impacts gathered through V&As.

Table 7.4 Example adaptations to reduce health risks from climate change impacts on water quality, quantity, and security

Municipal	• Improved or expanded activities related to the safety of municipal water supplies, including water testing (drinking and recreational), water treatment, water delivery, and stormwater management » Integrate climate change considerations into drinking water quality standards and objectives » Publish educational and advisory information on water quality » Advise on issuing boil water advisories • Community-based water monitoring programs • Climate and demographic projections integrated into floodplain mapping and land-use decision making • Vulnerability assessment of water system infrastructure (e.g., vulnerability mapping) • Redundancy in DWSs (e.g., more than one water source) • Mental health support and mental illness prevention and awareness initiatives targeted for those whose livelihoods depend on water (e.g., agriculturally dependent communities) • Water conservation, reuse, and capture-and-storage techniques to reduce climate change impacts • Protocols and procedures for chemical and contaminant risk management during emergencies • Expanding water reuse systems to offset reduced supply, increased demand, or both
Provincial/ territorial	• Enhanced or revised legislation governing municipal and public water supplies, including their construction and operation » Enhance or revise policies, regulations, and protocols regarding water quality inspections » Conduct inspections of municipal drinking water systems and laboratories that test drinking water » Operate water quality testing laboratories » Draft emergency response planning regarding water supplies » Enhance or revise water quality standards and watershed management

Provincial/ territorial (continued)	» Approve designated areas for water treatment plants based on climate risk » Enhance well-water safety » Implement national guidelines for drinking water safety • Mental health support and mental illness prevention and awareness initiatives targeted to those whose livelihoods depend on water (e.g., agriculturally dependent communities) • Protocols and procedures for chemical and contaminant risk management during emergencies • Monitoring of harmful algal bloom outbreaks
Federal	• Research on threats to drinking water in the context of climate change • Development of a recommended set of national guidelines for drinking water safety that integrate information on climate change risks • Nationally integrated approach to monitoring and surveillance for water-borne diseases
Cross-cutting	• Nature-based solutions (e.g., wetlands for agricultural wastewater treatment, buffer zone parks for flood control, etc.) • Climate change and health considerations and climate projections integrated into water resource management activities • Enhanced health risk communications practices to prepare for likely climate change impacts (e.g., advising consumers to avoid produce that may have been in contact with floodwater) • Exploration of equitable economic transition support for communities whose livelihoods are affected by water scarcity • Health education and outreach initiatives for users of gathered water • Decommissioning or renovation of water infrastructure at risk

Source: Adapted from Séguin, 2008; Berry et al., 2014a

For many water-related climate change impacts (e.g., flooding, drought, runoff-driven contamination) and land-use changes, DWS designs informed by watershed scale management can reduce dangerous exposures and risks to health. Adaptation actions can achieve significant health co-benefits as resilience is built; for example, improving community access to water (e.g., beaches, rivers, lakes) can benefit fitness by increasing recreational space, improving residents' sense of connection to the natural environment, and improving overall mental wellness (Gascon et al., 2017).

Nature-based solutions provide important opportunities for communities seeking to reduce land-use based exposures and vulnerabilities. Nature-based solutions are "actions that work with and enhance nature to support biodiversity and help address societal challenges" (Kapos et al., 2019, p. 16). Actions that adopt the design of natural systems or mimic them, as well as efforts to encourage a previously existing natural process (e.g., a wetland), all characterize a nature-based approach to climate adaptation. Nature-based solutions to reduce runoff and stormwater overflow, such as rain gardens (Autixier et al., 2014) and grassed swales (Bäckström, 2003), have been explored as a means of holding back water and allowing for the settling of particulates. These interventions remove contamination from water systems by increasing the hydraulic detention time (Li et al., 2016). Nature-based solutions can also help address both GHG mitigation (e.g., carbon sequestration by protecting existing or creating new green spaces) and adaptation objectives (e.g., improving water quality and reducing flood risk through the development of natural areas that can capture or control water, sometimes known as "blue spaces"). Many such actions offer greater cost savings than traditional grey infrastructure-based approaches, while providing additional co-benefits, including for health. For example, a park designed for flood defence, such as Toronto's Corktown Common Park (Waterfront Toronto, 2020), may also create recreational spaces and allow for the development of active transport infrastructure (e.g., bicycle and walking paths). Green spaces may also have health benefits for those who suffer from some forms of mental illness and generally may help improve quality of life for those who live or work nearby (Raymond et al., 2017).

Across Canada, various levels of government have experimented with financial incentives to drive land-use change. For example, following widespread flooding, New Brunswick's provincial government launched a buy-out program for homeowners most at risk of flooding (New Brunswick, 2019). Other regions have provided financial incentives to landowners who take action to protect water quality, such as to farmers who refrain from cultivating directly beside waterways (Clean Water Program, 2020).

Protecting health from water-related risks through an approach involving standards and guidelines, which is informed by familiar threats and past experience, may not increase resilience in the face of unknown or unexpected health risks, unless new knowledge of climate change risks is integrated into these activities. By working with stakeholders to apply a climate lens to guideline development, existing vulnerabilities may be reduced and resilience to future impacts increased. Risks from new pathogens and viruses to the health of Canadians from climate change impacts on water may require improved water quality monitoring and surveillance, as well as early warning capabilities to inform the actions of system operators. The water and public health sectors will need to approach this problem collaboratively and partner with all levels of government.

Leveraging community interest in water quality protection to help inform monitoring efforts may help improve resilience. For example, Indigenous communities across Canada face multi-faceted water system vulnerabilities. Communities in the North face challenges, such as the loss of permafrost, the contamination of tundra pond water sources, and the vulnerability of village sewage lagoons to climate hazards (Berner et al., 2016; McKnight, 2017). Communities recognize that these climate impacts on already stressed DWSs may increase the risk of water-borne disease in the future. Recognizing the growing burden of gastrointestinal illness on their community, a group of Inuit youth in Mittimatalik (Pond Inlet), with the support of Elders and research bodies, are working to apply both Inuit and scientific knowledge to assess the impact of climate change on local water quality and human health (Inuit Tapiriit Kanatami, 2019). Such community-led water monitoring programs have the potential to help inform climate-resilient planning for water systems across

Canada and, in some cases, may incentivize increased community stewardship of water resources. In addition, the Circuit Rider Training Program is a long-term capacity-building program that provides training and mentoring services to operators of First Nations DWSs and wastewater systems (ISC, 2015).

Currently, most municipal DWSs are centralized and often extract large volumes of water from a single source located a great distance from the population it serves. Reliance on a single source is risky, because a serious failure related to that source can have disastrous consequences (Boholm & Prutzer, 2017). In addition, centralized DWSs require large amounts of chemicals for treatment and energy to transport water, as well as a vast infrastructure (Speight, 2018), and can therefore have impacts on the environment. Shifting to less-centralized systems that incorporate multiple water sources (e.g., rainwater, greywater, multiple smaller groundwater supplies) and additional water protection areas can result in more resilient systems that could help mitigate the risks associated with climate change impacts on aging infrastructure (Boholm & Prutzer, 2017). This would also alleviate pressures associated with drought, decreased streamflow, and aquifer depletion by making better use of available water sources. Promoting water-saving practices, such as the use of low-flow showers and toilets and the use of greywater and rainwater, can also help to reduce water consumption.

In some cases, there will be limits to the effectiveness of large land-use changes, new protective infrastructure (either nature-based or traditional), and updates to DWSs or DWS operations, and the extent to which they can be adopted. In these cases, the development, promotion, and adoption of early warning systems with associated risk communications may play an important role in addressing and reducing health impacts from climate change (Wu et al., 2016). Early warning systems have been used with success to reduce the impacts of floods (Alfieri et al., 2012), infectious diseases (Ogden et al., 2019), extreme heat (see Chapter 10: Adaptation and Health System Resilience), and other health hazards by providing sufficient lead time for officials to respond to impending threats. Progress has been made toward integrating climate and weather data into warning systems for some climate-related impacts (e.g., Ogden et al., 2019), in order to better prepare both health officials and citizens. The opportunity exists to expand efforts to reduce risks of climate-related water-borne diseases, for example, by monitoring the human–wildlife interface, such as through the use of bio-sentinels that act as a proxy for human health impacts/risks (e.g., monitoring the health of a particular fish species) (Stephen & Duncan, 2017). This may prove particularly useful for impacts on water quality, such as harmful algal blooms.

Early warning systems can benefit from tools that present the spatial distribution of climate-related hazard exposures, vulnerability factors, and impacts on health in a visual format. The *Federal Flood Mapping Framework* (NRCan, 2018) has resulted in renewed emphasis on flood inundation mapping across Canada. At the local and regional levels, various groups have made efforts to apply innovative approaches to better understand the variation in impacts of floods across geographic regions. For example, in Quebec, a partnership between Laval University, Ouranos, and the Institut national de santé publique du Québec has integrated vulnerability indicators into flood mapping, providing valuable information for health and emergency management authorities to plan emergency response measures (Ouranos, 2018).

7.6 Knowledge Gaps

Climate change impacts on water quality, quantity, and security are complex, and many knowledge gaps exist. The ability to measure and monitor climate change impacts on water resources across Canada's diverse ecosystems and socio-cultural environments, in addition to resulting health outcomes, are basic requirements to address key knowledge gaps (Table 7.5). This work is crucial to developing effective interventions that can build resilience and reduce climate change-related health impacts.

Integrating Indigenous knowledge into efforts to prepare for and respond to climate-driven stressors on water quality, quantity, and security is a key component of research needed to protect health in a changing climate. Research from First Nations, Inuit, and Métis perspectives is lacking and requires attention. Research led by, or in partnership with, Métis communities is a notable gap to date. Climate change impacts and adaptation assessments, and adaptation policies and programs, are well-served when a broad evidence base, informed by different perspectives, communities, and knowledge systems, can be drawn from. Increasing climate research led by First Nations, Inuit, and Métis researchers will benefit all Canadians.

Table 7.5 Key research needs related to the health effects of climate change impacts on water quality, quantity, and security

CLIMATE CHANGE IMPACTS ON WATER RESOURCES AND IMPLICATIONS FOR HUMAN HEALTH
• Relationships between temperature and precipitation on the diverse Canadian flow regimes (e.g., switch in river basins from snow-dominated to rain-dominated regimes) • Impacts of changes in the cryosphere on water resources (e.g., effects of changes in albedo on permafrost and downstream water quality and quantity) • Effects of changes in the cryosphere on releases of chemical contaminant burdens (e.g., persistent organic pollutants and heavy metals) and subsequent impacts on food and water supplies • Impacts of wildfires on source water quality and availability, and how they vary across forest ecosystems • Effects of ocean and freshwater acidification and nutrient runoff from land in the context of climate change (e.g., adaptation in the agricultural sector) on harmful algal blooms

WATER RESOURCE MANAGEMENT AND SOURCE WATER PROTECTION

- Effects of climate change and land-use change on groundwater recharge over short and long timescales
- Effective measures for protecting DWSs from increased flooding-related health concerns (e.g., increases in bacterial contamination)
- Impacts of projected drought extremes on water resources and the most effective adaptations to protect health (e.g., individual storage capacity; water sharing across multiple jurisdictions)
- Effective government, management, and partnership models, including those with First Nations, Inuit, and Métis communities

DRINKING WATER AND DRINKING WATER SYSTEMS

- Factors that make water systems vulnerable to extreme rain events, and effective adaptation measures
- Health ramifications and possible DWS stresses from wildfire impacts on source water, particularly for untreated drinking water sources (e.g., "gathered water")
- Cost-effective adaptations for DWSs to address emerging contaminants (e.g., harmful algal blooms), which are expected to increase under climate change

PUBLIC HEALTH AND HEALTH CARE

- Health risks associated with water contaminated by residue from burned residential, industrial, and commercial materials as a result of wildfires
- Health risks of harmful algal blooms, and how they might increase with climate change
- Emerging new or previously rare water-borne pathogens (e.g., northward-moving *Naegleria fowleri*) and effective measures to protect health
- Impacts of changes in animal (e.g., waterfowl) and other vector populations on the distribution and transmission of water-borne diseases as the climate continues to change
- Health risks associated with water reuse and effective measures to protect health
- Effective technologies for producing potable water in future water-stress scenarios

7.7 Conclusion

The quality, quantity, and security of Canada's water resources are being affected by climate change, increasing risks to human health. Expected increases in both average temperatures and temperature extremes, along with heavy precipitation events, droughts, and wildfires in many regions of Canada, will place increased stress on water resources in freshwater, marine, and coastal systems, thereby creating greater risks to human health. A range of climate-sensitive pathogens or toxins currently affect the health of Canadians; these include algae, cyanobacteria, enteric viruses, and *Leptospira*, *Leptonema*, *Vibrio*, and *Legionella* bacteria. In addition, gradual warming and an increase in extreme events will continue to place stress on DWSs, potentially leading to the presence of biological or chemical agents in water, which could further lead to human exposure through drinking water, bathing, recreation, or ceremonial use. Climate change will pose even greater challenges for small and rural systems. The future health impacts due to climate change are uncertain because of a lack of projections for many of these health outcomes and because of the complex pathways through which people are affected, which involve social and behavioural factors.

Similar to other health concerns associated with climate change, evidence suggests that specific populations are at higher risk of these effects, including children, seniors, and people with chronic diseases. The health and well-being of many Indigenous Peoples and communities is disproportionately affected by challenges to water resources, which can arise from a variety of factors, such as insufficient water treatment technology, distribution systems and upgrades, water contamination caused by local industry, and difficulty retaining qualified water treatment plant operators. Climate change impacts on source water will exacerbate the effects of these challenges if further adaptations are not implemented to safeguard water resources and protect health in these communities. First Nations, Inuit, and Métis communities possess countless generations of accumulated knowledge which, through equitable partnerships, could be applied to protect health. Increased partnerships among First Nations, Inuit, and Métis peoples, health authorities, and water managers are needed to identify and address the health impacts specific to Indigenous populations of climate-driven changes to water resources and to implement effective options for community-level adaptation.

In the absence of enhanced efforts to adapt, the health of Canadians will increasingly be affected as the climate continues to change. By working to identify both vulnerabilities to public health and adaptation options, health authorities can reduce and adapt to these impacts and build the climate resilience of water systems. Although some adaptation options exist today, increased research is needed to understand the scope of both current and future impacts and the effectiveness of adaptation strategies and technologies. To evaluate the effectiveness of adaptation options, research is needed to identify the most effective means of monitoring water-related health hazards. Additionally, projections of possible future health impacts and proactive measures for communicating risks to the public, for example, through early warning systems, should be explored.

7.8 References

Abbott, L. P. (1986). *Vibrio* vulnificus in New Brunswick. *Canada Diseases Weekly Report, 12-14*, 57-8.

Ahern, M., Kovats, R. S., Wilkinson, P., Few, R., & Matthies, F. (2005). Global health impacts of floods: epidemiologic evidence. *Epidemiologic reviews*, *27*, 36–46. <https://doi.org/10.1093/epirev/mxi004>

Alderman, K., Turner, L. R., & Tong, S. (2012). Floods and human health: a systematic review. *Environment international*, *47*, 37–47. <https://doi.org/10.1016/j.envint.2012.06.003>

Alexander, J., Benford, D., Cockburn, A., Cravedi, J., Dogliotti, E., Di Domenico, A., … Verger, P. (2009). Scientific Opinion of the Panel on Contaminants in the Food Chain on a request from the European Commission on Marine Biotoxins in Shellfish – Saxitoxin Group. *The EFSA Journal, 7*(4), 1-76. <https://doi.org/10.2903/j.efsa.2009.1019>

Alfieri, L., Salamon, P., Pappenberger, F., Wetterhall, F., & Thielen, J. (2012). Operational early warning systems for water-related hazards in Europe. *Environmental Science & Policy, 21*, 35-49.

Anderson, D. M., Richlen, M. L., & Lefebvre, K. A. (2019). Harmful algal blooms in the Arctic. In E. Osborne, J. Richter-Menge, & M. Jeffries (Eds.), *Arctic Report Card: Update for 2018*. Retrieved from <https://arctic.noaa.gov/Report-Card/Report-Card-2018/ArtMID/7878/ArticleID/789/Harmful-Algal-Blooms-in-the-Arctic>

Andrey, J., Kertland, P., & Warren, F. J. (2014). Water and Transportation Infrastructure. In F. J. Warren, & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Ottawa, ON: Government of Canada.

Aramini, J., McLean, M., Wilson, J., Holt, J., Copes, R., Allen, B., & Sears, W. (2000). Drinking water quality and health-care utilization for gastrointestinal illness in greater Vancouver. *Canada Communicable Disease Report = Releve des Maladies Transmissibles au Canada*, *26*(24), 211–214.

Arctic Monitoring and Assessment Programme (AMAP). (2015). *AMAP Assessment 2015: Human Health in the Arctic*. Oslo, Norway.

Arctic Monitoring and Assessment Programme (AMAP). (2017). *Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017*. Oslo, Norway.

Ashbolt, N. J. (2015). Microbial Contamination of Drinking Water and Human Health from Community Water Systems. *Current Environmental Health Reports, 2*(1), 95–106. <DOI:10.1007/s40572-014-0037-5>

Assembly of First Nations (AFN). (2013). *Strategy to protect and advance Indigenous water rights.* Ottawa, ON. Retrieved from <https://www.afn.ca/uploads/files/water/firstnationswaterstrategy.pdf>

Auld, H., MacIver, D., & Klaassen, J. (2004). Heavy rainfall and waterborne disease outbreaks: the Walkerton example. *Journal of Toxicology and Environmental Health. Part A*, *67*(20-22), 1879–1887. <https://doi.org/10.1080/15287390490493475>

Autixier, L., Mailhot, A., Bolduc, S., Madoux-Humery, A. S., Galarneau, M., Prévost, M., & Dorner, S. (2014). Evaluating rain gardens as a method to reduce the impact of sewer overflows in sources of drinking water. *The Science of the Total Environment*, *499*, 238–247. <https://doi.org/10.1016/j.scitotenv.2014.08.030>

Azuma, K., Ikeda, K., Kagi, N., Yanagi, U., Hasegawa, K., & Osawa, H. (2014). Effects of water-damaged homes after flooding: health status of the residents and the environmental risk factors. *International Journal of Environmental Health Research*, *24*(2), 158–175. <https://doi.org/10.1080/09603123.2013.800964>

Bäckström M. (2003). Grassed swales for stormwater pollution control during rain and snowmelt. *Water Science and Technology : a Journal of the International Association on Water Pollution Research*, *48*(9), 123–132.

Baker-Austin, C., Trinanes, J. A., Taylor, N. G. H., Hartnell, R., Siitonen, A., Martinez-Urtaza, J. (2013). Emerging *Vibrio* risk at high latitudes in response to ocean warming. *Nature Climate Change, 3*, 73-77. <https://doi.org/10.1038/nclimate1628>

Bakker, K., & Cook, C. (2011). Water governance in Canada: Innovation and fragmentation. *Water Resources Development*, *27*(02), 275-289.

Banerjee, S. K., Rutley, R., & Bussey, J. (2018). Diversity and Dynamics of the Canadian Coastal *Vibrio* Community: an Emerging Trend Detected in the Temperate Regions. *Journal of Bacteriology*, *200*(15), e00787-17. <https://doi.org/10.1128/JB.00787-17>

Bell, J. (2019). Iqaluit seeks new emergency fix for another looming water shortage. *Nunatsiaq News*. Retrieved from <https://nunatsiaq.com/stories/article/iqaluit-seeks-new-emergency-fix-for-another-looming-water-shortage/>

Bellou, M., Kokkinos, P., & Vantarakis, A. (2013). Shellfish-borne viral outbreaks: a systematic review. *Food and Environmental Virology*, *5*(1), 13–23. <https://doi.org/10.1007/s12560-012-9097-6>

Berner, J., Brubaker, M., Revitch, B., Kreummel, E., Tcheripanoff, M., & Bell, J. (2016). Adaptation in Arctic circumpolar communities: food and water security in a changing climate. *International Journal of Circumpolar Health*, *75*, 33820. <https://doi.org/10.3402/ijch.v75.33820>

Berry, P., Clarke, K., Fleury, M .D. & Parker, S. (2014a). Human Health. In F. J. Warren, & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 191-232). Ottawa, ON: Natural Resources Canada. Retrieved from <http://publications.gc.ca/pub?id=9.699408&sl=0>

Berry, P., Enright, P. M., Shumake-Guillemot, J., Villalobos Prats, E., & Campbell-Lendrum, D. (2018). Assessing Health Vulnerabilities and Adaptation to Climate Change: A Review of International Progress. *International Journal of Environmental Research and Public Health*, *15*(12), 2626. <https://doi.org/10.3390/ijerph15122626>

Berry, P., Paterson, J., & Buse, C. (2014b). *Assessment of vulnerability to the health impacts of climate change in Middlesex-London*. London, ON: Middlesex-London Health Unit. Retrieved from <https://www.healthunit.com/climate-change>

Bertuzzo, E., Mari, L., Righetto, L., Gatto, M., Casagrandi, R., Rodriguez-Iturbe, I., & Rinaldo, A. (2012). Hydroclimatology of dual-peak annual cholera incidence: Insights from a spatially explicit model. *Geophysical Research Letters, 39*(5). doi: 10.1029/2011GL050723.

Bharadwaj, L., & Bradford, L. (2018). Indigenous water poverty: Impacts beyond physical health. In H. Exner-Pirot, B. Norbye, & L. Butler (Eds.), *Northern and Indigenous health and healthcare*. Saskatoon, SK: University of Saskatchewan.

Bigham, M., Galanis, E., Gustafson, R., Hoang, L., Louie, K., Faremo, A., Mcintyre, L., Isaac-Renton, J., Daly, P., Gustafson, L., Wong, B., Chong, S., Stone, J., & Rodriguez-Maynez, L. (2008). *Re-emergence of Pathogenic* Vibrio *Vulnificus on the Pacific Northwest Coast in 2007*. Vancouver, BC: Association of Medical Microbiology and Infectious Disease Canada. Retrieved from <http://www.cacmid.ca/wp-content/uploads/2008finalprogram1.pdf>

BluePlan Engineering. (2019). *Canadian Infrastructure Report Card 2019: Monitoring the State of Canada's Core Public Infrastructure*. Retrieved from <http://canadianinfrastructure.ca/downloads/canadian-infrastructure-report-card-2019.pdf>

Boholm, Å., & Prutzer, M. (2017). Experts' understandings of drinking water risk management in a climate change scenario. *Climate Risk Management, 16*, 133–144. doi:10.1016/j.crm.2017.01.003

Bonsal, B. R., Peters, D. L., Seglenieks, F., Rivera, A., & Berg, A. (2019). Changes in freshwater availability across Canada. In E. Bush & D.S. Lemmen (Eds.), *Canada's Changing Climate Report* (p. 261–342). Ottawa, ON: Government of Canada.

Botana, L. M. (2016). Toxicological Perspective on Climate Change: Aquatic Toxins. *Chemical Research in Toxicology*, *29*(4), 619–625. <https://doi.org/10.1021/acs.chemrestox.6b00020>

Brettle, M., Berry, P., Paterson, J., & Yasvinski, G. (2015). Determining Canadian water utility preparedness for the impacts of climate change. *Change and Adaptation in Socio-Ecological Systems, 2*(1). doi: 10.1515/cass-2015-0024.

British Columbia Centre for Disease Control (BC CDC). (2020). Vibrio *parahaemolyticus*. Retrieved from <http://www.bccdc.ca/health-info/diseases-conditions/vibrio-parahaemolyticus>

Britton, E., Hales, S., Venugopal, K., & Baker, M. G. (2010). Positive association between ambient temperature and salmonellosis notifications in New Zealand, 1965–2006. *Australian and New Zealand Journal of Public Health*, *34*(2), 126-129. doi:10.1111/j.1753-6405.2010.00495.x

Burkhardt, W., 3rd, & Calci, K. R. (2000). Selective accumulation may account for shellfish-associated viral illness. *Applied and environmental microbiology*, *66*(4), 1375–1378. <https://doi.org/10.1128/AEM.66.4.1375-1378.2000>

Bush, E., & Lemmen, D. (Eds.). (2019). *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/Climate-change/pdf/CCCR_ExecSumm-EN-040419-FINAL.pdf>

Campos, C. J., & Lees, D. N. (2014). Environmental transmission of human noroviruses in shellfish waters. *Applied and Environmental Microbiology*, *80*(12), 3552–3561. <https://doi.org/10.1128/AEM.04188-13>

Canadian Broadcasting Corporation (CBC). (2012). Shellfish harvesting banned off most of N.S. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/nova-scotia/shellfish-harvesting-banned-off-most-of-n-s-1.1138561>

Canadian Broadcasting Corporation (CBC). (2019). Officials Offer Food Safety Advice as Herring egg Harvest Opens on Vancouver Island. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/british-columbia/herring-egg-harvest-vancouver-island-food-safety-1.5039174>

Canadian Council of Ministers of the Environment. (2016). *Summary of Integrated Watershed Management Approaches Across Canada*. Retrieved from <https://ccme.ca/en/res/summaryofintegratedwatershedmanagementapproaches acrosscanada.pdf>

Canadian Food Inspection Agency (CFIA). (2012). *Hazard Analysis Critical Control Point (HACCP)*. Retrieved from <http://www.inspection.gc.ca/about-the-cfia/newsroom/food-safety-system/haccp/eng/1346306502207/1346306685922>

Canadian Parliamentary Standing Committee on National Defence. (2019). *Canada's Role in International Peace Operations and Conflict resolutions: Report of the Standing Committee on National Defence*. Retrieved from <https://www.ourcommons.ca/Content/Committee/421/NDDN/Reports/RP10491893/nddnrp16/nddnrp16-e.pdf>

Carmichael, W. W., & Boyer, G. L. (2016). Health impacts from cyanobacteria harmful algae blooms: Implications for the North American Great Lakes. *Harmful Algae, 54,* 194–212. doi:10.1016/j.hal.2016.02.00.

Canadian Council of Professional Engineers (CCPE). (2008). *Adapting to Climate Change: Canada's First National Engineering Vulnerability Assessment of Public Infrastructure.* Canadian Council of Professional Engineers. Retrieved from <https://pievc.ca/wp-content/uploads/2020/12/adapting_to_climate_change_report_final.pdf>

Centre for Research on the Epidemiology of Disasters (CRED) & United Nations Office for Disaster Risk Reduction (UNISDR). (2015). *The Human Cost of Weather Related Disasters 1995–2015.* Geneva, Switzerland. Retrieved from <https://www.preventionweb.net/files/46796_cop21weatherdisastersreport2015.pdf>

Charrois J. W. (2010). Private drinking water supplies: challenges for public health. *Canadian Medical Association Journal = Journal de l'Association Medicale Canadienne*, *182*(10), 1061–1064. <https://doi.org/10.1503/cmaj.090956>

Charron, D., Thomas, M., Waltner-Toews, D., Aramini, J., Edge, T., Kent, R., Maarouf, A., & Wilson, J. (2004). Vulnerability of waterborne diseases to climate change in Canada: a review. *Journal of Toxicology and Environmental Health. Part A*, *67*(20-22), 1667–1677. <https://doi.org/10.1080/15287390490492313>

Chhetri, B. K., Takaro, T. K., Balshaw, R., Otterstatter, M., Mak, S., Lem, M., Zubel, M., Lysyshyn, M., Clarkson, L., Edwards, J., Fleury, M. D., Henderson, S. B., & Galanis, E. (2017). Associations between extreme precipitation and acute gastro-intestinal illness due to cryptosporidiosis and giardiasis in an urban Canadian drinking water system (1997-2009). *Journal of Water and Health*, *15*(6), 898–907. <https://doi.org/10.2166/wh.2017.100>

Clean Water Program. (2020). *Clean Water Program*. Retrieved from <https://www.cleanwaterprogram.ca/>

Compton, M., Willis, S., Rezaie, B., & Humes, K. (2018). Food processing industry energy and water consumption in the Pacific Northwest. *Innovative Food Science & Emerging Technologies*, *47*, 371-383.

Conservation Ontario. (n.d.). *History of Conservation Authorities.* Retrieved from <https://conservationontario.ca/conservation-authorities/about-conservation-authorities/history-of-conservation-authorities>

Cook, A., Lowther, J., Price-Hayward, M., Lee, R. (2009). *Spatial and temporal pattern of norovirus contamination in a Pacific oyster fishery* (P. Lassus, Ed.). Seventh International Conference on Molluscan Shellfish Safety. Nantes, France.

Cook, C., Gavin, H., Berry, P., Guillod, B., Lange, B., Rey Vicario, D., & Whitehead, P. (2017). *Drought planning in England: a primer*. Environmental Change Institute.

Cook, D. W., Bowers, J. C., & DePaola, A. (2002). Density of total and pathogenic (tdh+) *Vibrio* parahaemolyticus in Atlantic and Gulf coast molluscan shellfish at harvest. *Journal of Food Protection*, *65*(12), 1873–1880. <https://doi.org/10.4315/0362-028x-65.12.1873>

Corso, P. S., Kramer, M. H., Blair, K. A., Addiss, D. G., Davis, J. P., & Haddix, A. C. (2003). Costs of Illness in the 1993 Waterborne Cryptosporidium Outbreak, Milwaukee, Wisconsin. *Emerging Infectious Diseases*, *9*(4), 426-431. <https://doi.org/10.3201/eid0904.020417>

Cowichan Watershed Board (CWB). (2018). *Governance Manual – Version 3*. Retrieved from <https://cowichanwatershedboard.ca/wp-content/uploads/2019/08/CWB-Gov-Manual-Version3-Sept-24-2018.pdf>

Curriero, F. C., Patz, J. A., Rose, J. B., & Lele, S. (2001). The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *American Journal of Public Health*, *91*(8), 1194–1199. <https://doi.org/10.2105/ajph.91.8.1194>

Curry, C. L., Islam, S. U., Zwiers, F. W., & Déry, S. J. (2019). Atmospheric Rivers Increase Future Flood Risk in Western Canada's Largest Pacific River. *Geophysical Research Letters, 46*(3), 1651-1661. <https://doi.org/10.1029/2018GL080720>

Curtis, P., & Gillis, H. (Eds.). (2016). *Annual Report Fort McMurray Waterworks System Approval.* Edmonton, AB: Alberta Environment and Parks.

Daley, K., Castleden, H., Jamieson, R., Furgal, C., & Ell, L. (2014). Municipal water quantities and health in Nunavut households: an exploratory case study in Coral Harbour, Nunavut, Canada. *International journal of circumpolar health*, *73*(1), 23843.

Daley, K., Hansen, L. T., Jamieson, R. C., Hayward, J. L., Piorkowski, G. S., Krkosek, W.,... & Corriveau, E. (2018). Chemical and microbial characteristics of municipal drinking water supply systems in the Canadian Arctic. *Environmental Science and Pollution Research*, *25*(33), 32926-32937.

Dancause, K. N., Veru, F., Andersen, R. E., Laplante, D. P., & King, S. (2013). Prenatal stress due to a natural disaster predicts insulin secretion in adolescence. *Early Human Development*, *89*(9), 773–776. <https://doi.org/10.1016/j.earlhumdev.2013.06.006>

Deeds, J. R., Wiles, K., Heideman, G. B., 6th, White, K. D., & Abraham, A. (2010). First U.S. report of shellfish harvesting closures due to confirmed okadaic acid in Texas Gulf coast oysters. *Toxicon : official Journal of the International Society on Toxinology*, *55*(6), 1138–1146. <https://doi.org/10.1016/j.toxicon.2010.01.003>

Delpla, I., Jung, A.-V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International, 35*(8), 1225–1233. doi: 10.1016/j.envint.2009.07.001

DePaola, A., Jones, J. L., Woods, J., Burkhardt, W., 3rd, Calci, K. R., Krantz, J. A., Bowers, J. C., Kasturi, K., Byars, R. H., Jacobs, E., Williams-Hill, D., & Nabe, K. (2010). Bacterial and viral pathogens in live oysters: 2007 United States market survey. *Applied and Environmental Microbiology*, *76*(9), 2754–2768. <https://doi.org/10.1128/AEM.02590-09>

Department of Fisheries and Oceans (DFO). (2020). *Marine harmful algal blooms and phycotoxins of concern to Canada*. Canadian Technical Report of Fisheries and Aquatic Sciences 3384. Retrieved from <https://waves-vagues.dfo-mpo.gc.ca/Library/4088319x.pdf>

Derksen, C., Burgess, D., Duguay, C., Howell, S., Mudryk, L., Smith, S., Thackeray, C., & Kirchmeier-Young, M. (2019). Changes in snow, ice, and permafrost across Canada. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report* (p.194–260). Ottawa, ON: Government of Canada.

De Roos, A. J., Gurian, P. L., Robinson, L. F., Rai, A., Zakeri, I., & Kondo, M. C. (2017). Review of Epidemiological Studies of Drinking-Water Turbidity in Relation to Acute Gastrointestinal Illness. *Environmental Health Perspectives*, *125*(8), 086003. <https://doi.org/10.1289/EHP1090>

Dickson, S., Webber, S., & Takaro, T. K. (2014). *Preparing BC for Climate Migration.* Vancouver, BC: Canadian Centre for Policy Alternatives. Retrieved from <https://www.policyalternatives.ca/sites/default/files/uploads/publications/BC%20Office/2014/11/ccpa-bc_ClimateMigration_web.pdf>

Doocy, S., Daniels, A., Packer, C., Dick, A., & Kirsch, T. D. (2013). The human impact of earthquakes: a historical review of events 1980-2009 and systematic literature review. *PLoS currents*, *5*, ecurrents.dis.67bd14fe457f1db0b5433a8ee20fb833. <https://doi.org/10.1371/currents.dis.67bd14fe457f1db0b5433a8ee20fb833>

Doyle, A., Barataud, D., Gallay, A., Thiolet, J. M., Le Guyaguer, S., Kohli, E., & Vaillant, V. (2004). Norovirus food-borne outbreaks associated with the consumption of oysters from the Etang de Thau, France, December 2002. *Euro Surveillance : Bulletin Europeen sur les Maladies Transmissibles = European Communicable Disease Bulletin*, *9*(3), 24–26. <https://doi.org/10.2807/esm.09.03.00451-en>

Ebi, K., Anderson, V., Berry, P., Paterson, J., & Yusa, A. (2016). *Ontario Climate Change and Health Vulnerability and Adaptation Assessment Guidelines: Technical Document.* Toronto, ON: Ontario Ministry of Health and Long-Term Care Public Health Policy and Programs Branch.

Edwards, B., Gray, M., & Hunter, B. (2015). The Impact of Drought on Mental Health in Rural and Regional Australia. *Social Indicators Research, 121,* 177–194. doi:10.1007/s11205-014-0638-2

Emelko, M.B., Silins, U., Bladon, K.D., & Stone, M. (2011). Implications of land disturbance on drinking water treatability in a changing climate: Demonstrating the need for "source water supply and protection" strategies. *Water Research, 45*(2), 461–472.

Emelko, M. B., Stone, M., Silins, U., Allin, D., Collins, A. L., Williams, C. H., Martens, A. M., & Bladon, K. D. (2016). Sediment-phosphorus dynamics can shift aquatic ecology and cause downstream legacy effects after wildfire in large river systems. *Global Change Biology*, *22*(3), 1168–1184. <https://doi.org/10.1111/gcb.13073>

Environment and Climate Change Canada (ECCC). (2016). *Water governance and legislation: shared responsibility*. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/water-overview/governance-legislation/shared-responsibility.html>

Etheridge S. M. (2010). Paralytic shellfish poisoning: seafood safety and human health perspectives. *Toxicon : Official Journal of the International Society on Toxinology*, *56*(2), 108–122. <https://doi.org/10.1016/j.toxicon.2009.12.013>

Feldhusen F. (2000). The role of seafood in bacterial food-borne diseases. *Microbes and Infection*, *2*(13), 1651–1660. <https://doi.org/10.1016/s1286-4579(00)01321-6>

Finnis, S., Krstic, N., McIntyre, L., Nelson, T. A., & Henderson, S. B. (2017). Spatiotemporal patterns of paralytic shellfish toxins and their relationships with environmental variables in British Columbia, Canada from 2002 to 2012. *Environmental Research*, *156*, 190–200. <https://doi.org/10.1016/j.envres.2017.03.012>

Ford, J. D., Berrang-Ford, L., King, M., & Furgal, C. (2010). Vulnerability of Aboriginal health systems in Canada to climate change. *Global Environmental Change*, *20*(4), 668-680.

Ford, J. D., Gough, W. A., Laidler, G. J., Macdonald, J., Irngaut, C., & Qrunnut, K. (2009). Sea ice, climate change, and community vulnerability in northern Foxe Basin, Canada. *Climate research, 38*(2), 137-154.

Fyfe, M., Yeung, S. T., Daly, P., Schallie, K., Kelly, M. T., & Buchanan, S. (1997). Outbreak of *Vibrio* parahaemolyticus related to raw oysters in British Columbia. *Canada Communicable Disease Report = Releve des Maladies Transmissibles au Canada*, *23*(19), 145–148.

Galanis, E., Mak, S., Otterstatter, M., Taylor, M., Zubel, M., Takaro, T. K., Kuo, M., & Michel, P. (2014). The association between campylobacteriosis, agriculture and drinking water: a case-case study in a region of British Columbia, Canada, 2005-2009. *Epidemiology and infection*, *142*(10), 2075–2084. <https://doi.org/10.1017/S095026881400123X>

Galway, L. P., Allen, D. M., Parkes, M. W., & Takaro, T. K. (2014). Seasonal variation of acute gastro-intestinal illness by hydroclimatic regime and drinking water source: a retrospective population-based study. *Journal of Water and Health*, *12*(1), 122–135. <https://doi.org/10.2166/wh.2013.105>

Gargano, J. W., Freeland, A. L., Morrison, M. A., Stevens, K., Zajac, L., Wolkon, A., Hightower, A., Miller, M. D., & Brunkard, J. M. (2015). Acute gastrointestinal illness following a prolonged community-wide water emergency. *Epidemiology and Infection*, *143*(13), 2766–2776. <https://doi.org/10.1017/S0950268814003501>

Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. *International Journal of Hygiene and Environmental Health*, *220*(8), 1207–1221. <https://doi.org/10.1016/j.ijheh.2017.08.004>

Genivar. (2007). *City of Portage La Prairie water resources infrastructure assessment phase II- pilot study.* Retrieved from <https://pievc.ca/wp-content/uploads/2007/11/City-of-Portage-la-Prairie_Final-Report.pdf>

George, J. (2019). City of Iqaluit says climate change is contributing to its water pipe woes. *Nunatsiaq News.* Retrieved from <https://nunatsiaq.com/stories/article/city-of-iqaluit-says-climate-change-is-contributing-to-its-water-pipe-woes/>

Gérin-Lajoie, J., Herrmann, T. M., MacMillan, G. A., Hébert-Houle, É., Monfette, M., Rowell, J. A., ... Dedieu, J. P. (2018). IMALIRIJIIT: a community-based environmental monitoring program in the George River watershed, Nunavik, Canada. *Écoscience*, *25*(4), 381-399.

Gleick, P., Iceland, C., & Trivedi, A. (2020). *Ending Conflicts over Water.* World Resources Institute. Retrieved from <https://files.wri.org/d8/s3fs-public/ending-conflicts-over-water.pdf>

Glibert, P. M., Icarus Allen, J., Artioli, Y., Beusen, A., Bouwman, L., Harle, J., Holmes, R., & Holt, J. (2014). Vulnerability of coastal ecosystems to changes in harmful algal bloom distribution in response to climate change: projections based on model analysis. *Global Change Biology*, *20*(12), 3845–3858. <https://doi.org/10.1111/gcb.12662>

Gobler, C. J., Doherty, O. M., Hattenrath-Lehmann, T. K., Griffith, A. W., Kang, Y., & Litaker, R. W. (2017). Ocean warming since 1982 has expanded the niche of toxic algal blooms in the North Atlantic and North Pacific oceans. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(19), 4975–4980. <https://doi.org/10.1073/pnas.1619575114>

Goldhar, C., Bell, T., & Wolf, J. (2013a). Rethinking existing approaches to water security in remote communities: an analysis of two drinking water systems in Nunatsiavut, Labrador, Canada. *Water Alternatives, 6*(3), 462.

Goldhar C., Bell T., & Wolf J. (2013b). Vulnerability to Freshwater Changes in the Inuit Settlement Region of Nunatsiavut, Labrador: A Case Study from Rigolet. *ARCTIC, 67*(1), 1-133. <https://doi.org/10.14430/arctic4365>

Gompf, S. G., & Garcia, C. (2019). Lethal encounters: The evolving spectrum of amoebic meningoencephalitis. *IDCases*, *15*, e00524. <https://doi.org/10.1016/j.idcr.2019.e00524>

Government of Canada. (2020). *HealthADAPT.* Retrieved from <https://www.canada.ca/en/health-canada/programs/health-adapt.html>

Government of Northwest Territories (GNWT). (2016). *NWT Water Stewardship Strategy Action Plan 2016-2020.* Retrieved from <https://www.enr.gov.nt.ca/en/services/water-management-and-monitoring/water-stewardship-nwt>

Grattan, L. M., Boushey, C. J., Liang, Y., Lefebvre, K. A., Castellon, L. J., Roberts, K. A., Toben, A. C., & Morris, J. G. (2018). Repeated Dietary Exposure to Low Levels of Domoic Acid and Problems with Everyday Memory: Research to Public Health Outreach. *Toxins*, *10*(3), 103. <https://doi.org/10.3390/toxins10030103>

Greck and Associates Limited. (2018). *MVCA Gorrie Dam Future Plans Study.* Prepared for Maitland Valley Conservation Authority. Retrieved from <http://www.mvca.on.ca/wp-content/uploads/2018/11/Gorrie-Dam-Future-Plans-Study-Nov.-2018.pdf>

Grey Bruce Health Unit. (2017). *Climate Change and Public Health in Grey Bruce Health Unit: Current conditions and future projections.* Owen Sound, ON: Grey Bruce Health Unit. Retrieved from <https://www1.publichealthgreybruce.on.ca/Portals/0/Topics/Healthy_Environments/Climate%20Change%20in%20GBHU%20-%20Report%20%282017%29.pdf>

Guehlstorf, N., & Hallstrom, L. K. (2012). Environmental Reviews and Case Studies: Participatory Watershed Management: A Case Study from Maritime Canada. *Environmental Practice*, *14*(2), 143-153.

Haley, B. J., Kokashvili, T., Tskshvediani, A., Janelidze, N., Mitaishvili, N., Grim, C. J., Constantin de Magny, G., Chen, A. J., Taviani, E., Eliashvili, T., Tediashvili, M., Whitehouse, C. A., Colwell, R. R., & Huq, A. (2014). Molecular diversity and predictability of *Vibrio* parahaemolyticus along the Georgian coastal zone of the Black Sea. *Frontiers in Microbiology*, *5*, 45. <https://doi.org/10.3389/fmicb.2014.00045>

Hallema, D. W., Robinne, F. N., & Bladon, K. D. (2018). Reframing the challenge of global wildfire threats to water supplies. *Earth's Future*, *6*(6), 772-776.

Harper, A. R., Doerr, S. H., Santin, C., Froyd, C. A., & Sinnadurai, P. (2018). Prescribed fire and its impacts on ecosystem services in the UK. *The Science of the total Environment*, *624*, 691–703. <https://doi.org/10.1016/j.scitotenv.2017.12.161>

Harper, S. L., Edge, V. L., Schuster-Wallace, C. J., Berke, O., & McEwen, S. A. (2011). Weather, water quality and infectious gastrointestinal illness in two Inuit communities in Nunatsiavut, Canada: potential implications for climate change. *EcoHealth*, *8*(1), 93–108. <https://doi.org/10.1007/s10393-011-0690-1>

Health Canada. (2005). *Guidance for providing safe drinking water in areas of federal jurisdiction - Version 1*. Retrieved from <http://publications.gc.ca/site/eng/459848/publication.html>

Health Canada. (2012). *Guidelines for Canadian Recreational Water Quality*. Retrieved from <https://www.canada.ca/content/dam/canada/health-canada/migration/healthy-canadians/publications/healthy-living-vie-saine/water-recreational-recreative-eau/alt/pdf/water-recreational-recreative-eau-eng.pdf>

Health Canada. (2015). *Guidance for Issuing and Rescinding Boil Water Advisories in Canadian Drinking Water Supplies*. Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada. Ottawa, ON. Retrieved from <https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidance-issuing-rescinding-boil-water-advisories-canadian-drinking-water-supplies.html>

Health Canada. (2019a). *Guidelines for Canadian Drinking Water Quality - Summary Table*. Retrieved from <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/water-quality/guidelines-canadian-drinking-water-quality-summary-table.html>

Health Canada. (2019b). *Drinking water quality in Canada*. Retrieved from <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/water-quality/drinking-water.html>

Health Canada. (2020). *Health Canada's Maximum Levels for Chemical Contaminants in Foods*. Retrieved from <https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/maximum-levels-chemical-contaminants-foods.html>

Henstra, D., & Thistlethwaite, J. (2017). *Flood Risk Management: What Is the Role for the Government of Canada?* Centre for International Governance Innovation. Retrieved from <https://www.cigionline.org/sites/default/files/documents/Policy%20Brief%20No.103_0.pdf>

Heymann, D. (Ed.). (2015). *Control of Communicable Diseases Manual* (20th ed.). Washington, DC: APHA Press.

Hilborn, E. D., & Beasley, V. R. (2015). One health and cyanobacteria in freshwater systems: animal illnesses and deaths are sentinel events for human health risks. *Toxins*, *7*(4), 1374–1395. <https://doi.org/10.3390/toxins7041374>

Hori, Y., Cheng, V. Y., Gough, W. A., Jien, J. Y., & Tsuji, L. J. (2018). Implications of projected climate change on winter road systems in Ontario's Far North, Canada. *Climatic Change*, *148*(1-2), 109-122.

Hovelsrud, G. K., Poppel, B., van Oort, B., & Reist, J. D. (2011). Arctic Societies, Cultures, and Peoples in a Changing Cryosphere. *Ambio*, *40*(Suppl 1), 100–110. <https://doi.org/10.1007/s13280-011-0219-4>

Hrudey, S. E., & Hrudey, E. (2004). *Safe Drinking Water: Lessons from Recent Outbreaks in Affluent Nations*. London, United Kingdom: IWA Publishing.

Hrudey, S. E., Payment, P., Huck, P. M., Gillham, R. W., & Hrudey, E. J. (2003). A fatal waterborne disease epidemic in Walkerton, Ontario: comparison with other waterborne outbreaks in the developed world. *Water science and technology : a journal of the International Association on Water Pollution Research*, *47*(3), 7–14.

Hulin, M., Simoni, M., Viegi, G., & Annesi-Maesano, I. (2012). Respiratory health and indoor air pollutants based on quantitative exposure assessments. *The European Respiratory Journal*, *40*(4), 1033–1045. <https://doi.org/10.1183/09031936.00159011>

Hunter, P. R., & Thompson, R. C. (2005). The zoonotic transmission of Giardia and Cryptosporidium. *International Journal for Parasitology*, *35*(11-12), 1181–1190. <https://doi.org/10.1016/j.ijpara.2005.07.009>

Il Jeong, D., & Sushama, L. (2018). Rain-on-snow events over North America based on two Canadian regional climate models. *Climate Dynamics, 50*(1-2), 303–316. doi:10.1007/s00382-017-3609-x

Indigenous Services Canada (ISC). (2015). *Circuit Rider Training Program*. Retrieved from <https://www.sac-isc.gc.ca/eng/1313424571273/1533818103401>

Indigenous Services Canada (ISC). (2019). *Community Voices on Climate Change and Health Adaptation in Northern Canada*. Ottawa, ON. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/19-012-climate-change-c2-ang.pdf>

Indigenous Services Canada (ISC). (2020a). *Ending long-term drinking water advisories*. Retrieved from <https://www.sac-isc.gc.ca/eng/1506514143353/1533317130660>

Indigenous Services Canada (ISC). (2020b). *Flooding in First Nations communities*. Retrieved from <https://www.sac-isc.gc.ca/eng/1397740805675/1535120329798>

Inuit Tapiriit Kanatami (ITK). (2019). National Inuit Climate Change Strategy. Retrieved from <https://www.itk.ca/wp-content/uploads/2019/06/ITK_Climate-Change-Strategy_English.pdf>

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and Sectoral Aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change* (C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White, Eds.). Cambridge, United Kingdom: Cambridge University Press.

International Joint Commission (IJC). (2017). *Human Health Effects of Cyanobacterial Toxins in the Great Lakes Region: A Science and Monitoring Assessment.* Retrieved from <https://www.ijc.org/sites/default/files/2019-04/HPABAlgalBloomFinal.pdf>

Jagai, J. S., Griffiths, J. K., Kirshen, P. K., Webb, P., & Naumova, E. N. (2012). Seasonal patterns of gastrointestinal illness and streamflow along the Ohio River. *International Journal of Environmental Research and Public Health*, *9*(5), 1771–1790. <https://doi.org/10.3390/ijerph9051771>

Jalliffier-Verne, I., Leconte, R., Huaringa-Alvarez, U., Madoux-Humery, A. S., Galarneau, M., Servais, P., Prévost, M., & Dorner, S. (2015). Impacts of global change on the concentrations and dilution of combined sewer overflows in a drinking water source. *The Science of the Total Environment*, *508*, 462–476. <https://doi.org/10.1016/j.scitotenv.2014.11.059>

Jung, Y., Jang, H., & Matthews, K. R. (2014). Effect of the food production chain from farm practices to vegetable processing on outbreak incidence. *Microbial Biotechnology*, *7*(6), 517–527. <https://doi.org/10.1111/1751-7915.12178>

Kang, D. H., Shi, X., Gao, H., Déry, S. J. (2014). On the changing contribution of snow to the hydrology of the Fraser River Basin, Canada. *Journal of Hydrometeorology, 15*(4), 1344-1365.

Kapos, V., Wicander, S., Salvaterra, T., Dawkins, K., & Hicks, C. (2019). *The Role of the Natural Environment in Adaptation, Background Paper for the Global Commission on Adaptation*. Washington, DC: Global Commission on Adaptation.

Kelly, M. T. (1991). Pathogenic *Vibrio*naceae in patients and the environment. *Undersea Biomedical Research, 18*(3), 193-6.

Khaira, G., & Galanis, E. (2007). Descriptive epidemiology of *Vibrio* parahaemolyticus and other *Vibrio* species infections in British Columbia: 2001-2006. *Canada Communicable Disease Report = Releve des Maladies Transmissibles au Canada*, *33*(11), 12–22.

Khan, S. J., Deere, D., Leusch, F. D., Humpage, A., Jenkins, M., & Cunliffe, D. (2015). Extreme weather events: Should drinking water quality management systems adapt to changing risk profiles?. *Water research*, *85*, 124–136. <https://doi.org/10.1016/j.watres.2015.08.018>

Kim, S., Chu, K. H., Al-Hamadani, Y. A. J., Park, C. M., Jang, M., Kim, D.-H., Yu, M., Heo, J., Yoon, Y. (2018). Removal of contaminants of emerging concern by membranes in water and wastewater: A review. *Chemical Engineering Journal, 335*(1), 896–914. doi:10.1016/j.cej.2017.11.044

Kinney, P. L., Matte, T., Knowlton, K., Madrigano, J., Petkova, E., Weinberger, K., Quinn, A., Arend, M., & Pullen, J. (2015). New York City Panel on Climate Change 2015 Report. Chapter 5: Public health impacts and resiliency. *Annals of the New York Academy of Sciences*, *1336*, 67–88. <https://doi.org/10.1111/nyas.12588>

Kirby, R. M., Bartram, J., & Carr, R. (2003). Water in food production and processing: quantity and quality concerns. *Food Control*, *14*(5), 283-299.

Klassen, J., & Allen, D. M. (2017). Assessing the risk of saltwater intrusion in coastal aquifers. *Journal of Hydrology, 551*, 730–745. doi:10.1016/j.jhydrol.2017.02.044

Kleywegt, S., Pileggi, V., Yang, P., Hao, C., Zhao, X., Rocks, C., Thach, S., Cheung, P., & Whitehead, B. (2011). Pharmaceuticals, hormones and bisphenol A in untreated source and finished drinking water in Ontario, Canada--occurrence and treatment efficiency. *The Science of the Total Environment*, *409*(8), 1481–1488. <https://doi.org/10.1016/j.scitotenv.2011.01.010>

Konrad, S., Paduraru, P., Romero-Barrios, P., Henderson, S. B., & Galanis, E. (2017). Remote sensing measurements of sea surface temperature as an indicator of *Vibrio* parahaemolyticus in oyster meat and human illnesses. *Environmental Health*, *16*(1), 92. <https://doi.org/10.1186/s12940-017-0301-x>

Kovacs, P., & Sandink, D. (2013). *Best Practices for Reducing the Risk of Future Damage to Homes from Riverine and Urban Flooding: A Report on Recovery and Rebuilding in Southern Alberta.* Toronto, ON: Institute for Catastrophic Loss Reduction. Retrieved from <http://www.iclr.org/images/Alberta_flood_risk_2013_PDF.pdf>

Kovats, R. S., & Akhtar, R. (2008). Climate, climate change and human health in Asian cities. *Environment and Urbanization, 20*(1), 165–175. doi:10.1177/0956247808089154

Lake, I. R., Bentham, G., Kovats, R. S., & Nichols, G. L. (2005). Effects of weather and river flow on cryptosporidiosis. *Journal of Water and Health*, *3*(4), 469–474. <https://doi.org/10.2166/wh.2005.048>

Lal, A., Baker, M. G., Hales, S., & French, N. P. (2013). Potential effects of global environmental changes on cryptosporidiosis and giardiasis transmission. *Trends in Parasitology*, *29*(2), 83–90. <https://doi.org/10.1016/j.pt.2012.10.005>

Lam, K. L., Stokes-Draut, J. R., Horvath, A., Lane, J. L., Kenway, S. J., & Lant, P. A. (2017). Life-cycle energy impacts for adapting an urban water supply system to droughts. *Water Research*, *127*, 139–149. <https://doi.org/10.1016/j.watres.2017.10.016>

Le Guyader, F., Haugarreau, L., Miossec, L., Dubois, E., & Pommepuy, M. (2000). Three-year study to assess human enteric viruses in shellfish. *Applied and Environmental Microbiology*, *66*(8), 3241–3248. <https://doi.org/10.1128/AEM.66.8.3241-3248.2000>

Lemmen, D., & Warren, F. (Eds.). (2004). *Climate change impacts and adaptation: A Canadian perspective*. Ottawa, ON: Natural Resources Canada.

Levinson, M., Whelan, M., & Butler, A. (2017). *A Changing Climate: Assessing Health Impacts & Vulnerabilities Due to Climate Change within Simcoe Muskoka*. Barrie, ON: Simcoe-Muskoka District Health Unit.

Levy, B. S., & Sidel, V. W. (2011). Water rights and water fights: preventing and resolving conflicts before they boil over. *American Journal of Public Health*, *101*(5), 778–780. <https://doi.org/10.2105/AJPH.2010.194670>

Levy, K., Woster, A. P., Goldstein, R. S., & Carlton, E. J. (2016). Untangling the Impacts of Climate Change on Waterborne Diseases: a Systematic Review of Relationships between Diarrheal Diseases and Temperature, Rainfall, Flooding, and Drought. *Environmental Science & Technology*, *50*(10), 4905–4922. <https://doi.org/10.1021/acs.est.5b06186>

Li, H., Li, K., & Zhang, X. (2016). Performance evaluation of Grassed swales for stormwater pollution control. *Procedia Engineering, 154*, 898–910. doi:10.1016/j.proeng.2016.07.481

Lloyd, E. (2017). *Drought Disaster Planning and Adaptation in Rural British Columbia* [Master's Thesis, Royal Roads University]. Royal Roads University. Retrieved from <https://viurrspace.ca/handle/10613/5021>

Logar-Henderson, C., Ling, R., Tuite, A. R., & Fisman, D. N. (2019). Effects of large-scale oceanic phenomena on non-cholera *vibrio*sis incidence in the United States: implications for climate change. *Epidemiology and Infection*, *147*, e243. <https://doi.org/10.1017/S0950268819001316>

Lowe, D., Ebi, K. L., & Forsberg, B. (2013). Factors increasing vulnerability to health effects before, during and after floods. *International Journal of Environmental Research and Public Health*, *10*(12), 7015–7067. <https://doi.org/10.3390/ijerph10127015>

Luh, J., Royster, S., Sebastian, D., Ojomo, E., & Bartram, J. (2017). Expert assessment of the resilience of drinking water and sanitation systems to climate-related hazards. *The Science of the Total Environment*, *592*, 334–344. <https://doi.org/10.1016/j.scitotenv.2017.03.084>

Maalouf, H., Pommepuy, M., & Le Guyader, F. S. (2010). Environmental Conditions Leading to Shellfish Contamination and Related Outbreaks. *Food and Environmental Virology, 2*(3), 136-45.

MacDougall, L., Majowicz, S., Doré, K., Flint, J., Thomas, K., Kovacs, S., & Sockett, P. (2008). Under-reporting of infectious gastrointestinal illness in British Columbia, Canada: who is counted in provincial communicable disease statistics? *Epidemiology and Infection*, *136*(2), 248–256. <https://doi.org/10.1017/S0950268807008461>

Madoux-Humery, A. S., Dorner, S., Sauvé, S., Aboulfadl, K., Galarneau, M., Servais, P., & Prévost, M. (2016). The effects of combined sewer overflow events on riverine sources of drinking water. *Water Research*, *92*, 218–227. <https://doi.org/10.1016/j.watres.2015.12.033>

Mann, A. G., Tam, C. C., Higgins, C. D., & Rodrigues, L. C. (2007). The association between drinking water turbidity and gastrointestinal illness: a systematic review. *BMC Public Health*, *7*, 256. <https://doi.org/10.1186/1471-2458-7-256>

Martin, D., Bélanger, D., Gosselin, P., Brazeau, J., Furgal, C., & Déry, S. (2007). Drinking water and potential threats to human health in Nunavik: adaptation strategies under climate change conditions. *Arctic*, 195-202.

Martin, D. A. (2016). At the nexus of fire, water and society. *Philosophical Transactions of the Royal Society B: Biological Sciences, 371*, 1696. doi:10.1098/rstb.2015.0172

Martinez-Urtaza, J., Bowers. J. C., Trinanes, J., & DePaola, A. (2010). Climate anomalies and the increasing risk of *Vibrio* parahaemolyticus and *Vibrio* vulnificus illnesses. *Food Research International, 43*(7), 1780-90. <https://doi.org/10.1016/j.foodres.2010.04.001>

McCabe, R. M., Hickey, B. M., Kudela, R. M., Lefebvre, K. A., Adams, N. G., Bill, B. D., Gulland, F. M., Thomson, R. E., Cochlan, W. P., & Trainer, V. L. (2016). An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophysical Research Letters*, *43*(19), 10366–10376. <https://doi.org/10.1002/2016GL070023>

McClearn, M. (2020). Climate change threatens Canada's dams - but who's keeping track? *The Globe and Mail*. Retrieved from <https://www.theglobeandmail.com/canada/article-climate-change-will-push-canadas-dams-to-their-limits-but-due-to/>

McGregor, D. (2012). Traditional knowledge: Considerations for protecting water in Ontario. *International Indigenous Policy Journal, 3*(3), 1-21. <https://doi.org/10.18584/iipj.2012.3.3.11>

McKnight, E. (2017). Characterizing and monitoring the water properties and dynamics of Lhù'ààn Mân̈ (Kluane Lake), Yukon, in the face of climate change. *ARCTIC, 70*(4), 435-40. doi:10.14430/arctic4692

McLaughlin, J. B., DePaola, A., Bopp, C. A., Martinek, K. A., Napolilli, N. P., Allison, C. G., Murray, S. L., Thompson, E. C., Bird, M. M., & Middaugh, J. P. (2005). Outbreak of *Vibrio* parahaemolyticus gastroenteritis associated with Alaskan oysters. *The New England Journal of Medicine*, *353*(14), 1463–1470. <https://doi.org/10.1056/NEJMoa051594>

McLeman, R. (2011). *Climate change, migration and critical international security considerations: IOM Migration Research Series.* Geneva, Switzerland: International Organization for Migration. Retrieved from <https://publications.iom.int/system/files/pdf/mrs42.pdf>

McLeman, R. (2019). International migration and climate adaptation in an era of hardening borders. *Nature Climate Change*, *9*(12), 911-918. doi:10.1038/s41558-019-0634-2

Mezzacapo, M., Takaro, T. K., Buckeridge, D., Foldy, S., & Boehme, J. (2018). *Data Challenges for Environmental Factors and Gastrointestinal Illness in Great Lakes Cities*. International Association for Great Lakes Research Annual Meeting 2018.

Miller, A., Cumming, E., & McIntyre, L. (2018). *Summary Working Group Report of the Environmental Transmission of Norovirus into Oysters.* Vancouver, BC: Environmental Health Services and BC Centre for Disease Control.

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity is dead: Whither water management? *Science, 319*(5863), 573-574. doi:10.1126/science.1151915.

Moffatt, H., & Struck, S. (2011). *Water-borne disease outbreaks in Canadian Small Drinking Water Systems.* National Collaborating Centres for Public Health. Retrieved from <https://www.ncceh.ca/sites/default/files/SDWS_Water-borne_EN.pdf>

Moore, S. K., Johnstone, J. A., Banas, N. S., & Salathé, E. P. (2015). Present-day and future climate pathways affecting *Alexandrium* blooms in Puget Sound, WA, USA. *Harmful Algae*, *48*, 1–11. <https://doi.org/10.1016/j.hal.2015.06.008>

Moore, S. K., Trainer, V. L., Mantua, N. J., Parker, M. S., Laws, E. A., Backer, L. C., & Fleming, L. E. (2008). Impacts of climate variability and future climate change on harmful algal blooms and human health. *Environmental Health, 7*(Suppl. 2), S4.

Morris, T., & Brandes, O. M. (2013). *The state of the water movement in British Columbia: a waterscape scan & needs assessment of BC watershed-based groups*. POLIS Project on Ecological Governance, University of Victoria & Real Estate Foundation of British Columbia.

Morrison, K. D., & Kolden, C. A. (2015). Modeling the impacts of wildfire on runoff and pollutant transport from coastal watersheds to the nearshore environment. *Journal of Environmental Management*, *151*, 113–123. <https://doi.org/10.1016/j.jenvman.2014.12.025>

Mudryk, L., Derksen, C., Howell, S., Laliberté, F., Thackeray, C., Sospe - dra-Alfonso, R., Vionnet, V., Kushner, P., & Brown, R. (2018). Canadian snow and sea ice: historical trends and projections. *The Cryosphere, 12*, 1157–1176. doi:10.5194/tc-12-1157-2018

Murphy, H. M., Thomas, M. K., Medeiros, D. T., McFadyen, S., & Pintar, K. D. M. (2016a). Estimating the number of cases of acute gastrointestinal illness (AGI) associated with Canadian municipal drinking water systems. *Epidemiology and Infection*, *144*(7), 1371–1385. <https://doi.org/10.1017/S0950268815002083>

Murphy, H. M., Thomas, M. K., Schmidt, P. J., Medeiros, D. T., McFadyen, S., & Pintar, K. D. (2016b). Estimating the burden of acute gastrointestinal illness due to Giardia, Cryptosporidium, Campylobacter, E. coli O157 and norovirus associated with private wells and small water systems in Canada. *Epidemiology and Infection*, *144*(7), 1355–1370. <https://doi.org/10.1017/S0950268815002071>

Naser, A. M., Rahman, M., Unicomb, L., Doza, S., Gazi, M. S., Alam, G. R., Karim, M. R., Uddin, M. N., Khan, G. K., Ahmed, K. M., Shamsudduha, M., Anand, S., Narayan, K., Chang, H. H., Luby, S. P., Gribble, M. O., & Clasen, T. F. (2019). Drinking Water Salinity, Urinary Macro-Mineral Excretions, and Blood Pressure in the Southwest Coastal Population of Bangladesh. *Journal of the American Heart Association*, *8*(9), e012007. <https://doi.org/10.1161/JAHA.119.012007>

Natural Resources Canada (NRCan). (2018). *Federal Flood Mapping Framework.* Retrieved from <http://ftp.geogratis.gc.ca/pub/nrcan_rncan/publications/ess_sst/308/308128/gip_112_v2_0_en.pdf>

Natural Resources Canada (NRCan). (2021). *Building Regional Adaptation Capacity and Expertise (BRACE) Program.* Retrieved from <https://www.nrcan.gc.ca/climate-change/impacts-adaptations/building-regional-adaptation-capacity-and-expertise-brace-program/21324>

New Brunswick. (2019). *Residents affected by flooding can apply for disaster relief and increased advance payments*. Retrieved from <https://www2.gnb.ca/content/gnb/en/news/public_alerts/public_alert.2019.05.0281.html>

Newton, A., Kendall, M., Vugia, D. J., Henao, O. L., & Mahon, B. E. (2012). Increasing rates of *vibrio*sis in the United States, 1996-2010: review of surveillance data from 2 systems. *Clinical Infectious Diseases, 54 Suppl 5*(0 5), S391–S395. <https://doi.org/10.1093/cid/cis243>

Ogden, N. H., Lindsay, L. R., Ludwig, A., Morse, A. P., Zheng, H., & Zhu, H. (2019). Weather-based forecasting of mosquito-borne disease outbreaks in Canada. *Canada Communicable Disease Report = Releve des Maladies Transmissibles au Canada*, *45*(5), 127–132. <https://doi.org/10.14745/ccdr.v45i05a03>

Ouranos. (2018). *Atlas web de la vulnérabilité de la population québécoise aux aléas climatiques.* Retrieved from <https://atlas-vulnerabilite.ulaval.ca/projet/>

Overland, J., Dunlea, E., Box, J. E., Corell, R., Forsius, M., Kattsov, V., Olsen, M. S., Pawlak, J., Reiersen, L. O., & Wang, M. (2018). The urgency of Arctic change. Polar Science, 21, 6-13. doi:10.1016/j.polar.2018.11.008

Paillard, C., Le Roux, F., & Borrego, J. J. (2004). Bacterial disease in marine bivalves, a review of recent studies: trends and evolution. *Aquatic Living Resources, 17*(4), 477-98. <https://doi.org/10.1051/alr:2004054>

Parkes, M. W., Morrison, K. E., Bunch, M. J., Hallström, L. K., Neudoerffer, R. C., Venema, H. D., & Waltner-Toews, D. (2010). Towards integrated governance for water, health and social–ecological systems: The watershed governance prism. *Global Environmental Change*, *20*(4), 693-704.

Parveen, S., Hettiarachchi, K. A., Bowers, J. C., Jones, J. L., Tamplin, M. L., McKay, R., Beatty, W., Brohawn, K., Dasilva, L. V., & Depaola, A. (2008). Seasonal distribution of total and pathogenic *Vibrio* parahaemolyticus in Chesapeake Bay oysters and waters. *International Journal of Food Microbiology*, *128*(2), 354–361. <https://doi.org/10.1016/j.ijfoodmicro.2008.09.019>

Patrick, R. (2018). Adapting to Climate Change through Source Water Protection: Case Studies from Alberta and Saskatchewan, Canada. *International Indigenous Policy Journal, 9*(3). doi:10.18584/iipj.2018.9.3.1

Perl, T. M., Bédard, L., Kosatsky, T., Hockin, J. C., Todd, E. C., & Remis, R. S. (1990). An outbreak of toxic encephalopathy caused by eating mussels contaminated with domoic acid. *The New England Journal of Medicine*, *322*(25), 1775–1780. <https://doi.org/10.1056/NEJM199006213222504>

Pescaroli, G., & Alexander, D. (2018). Understanding compound, interconnected, interacting, and cascading risks: A holistic framework. *Risk Analysis, 38*(11), 2245-2257. <https://doi.org/10.1111/risa13128>

Pick, F. R. (2016). Blooming algae: a Canadian perspective on the rise of toxic cyanobacteria; *Canadian Journal of Fisheries and Aquatic Sciences, 73*(7), 1149–1158. <https://doi.org/10.1139/cjfas-2015-0470>

Picketts, I. M., Parkes, M. W., & Déry, S. (2017). Climate change and resource development impacts in watersheds: insights from the Nechako River Basin, Canada. *The Canadian Geographer, 61*(2), 196-211. <https://doi.org/10.1111/cag.12327>

Pons, W., Young, I., Truong, J., Jones-Bitton, A., McEwen, S., Pintar, K., & Papadopoulos, A. (2015). A Systematic Review of Waterborne Disease Outbreaks Associated with Small Non-Community Drinking Water Systems in Canada and the United States. *PloS one*, *10*(10), e0141646. <https://doi.org/10.1371/journal.pone.0141646>

Prakash, A., Medcof, J. C., & Tennant, A. D. (1971). *Paralytic shellfish poisoning in eastern Canada.* Fisheries Research Board of Canada. Retrieved from <https://waves-vagues.dfo-mpo.gc.ca/Library/1498.pdf>

Public Sector Digest Inc. (PSD), Canadian Water Network, Canadian Water and Wastewater Association, Federation of Canadian Municipalities. (2019). *Cases Studies: Using Better Data to Identify Climate Change-Related Infrastructure Vulnerabilities in Canadian Communities.* Retrieved from <https://cwn-rce.ca/wp-content/uploads/Case-Studies-Using-Better-Data-to-Identify-Climate-Change-Related-Infrastructure-Vulnerabilities-in-Canadian-Communities.pdf>

Ravel, A., Greig, J., Tinga, C., Todd, E., Campbell, G., Cassidy, M., Marshal, B., & Pollari, F. (2009). Exploring historical Canadian food-borne outbreak data sets for human illness attribution. *Journal of Food Protection*, *72*(9), 1963-1976.

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy, 77*, 15-24. <https://doi.org/10.1016/j.envsci.2017.07.008>

Rigaud, K. K., de Sherbinin, A., Jones, B., Bergmann, J., Clement, V., Ober, K., Schewe, J., Adamo, S., McCusker, B., Heuser, S., & Midgley, A. (2018). *Groundswell: Preparing for Internal Climate Migration.* Washington, DC: World Bank. Retrieved from <https://openknowledge.worldbank.org/handle/10986/29461>

Robinne, F.N., Bladon, K.D., Silins,U., Emelko, M.B., Flannigan, M.D., Parisien, M.A., Wang, X.,. Kienzle, S.W., & Dupont, D.P. (2019). A Regional-Scale Index for Assessing the Exposure of Drinking-Water Sources to Wildfires. *Forests, 10*(5), 384. <https://doi.org/10.3390/f10050384>

Rossi, R. J., & Toran, L. (2019). Exploring the potential for groundwater inundation in coastal US cities due to interactions between sewer infrastructure and global change. *Environmental Earth Sciences, 78*(8), 258. doi:10.1007/s12665-019-8261-9

Sanderson, D., Picketts, I. M., Déry, S. J., Fell, B., Baker, S., Lee-Johnson, E., & Auger, M. (2015). Climate change and water at Stellat-en First Nation, British Columbia, Canada: Insights from western science and traditional knowledge. *The Canadian Geographer, 59*(2), 136-150.

Schnitter, R., & Berry, P. (2019). The Climate Change, Food Security and Human Health Nexus in Canada: A Framework to Protect Population Health. *International Journal of Environmental Research and Public Health*, *16*(14), 2531. <https://doi.org/10.3390/ijerph16142531>

Schuster, C. J., Ellis, A. G., Robertson, W. J., Charron, D. F., Aramini, J. J., Marshall, B. J., & Medeiros, D. T. (2005). Infectious disease outbreaks related to drinking water in Canada, 1974-2001. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *96*(4), 254–258. <https://doi.org/10.1007/BF03405157>

Schwartz, J., Levin, R., & Goldstein, R. (2000). Drinking water turbidity and gastrointestinal illness in the elderly of Philadelphia. *Journal of Epidemiology and Community Health*, *54*(1), 45–51. <https://doi.org/10.1136/jech.54.1.45>

Séguin, J. (Ed.). (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity*. Ottawa, ON: Health Canada. Retrieved from <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Semenza, J. C., Herbst, S., Rechenburg, A., Suk, J. E., Höser, C., Schreiber, C., & Kistemann, T. (2012). Climate Change Impact Assessment of Food- and Waterborne Diseases. *Critical Reviews in Environmental Science and Technology*, *42*(8), 857–890. <https://doi.org/10.1080/10643389.2010.534706>

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M., Jaeger, E. B., Lehner, I., Orlowsky, B., & Teuling, A. J. (2010). Investigating soil moisture–climate interactions in a changing climate: A review. *Earth-Science Reviews*, *99*(3-4), 125–161. doi:10.1016/j.earscirev.2010.02.004

Shamkhali Chenar, S., & Deng, Z. (2017). Environmental indicators for human norovirus outbreaks. *International Journal of Environmental Health Research*, *27*(1), 40–51. <https://doi.org/10.1080/09603123.2016.1257705>

Sharma, A., Burn, S., Gardner, T., & Gregory A. (2010). Role of decentralised systems in the transition of urban water systems; Water Science and Technology. *Water Supply*, *10*(4), 577–583. doi:10.2166/ws.2010.187

Shrubsole, D., Walters, D., Veale, B., & Mitchell, B. (2017). Integrated Water Resources Management in Canada: the experience of watershed agencies. *International Journal of Water Resources Development*, *33*(3), 349-359. <https://doi.org/10.1080/07900627.2016.1244048>

Shuster-Wallace, C., Sandford, R., & Merril, S. (2019). *Water futures for the world we want: Opportunities for research, practice, and leadership in achieving SDG6*. Saskatoon, SK: University of Saskatchewan. Retrieved from <https://gwf.usask.ca/documents/water_futures_for_the_world_we_want.pdf>

Shuster-Wallace, C., Sandford, R., & Merril, S. (2020). Climate change, pollution and urbanization threaten water in Canada. *The Conversation*. Retrieved from <https://theconversation.com/climate-change-pollution-and-urbanization-threaten-water-in-canada-127876>

Smith, B. A., & Fazil, A. (2019). Climate change and infectious diseases: The challenges: How will climate change impact microbial food-borne disease in Canada? *Canada Communicable Disease Report*, *45*(4), 108-113. <https://doi.org/10.14745/ccdr.v45i04a05>

Smith, D. M., Matthews, J. H., Bharati, L., Borgomeo, E., McCartney, M., Mauroner, A., Nicol, A., Rodriguez, D., Sadoff, C., Suhardiman, D., Timboe, I., Amarnath, G., & Anisha, N. (2019). *Adaptation's thirst: Accelerating the convergence of water and climate action*. Background Paper prepared for the 2019 report of the Global Commission on Adaptation. Washington, DC. Retrieved from <http://www.iwmi.cgiar.org/Publications/Other/PDF/adaptations-thirst-gca-background-paper.pdf>

Somers, G., & Nishimura, P. (Eds). (2012). *Managing groundwater resources: Assessing the impact of climate change on salt-water intrusion of coastal aquifers in Atlantic Canada*. Prince Edward Island Environment, Labour and Justice. Retrieved from <http://www.gov.pe.ca/photos/original/cle_WA2.pdf>

Speight, V. (2018). Sustainable water systems of the future: how to ensure public health protection? *Perspectives in Public Health*, *138*(5), 248–249. doi:10.1177/1757913918790146

Statistics Canada. (2009). *Human Activity and the Environment: Annual Statistics*. Retrieved from <https://www150.statcan.gc.ca/n1/en/pub/16-201-x/16-201-x2009000-eng.pdf?st=2TCSV5or>

Statistics Canada. (2011). *Households and the environment survey (HES)*. Retrieved from <https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=3881>

Statistics Canada. (2013). *Survey of Drinking Water Plants 2011*. Minister of Industry. Retrieved from <https://www150.statcan.gc.ca/n1/en/pub/16-403-x/16-403-x2013001-eng.pdf?st=JPnR4dOl>

Statistics Canada. (2021). *Table 38-10-0277-01 Treatment of main source of water by households, Canada, provinces and census metropolitan areas (CMA)*. Retrieved from <https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810027701>

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: guiding human development on a changing planet. *Science*, *347*(6223), 1259855. <https://doi.org/10.1126/science.1259855>

Stephen, C., & Duncan, C. (2017). Can wildlife surveillance contribute to public health preparedness for climate change? A Canadian perspective. *Climatic Change*, *141*(2), 259-271.

Sundarambal, P., Balasubramanian, R., Tkalich, P., & He, J. (2010). Impact of biomass burning on ocean water quality in Southeast Asia through atmospheric deposition: field observations. *Atmospheric Chemistry and Physics*, *10*(23), 11323-11336. <https://doi.org/10.5194/acp-10-11323-2010>

Taylor, M., Cheng, J., Sharma, D., Bitzikos, O., Gustafson, R., Fyfe, M., Greve, R., Murti, M., Stone, J., Honish, L., Mah, V., Punja, N., Hexemer, A., McIntyre, L., Henry, B., Kendall, P., Atkinson, R., Buenaventura, E., Martinez-Perez, A., Galanis, E., … Team, T. (2018). Outbreak of *Vibrio* parahaemolyticus Associated with Consumption of Raw Oysters in Canada, 2015. *Food-borne Pathogens and Disease*, *15*(9), 554–559. <https://doi.org/10.1089/fpd.2017.2415>

Taylor, M., McIntyre, L., Ritson, M., Stone, J., Bronson, R., Bitzikos, O., Rourke, W., Galanis, E., & Outbreak Investigation Team. (2013a). Outbreak of Diarrhetic Shellfish Poisoning associated with mussels, British Columbia, Canada. *Marine Drugs*, *11*(5), 1669–1676. <https://doi.org/10.3390/md11051669>

Taylor, R. G., Scanlon, B., Döll, P., Rodell, M., van Beek, R., Wada, Y., Longuevergne, L., Leblanc, M., Famiglietti, J. S., Edmunds, M., … Holger, T. (2013b). Ground water and climate change. *Nature Climate Change, 3*(4), 322–329. doi:10.1038/nclimate1744

Thienpont, J. R., Johnson, D., Nesbitt, H., Kokelj, S. V., Pisaric, M .F., Smol, J. P. (2012). Arctic coastal freshwater ecosystem responses to a major saltwater intrusion: A landscape-scale palaeolimnological analysis. *The Holocene, 22*(12), 1451-1460. <https://doi.org/10.1177/0959683612455538>

Thistlethwaite, J. Miano, A., Henstra, D., & Scott, D. (2020). *Indigenous Reserve Lands in Canada Face High Flood Risk*. Centre for International Governance and innovation. Retrieved from <https://www.cigionline.org/sites/default/files/documents/PB%20no.159.pdf>

Thomas, M. K., Murray, R., Flockhart, L., Pintar, K., Pollari, F., Fazil, A., Nesbitt, A., & Marshall, B. (2013). Estimates of the burden of food-borne illness in Canada for 30 specified pathogens and unspecified agents, circa 2006. *Food-borne Pathogens and Disease*, *10*(7), 639–648. <https://doi.org/10.1089/fpd.2012.1389>

Thurton, D. (2017). Fort McMurray seeing big spike in water-treatment costs. *CBC News Edmonton*. Retrieved from <https://www.cbc.ca/news/canada/edmonton/fort-mcmurray-wildfire-water-treatmentcosts-contaminants-1.3973249>

Todd, E. C. (1997). Seafood-associated diseases and control in Canada. *Revue scientifique et technique (International Office of Epizootics)*, *16*(2), 661–672. <https://doi.org/10.20506/rst.16.2.1058>

Trtanj, J., Jantarasami, L., Brunkard, J., Collier, T., Jacobs, J., Lipp, E., McLellan, S., Moore, S., Paerl, H., Ravenscroft, J., Sengco, M., & Thurston, J. (2016). Climate Impacts on Water-Related Illness. In A. Crimmins, J. Balbus, J. L. Gamble, C. B. Beard, J. E. Bell, D. Dodgen, R. J. Eisen, N. Fann, M. D. Hawkins, S. C. Herring, L. Jantarasami, D. M. Mills, S. Saha, M. C. Sarofim, J. Trtanj, & L. Ziska (Eds.), *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (p. 157-187). Washington, DC: U.S. Global Change Research Program. <http://dx.doi.org/10.7930/J0R49NQX>

Turgeon, P., Michel, P., Levallois, P., Archambault, M., & Ravel, A. (2011). Fecal Contamination of Recreational Freshwaters: the Effect of Time-Independent Agroenvironmental Factors. *Water Quality, Exposure and Health, 3*(2), 109–118. doi:10.1007/s12403-011-0048-5

Turner, J. W., Good, B., Cole, D., & Lipp, E. K. (2009). Plankton composition and environmental factors contribute to *Vibrio* seasonality. *The ISME Journal*, *3*(9), 1082–1092. <https://doi.org/10.1038/ismej.2009.50>

Uhlmann, S., Galanis, E., Takaro, T., Mak, S., Gustafson, L., Embree, G., Bellack, N., Corbett, K., & Isaac-Renton, J. (2009). Where's the pump? Associating sporadic enteric disease with drinking water using a geographic information system, in British Columbia, Canada, 1996-2005. *Journal of Water and Health*, *7*(4), 692–698. <https://doi.org/10.2166/wh.2009.108>

Uslu, M. O., Jasim, S., Arvai, A., Bewtra, J., & Biswas, N. (2013). A survey of Occurrence and Risk Assessment of Pharmaceutical Substances in the Great Lakes Basin. *Ozone: Science and Engineering, 35*(4), 249-262. doi:10.1080/01919512.2013.793595

Vandersea, M. W., Kibler, S. R., Tester, P. A., Holderied, K., Hondolero, D. E., Powell, K., Baird, S., Doroff, A., Dugan, D., & Litaker, R. W. (2018). Environmental factors influencing the distribution and abundance of *Alexandrium* catenella in Kachemak bay and lower cook inlet, Alaska. *Harmful Algae*, *77*, 81–92. <https://doi.org/10.1016/j.hal.2018.06.008>

Vezzulli, L., Grande, C., Reid, P. C., Helaouet, P., Edwards, M., Hofle, M. G., Brettar, I., Colwell, R. R., Pruzzo, C. (2016). Climate influence on *Vibrio* and associated human diseases during the past half-century in the coastal North Atlantic. *Proceedings of the National Academy of Science of the United States of America, 113*(34), E5062-71. <https://doi.org/10.1073/pnas.1609157113>

Vezzulli, L., Pruzzo, C., Huq, A., & Colwell, R. R. (2010). Environmental reservoirs of *Vibrio* cholerae and their role in cholera. *Environmental Microbiology Reports*, *2*(1), 27–33. <https://doi.org/10.1111/j.1758-2229.2009.00128.x>

Vincent, L. A., Zhang, X., Brown, R. D., Feng, Y., Mekis, E., Milewska, E. J., Wan, H., Wang, X. L. (2015). Observed Trends in Canada's Climate and Influence of Low-Frequency Variability Modes. *Journal of Climate, 28*(11), 4545–4560. doi:10.1175/JCLI-D-14-00697.1

Vinh, D. C., Mubareka, S., Fatoye, B., Plourde, P., & Orr, P. (2006). *Vibrio* vulnificus Septicemia After Handling Tilapia Species Fish: A Canadian Case Report and Review. *The Canadian Journal of Infectious Diseases & Medical Microbiology = Journal Canadien des Maladies Infectieuses et de la Microbiologie Medicale*, *17*(2), 129–132. <https://doi.org/10.1155/2006/164681>

Visciano, P., Schirone, M., Berti, M., Milandri, A., Tofalo, R., & Suzzi, G. (2016). Marine Biotoxins: Occurrence, Toxicity, Regulatory Limits and Reference Methods. *Frontiers in Microbiology*, *7*, 1051. <https://doi.org/10.3389/fmicb.2016.01051>

Vollaard, A. M., Ali, S., van Asten, H. A., Widjaja, S., Visser, L. G., Surjadi, C., & van Dissel, J. T. (2004). Risk factors for typhoid and paratyphoid fever in Jakarta, Indonesia. *JAMA*, *291*(21), 2607–2615. <https://doi.org/10.1001/jama.291.21.2607>

Wang, J., & Deng, Z. (2016). Modeling and Prediction of Oyster Norovirus Outbreaks along Gulf of Mexico Coast. *Environmental Health Perspectives*, *124*(5), 627–633. <https://doi.org/10.1289/ehp.1509764>

Wang, X., Thompson, D. K., Marshall, G. A., Tymstra, C., Carr, R., & Flannigan, M. D. (2015). Increasing frequency of extreme fire weather in Canada with climate change. *Climatic Change, 130*(4), 573–586. doi:10.1007/s10584-015-1375-5

Waterfront Toronto. (2020). *Corktown Common Park.* Retrieved from <https://waterfrontoronto.ca/nbe/portal/waterfront/Home/waterfronthome/projects/corktown+commo>

Watson, V. (2017). Perception of water among the Inuit community in Iqaluit, Nanvut: An anti-colonialist feminist political ecology [Master's Thesis, York University]. Toronto, ON: York University. Retrieved from <https://yorkspace.library.yorku.ca/xmlui/bitstream/handle/10315/34466/Watson_Victoria_C_2017_Masters.pdf?sequence=2&isAllowed=y>

Wiener, M. J., Jafvert, C. T., & Nies, L. F. (2016). The assessment of water use and reuse through reported data: A US case study. *The Science of the Total Environment*, *539*, 70–77. <https://doi.org/10.1016/j.scitotenv.2015.08.114>

Westra, S., Alexander, L. V., & Zwiers, F. W. (2013). Global Increasing Trends in Annual Maximum Daily Precipitation. *Journal of Climate, 26*(11), 3904–3918. <https://doi.org/10.1175/JCLI-D-12-00502.1>

Whitehead, P. G., Wilby, R. L., Battarbee, R. W., Kernan, M., & Wade, A. J. (2009). A review of the potential impacts of climate change on surface water quality. *Hydrological Sciences Journal, 54*(1), 101–123. <https://doi.org/10.1623/hysj.54.1.101>

Wilson, J., Aramini, J., Clarke, S., Novotny, M., Quist, M., & Keegan, V. (2009). *Retrospective surveillance for drinking water-related illnesses in Canada, 1993-2008*. Novometrix Research Inc. Retrieved from <http://www.ncceh.ca/sites/default/files/DW_Illnesses_Surveillance_Aug_2009.pdf>

World Health Organization. (2013). *Protecting health from climate change: vulnerability and adaptation assessment.* Geneva, Switzerland. Retrieved from <https://apps.who.int/iris/handle/10665/104200>

World Health Organization. (2014). *Constitution of the World Health Organization.* Retrieved from <https://www.who.int/governance/eb/who_constitution_en.pdf>

World Health Organization. (2017). *Climate-resilient water safety plans: managing health risks associated with climate variability and change.* Geneva, Switzerland. Retrieved from <https://apps.who.int/iris/bitstream/handle/10665/258722/9789241512794-eng.pdf?sequence=1&isAllowed=y>

Wotton, M. B., Flannigan, M. D., & Marshall, G. A. (2017). Potential climate change impacts on fire intensity and key wildfire suppression thresholds in Canada. *Environmental Research Letters, 12*(9). doi:10.1088/1748-9326/aa7e6e

Wu, X., Lu, Y., Zhou, S., Chen, L., & Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment International, 86*, 14-23. <https://doi.org/10.1016/j.envint.2015.09.007>

Yusa, A., Berry, P., J Cheng, J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate Change, Drought and Human Health in Canada. *International Journal of Environmental Research and Public Health*, *12*(7), 8359–8412. <https://doi.org/10.3390/ijerph120708359>

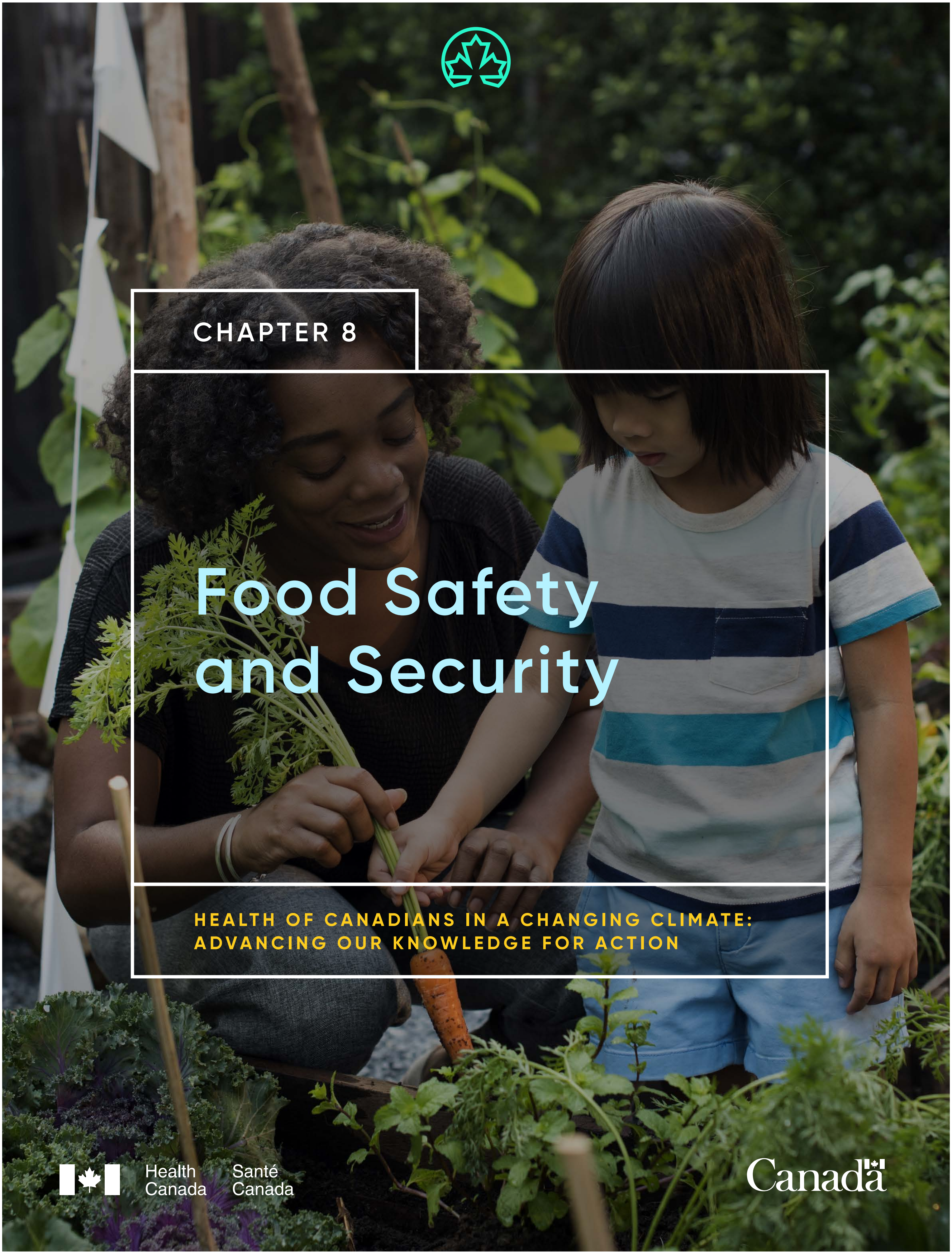
Zamyadi, A., Dorner, S., Sauvé, S., Ellis, D., Bolduc, A., Bastien, C., & Prévost, M. (2013). Species-dependence of cyanobacteria removal efficiency by different drinking water treatment processes. *Water Research*, *47*(8), 2689–2700. <https://doi.org/10.1016/j.watres.2013.02.040>

Zamyadi, A., Romanis, C., Mills, T., Neilan, B., Choo, F., Coral, L. A., Gale, D., Newcombe, G., Crosbie, N., Stuetz, R., & Henderson, R. K. (2019). Diagnosing water treatment critical control points for cyanobacterial removal: Exploring benefits of combined microscopy, next-generation sequencing, and cell integrity methods. *Water Research*, *152*, 96–105. <https://doi.org/10.1016/j.watres.2019.01.002>

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G. & Kharin, V. V. (2019). Changes in Temperature and Precipitation Across Canada. In E. Bush & D. S. Lemmen (Eds.), *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019>

Zimmerman, L. (2015). Phytoplankton. In *Biological Resources*. Retrieved from <https://coast.noaa.gov/data/docs/nerrs/Reserves_ACE_SiteProfile.pdf>

Zubrycki, K., Roy, D., Venema, H. D., & Brooks, D. B. (2011). *Water Security in Canada: Responsibilities of the federal government*. Winnipeg, MB: International Institute for Sustainable Development. Retrieved from <https://www.iisd.org/system/files/publications/water_security_canada.pdf>



CHAPTER 8

Food Safety and Security

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Authors

Sherilee L. Harper, University of Alberta

Rebekka Schnitter, Health Canada

Contributing Authors

Aamir Fazil, Public Health Agency of Canada

Manon Fleury, Public Health Agency of Canada

James Ford, University of Leeds

Nia King, Queen's University

Alexandra Lesnikowski, Concordia University

Deborah McGregor, York University

Jaclyn Paterson, Health Canada

Ben Smith, Public Health Agency of Canada

Hannah Tait Neufeld, University of Waterloo

Acknowledgements

Amreen Babujee, University of Alberta

Katharine Neale, University of Alberta

Alexandra Sawatzky, University of Alberta

Shanaya Singh, Health Canada

Suggested Citation

Harper, S. L., Schnitter, R., Fazil, A., Fleury, M., Ford, J., King, N., Lesnikowski, A., McGregor, D., Paterson, J., Smith, B., & Neufeld, H. T. (2022). Food Security and Food Safety. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

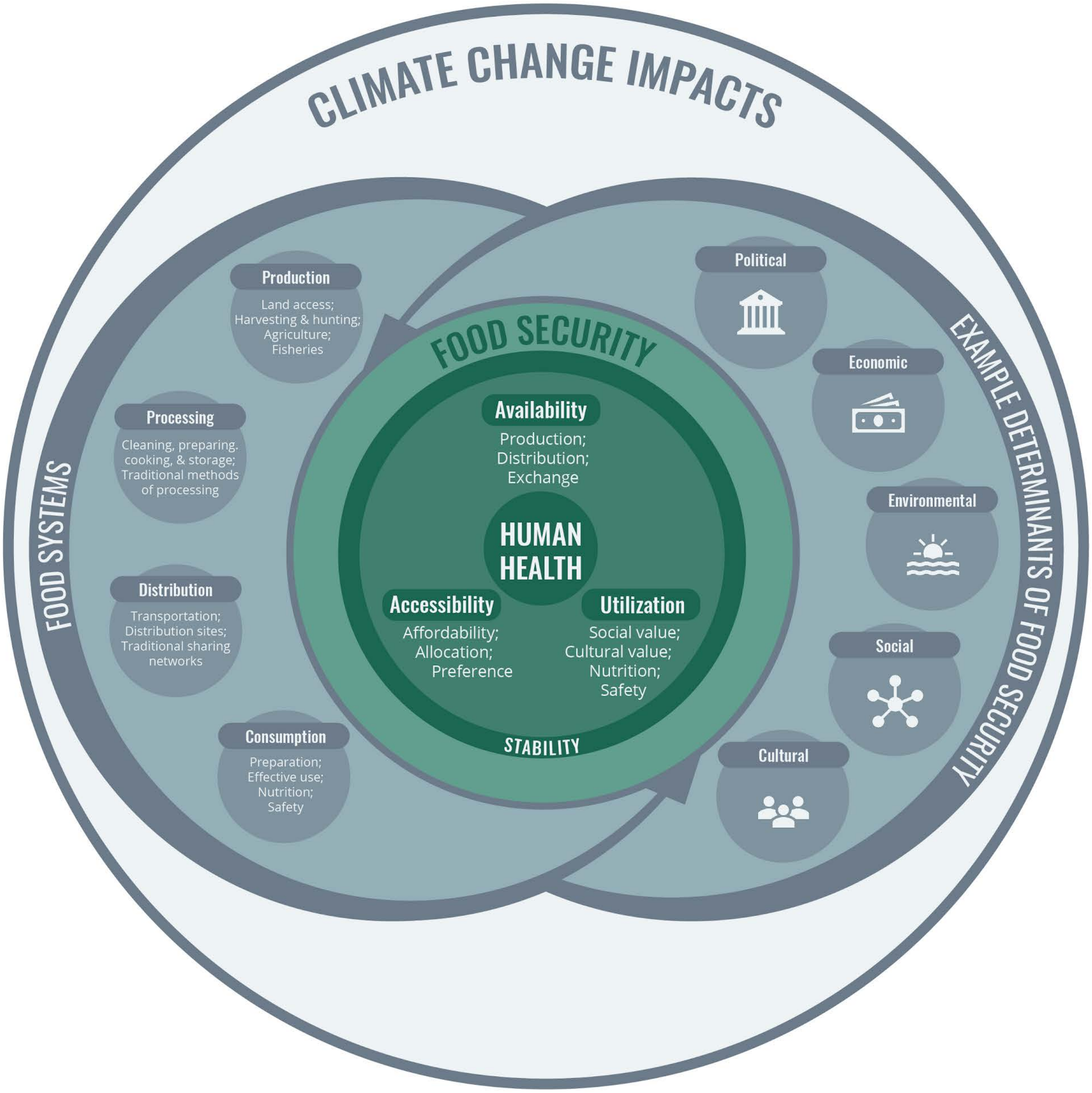
Summary

Changes in climate are affecting food security and food safety in Canada. Climate change is increasing risks of food insecurity through disruptions to food systems, rises in food prices, and negative nutritional effects. Precipitation, temperature, and extreme weather events are projected to increase the introduction of pathogens (viruses, bacteria, and parasites) to food, causing food-borne illness. Chemical contaminants that have harmful health effects may also be introduced into Canada's food systems more frequently through various climate-sensitive environmental exposure pathways. The impacts of climate change on food security and food safety will not be equitably distributed, and Canada's Northern region and Indigenous Peoples will likely experience the most severe effects. Adaptation measures include monitoring of health outcomes related to food safety; conducting vulnerability and adaptation assessments that address climate-related impacts to food security and food safety; utilizing both Western science and Indigenous knowledge; developing adaptation plans within all levels of government and in all regions, particularly in Northern Canada; conducting risk communication and education; and tackling root causes of vulnerability.

Key Messages

- Warming temperatures, changing precipitation patterns, and more frequent and severe extreme weather events will increase risks to key components of food systems in Canada, such as the production, processing, distribution, preparation, and consumption of food.
- Climate change impacts on food systems, rises in food prices, and negative nutritional effects have already negatively influenced food security and food safety, both of which have important implications for human health. Globally, climate change is projected to have negative effects on the nutritional content and overall yield of some agricultural commodities, particularly subsistence crops including grains and legumes. Changes in biodiversity from climate change may also result in nutritional challenges, for example, from declining availability of traditional food sources. As a result, climate change is projected to affect the health of Canadians by affecting the amount of nutrients they obtain from their food, as well as the stability of food availability, accessibility, and use.
- Climate change is projected to exacerbate existing food safety challenges in Canada and create new ones. Precipitation, temperature, and extreme weather events affect the introduction of pathogens to foods and their ability to grow to levels that cause food-borne illness. Climate change may also affect human behaviours, such as food handling and consumption practices (such as barbeques, picnics).

- Climate change impacts on food security and food safety vary greatly across Canada, reflecting underlying societal, cultural, environmental, and economic factors and inequities. While it is difficult to estimate the precise magnitude of current and future climate change impacts on food insecurity, these impacts are expected to exacerbate health-related risks for Canadians.
- Climate change may increase the exposure of Canadians to chemical contaminants, such as persistent organic pollutants and heavy metals that can have harmful health effects. These chemical contaminants can be introduced into Canada's food systems through various environmental exposure pathways and then accumulate in plant and animal tissues that are consumed. Many of these chemicals can exacerbate existing health risks for Canadians and create new ones, which underlines the importance of Canada's surveillance programs.
- Climate change is affecting Indigenous food systems and contributing to declining availability, accessibility, and quality of traditionally harvested foods, which play an important role in community and individual health and well-being. Climate change has already affected nutrition, mental health outcomes, and food sovereignty. Indigenous food security must be understood within the context of historical and ongoing colonialism. Indigenous self-determination and the gendered and intergenerational transmission of Indigenous knowledge are central to Indigenous food security and sovereignty and needed adaptation actions.
- Adaptation actions that increase food system resilience, including collaboration of health authorities among a broad range of food system actors and sectors, are necessary to minimize risks to human health from climate change. Efforts are underway across Canada to respond to and prepare for the impacts of climate change on food systems in order to protect and support health and well-being. Further adaptations will reduce future risks.



Conceptual framework outlining the relationships among food security, food safety, and health in a changing climate.

Overview of Climate Change Impacts on Food Safety and Security

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Food security	• Increased disruptions to food systems affecting the stability of food availability, accessibility, and use • Climate-related reductions in biological diversity in sensitive ecological environments, leading to less sustainable land and aquatic ecosystems • Modification of nutrient content and overall production of some agricultural commodities • Increased economic pressures on low-income and subsistence food users due to increasing food prices and changing availability of local and traditionally harvested foods	• Impacts on nutrition due to decreased availability of local and traditional foods • Impacts on nutrition due to effects on the amount of nutrients obtained from food • Adverse birth outcomes • Impacts on maternal health • Impacts on child development • Exacerbation of chronic diseases • Impacts on mental health and emotional well-being • Impacts on health services; for example, adults experiencing food insecurity require more health care services and are more likely to become high-cost health care users

HEALTH IMPACT OR HAZARD CATEGORY	CLIMATE-RELATED CAUSES	POSSIBLE HEALTH EFFECTS
Food safety	• Changing climatic conditions can affect the transportation and deposition of chemical contaminants in food systems • Acute and slow-onset climate change impacts (such as changes in precipitation, temperature, and extreme weather events) can alter the occurrence and survival of microbial pathogens in food and result in increased prevalence of food-borne illness • Extended warm weather seasons can increase the risks to Canadians via increased opportunities for food mishandling (such as barbequing, picnics) and changes to food preferences based on food availability (such as extended availability of high-risk food products such as fresh produce), increasing risk of exposure to food-borne illness	• Chemical toxicity at high levels can lead to cancer, cardiovascular disorders, kidney and bone damage, negative immune system effects, developmental, endocrine disruption, reproductive disorders, cognitive, behavioural, and motor impairments; currently the levels of chemical contaminants in retail foods is monitored closely in Canada, which underlines the importance of Canada's surveillance programs in a changing climate • Microbial food-borne illnesses (giardiasis, campylobacteriosis, salmonellosis) lead to diarrhea, vomiting, stomach cramps, low-grade fever, chills, headache, muscle aches, fatigue, weight loss, loss of appetite, severe dehydration, inflammation of the brain, meningitis, liver disease, birth defects, stillbirth, and premature delivery • In severe cases, chemical or microbial food-borne illness can result in death • Impacts on health services, for example, enhanced national and international surveillance and monitoring of food-borne illness

8.1 Introduction

Climate change has widespread implications for food systems globally and in Canada, with important health consequences. These climate change impacts touch all components of food systems, including food production, processing, distribution, preparation, and consumption. Without adaptation, climate change will result in a negative net impact on global food systems (Porter et al., 2014; Smith et al., 2014; Springmann et al., 2016; IPCC, 2019a). For instance, increasing water insecurity, combined with rising crop irrigation demands due to warming temperatures and less rainfall, are projected to result in substantial global net reductions in staple crop yields (Jiménez Cisneros et al., 2014; Porter et al., 2014); decreased fisheries catch (FAO, 2015; Arnell et al., 2016); lower nutrient concentrations in staple foods (FAO, 2015); and increased global food prices (Porter et al., 2014). Such climate change impacts on global food systems have important implications for both *food security* (i.e., stable access to sufficient and nutritious food to meet dietary needs and food preferences for healthy lives) and *food safety* (i.e., access to food that is not contaminated with pathogens or chemical contaminants at levels that could lead to adverse health effects). Thus, these impacts will pose significant challenges to human health, including impacts on nutrition, mental wellness, and food-borne illnesses (Bradbear & Friel, 2013; Bowen & Ebi, 2015; Springmann et al., 2016). These health risks are substantial; globally, food-related mortality attributed to climate change is projected to "far exceed" all other climate-related health effects (WHO, 2014).

In Canada, climate change is already affecting food security and safety, particularly in the North (Berry et al., 2014a; CCA, 2014). Climate change impacts on food and agriculture, as well as health and well-being, are among the top climate change threats that are expected to lead to significant losses, damage, and/or disruptions in Canada over the next 20 years (CCA, 2019). While the impacts of climate change on food systems in Canada will be widespread, they will not be distributed equitably, with some populations, subpopulations, and regions experiencing greater barriers to adaptation and disproportionate impacts. Despite these risks, food issues have received less attention than other health outcomes in climate-health research (Smith et al., 2014; Verner et al., 2016), although research on climate change impacts on food systems and human health in Canada is beginning to increase.

This chapter explores the linkages among climate change, food systems, and human health to understand current risks and how Canadians could be affected in the future. It also examines the adaptation options available for reducing health risks. To this end, this chapter first outlines the conceptual framework used to conduct this analysis. Then, climate change impacts on food systems in the context of human health are described. Within food systems, three elements are assessed: climate change impacts on food security and related health outcomes, with specific attention to nutrition; on microbial food safety (food-borne pathogens); and on chemical food safety (chemical contaminants). The chapter then examines adaptation opportunities to reduce food-related health risks and presents illustrative case studies. The final section of this chapter highlights knowledge gaps and recommendations related to food systems and adaptation. Throughout the chapter, Boxes 8.1 to 8.6 highlight critical cross-cutting concepts and phenomena, as well as presenting case studies that showcase climate change impacts and adaptation.

8.2 Conceptual Framework and Methods

8.2.1 Conceptualizing Climate Change, Food Systems, and Human Health

This chapter is guided by a framework (Schnitter & Berry, 2019) that conceptualizes the breadth and complexity of climate change impacts on food systems and hence on human health (Figure 8.1). The framework describes the dynamic relationship among food systems, primary dimensions and determinants of food security and safety, and human health outcomes in a changing climate.

Within this framework, *food systems* consist of activities and elements spanning multiple sectors related to food production, processing, distribution, preparation, and consumption (Gregory et al., 2005; Ericksen, 2008; Anand et al., 2015; HLPE, 2017). These food system components include non-commercial and commercial production, transportation, washing, cooking, preparation, storage, consumption, and use of food (Ingram, 2009; Friel, 2019) and are often interconnected, with the activities of one component affecting the operations of others.

Food systems underpin the primary dimensions of *food security* by supporting the stability and strength of its pillars: food availability, accessibility, and use (Table 8.1) (Pinstrup-Andersen, 2013; Friel & Ford, 2015; Nelson et al., 2016). Food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). In contrast, *food insecurity* exists whenever any of these pillars are unfulfilled. Influenced by political, economic, social, and environmental factors (Ericksen, 2008), food security can be measured at different spatial and temporal scales (Gregory et al., 2005) and occurs on a spectrum (e.g., food secure, marginally food insecure, moderately food insecure, severely food insecure) (Health Canada, 2020). Food security or insecurity affects health and well-being and, thus, is a public health issue.

Food security cannot exist without *food safety*. The safety of food for human consumption can be compromised at any point in food systems, and the ingestion of contaminated food can result in adverse health effects and, in severe cases, death. Food safety systems are critical for ensuring that the food consumed by Canadians is safe to eat, and that pathogens or contaminants are not present in foods at levels that can cause harm. Two elements of food safety and their relationship to climate change are explored in this chapter: food-borne pathogens and chemical contaminants.

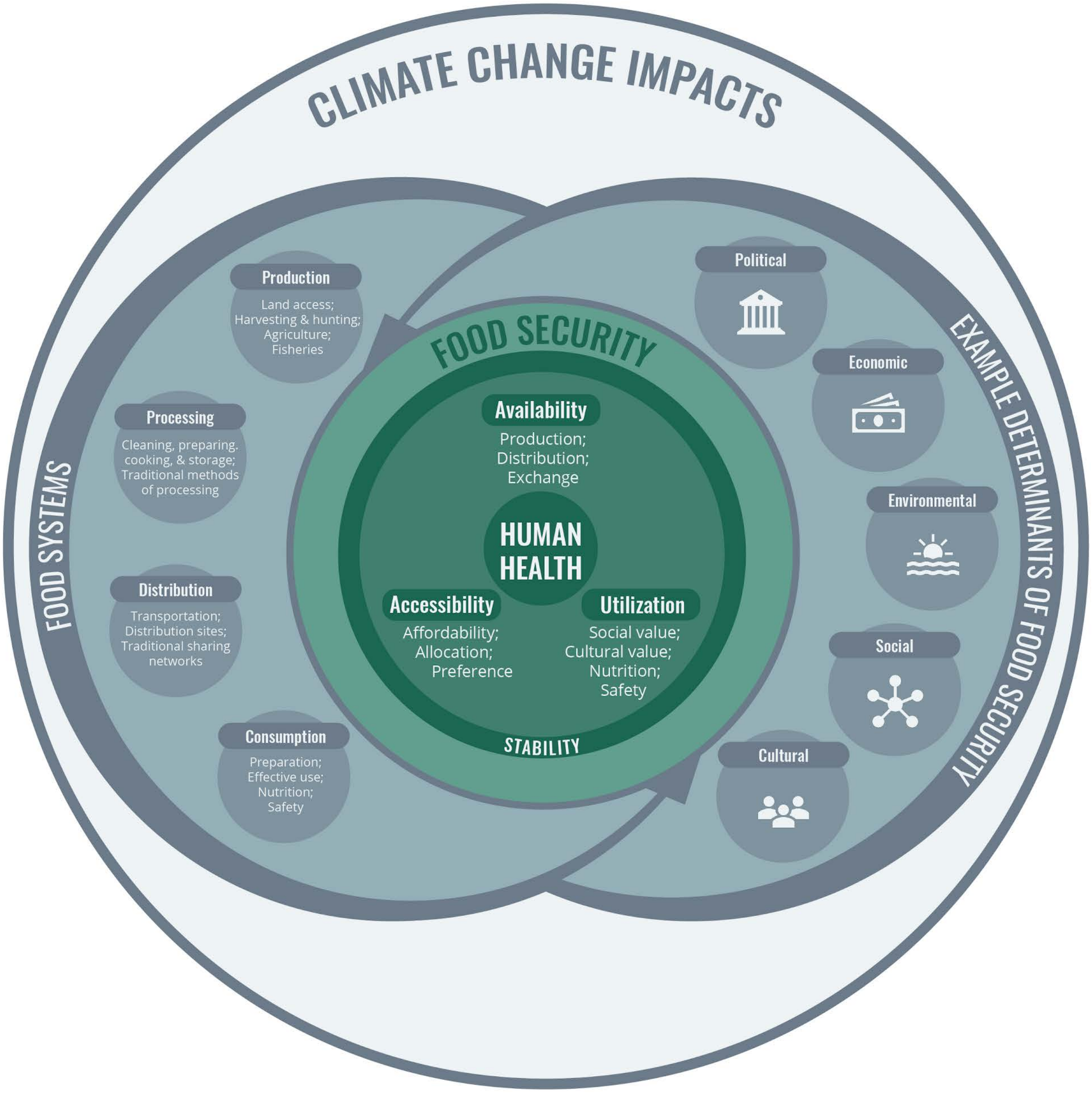


Figure 8.1 Conceptual framework outlining the relationships among food security, food safety, and health in a changing climate.

Table 8.1 Pillars of food security and their elements

FOOD SECURITY PILLARS	ELEMENTS OF PILLARS
Food availability	• Production: Amount and types of food available • Distribution: How food is made available, in what form, when, and to whom • Exchange: How much of the available food is obtained through exchange mechanisms such as food sharing, bartering, trading, purchasing, or loans
Food accessibility	• Affordability: The purchasing power of households or communities relative to the price of food; the cost associated with harvesting, hunting, and fishing of local, traditional, and/or country[1] foods • Allocation: The economic, social, and political mechanisms governing when, where, and how food can be accessed by people • Preference: Social, religious, and/or cultural norms, values, and practices that influence consumer demand for certain types of food
Food use	• Nutritional value: How much of the daily requirements of calories, macronutrients, and micronutrients are provided by the food people consume • Social value: The social, religious, and/or cultural functions and benefits that food provides • Food safety: Microbial or chemical contamination introduced during producing, processing, packaging, distribution, handling, or marketing food
Stability	• Long-term stability of food availability, accessibility, and use

Source: Adapted from Ericksen, 2008

1 Traditional Inuit food, also known as country food, is an integral part of Inuit identity and culture, is a significant source of nutrients, and contributes to individual and community health and well-being. It includes marine animals (e.g., walrus, seals, etc.), caribou, birds, fish, and foraged foods.

8.2.2 Identifying, Assessing, and Synthesizing Evidence

A rigorous, systematic, and flexible approach was used to identify literature and evidence relevant to climate change, food systems, and health. The approach comprised three elements: building from previous assessments; conducting a comprehensive search of peer-reviewed and grey literature; and learning from public consultations and engagement.

This chapter built on international (IPCC, 2018; IPCC 2019a; IPCC, 2019b), national (Lemmen et al., 2008; Warren & Lemmen, 2014), and human health-specific assessments that summarized literature on the impacts of climate change on food-related health (Séguin, 2008; USGCRP, 2016). The chapter draws particularly on two chapters from the health-specific assessments *The Impacts of Climate Change on Water-, Food-, Vector- and Rodent-Borne Diseases* (Charron et al., 2008) and *Food Safety, Nutrition, and Distribution* (Ziska et al., 2016).

Literature published since the previous Canadian National Climate Change and Health Assessment in 2008 (Séguin, 2008) was identified and assessed using two separate literature searches, focusing on climate change impacts on food security and food safety in Canada. Five databases (PubMed, Web of Science, Scopus, Embase via Ovid, and MEDLINE via Ovid) were searched using search strings developed in consultation with a research librarian. The reference lists of all relevant literature were examined to identify articles not captured in the database search. Websites of key government and international agencies (e.g., provincial and territorial government websites, Public Health Agency of Canada, Health Canada, Canadian Food Inspection Agency, Food and Agriculture Organization of the United Nations, World Health Organization, US Centers for Disease Control and Prevention, World Food Programme) were examined to identify relevant grey literature. No language restrictions were placed on either search. Citations identified through these searches went through two levels of screening conducted by two independent reviewers. First, the titles and abstracts were screened for relevance, then, the full texts of articles were screened for relevance. Literature that discussed food security and/or food safety in the context of human health and climate change was included in this assessment. While Canadian research was prioritized, international research with results relevant to the Canadian context was also included.

The existing literature on climate change impacts on Indigenous food security primarily focuses on Inuit and First Nations peoples, with very limited Métis-specific literature (Halseth, 2015; Beaudin-Reimer, 2020). Wherever possible, specific Indigenous Peoples are distinguished in this chapter to reflect the diverse perspectives and experiences among First Nations, Inuit, and Métis peoples and communities. However, some generalizations are made, depending on the number and nature of citations used (e.g., Indigenous Peoples reflect more than one Indigenous group being referenced) and in instances where there may be shared experiences.

8.3 Climate Change Impacts on Food Systems in Canada

Globalization has created a global food system, in which Canada participates by exporting and importing raw and prepared food products to and from other regions of the world (Lake et al., 2012; O'Riordan & Lenton, 2013). Within Canada, regional and local food systems also co-exist and operate within smaller geographic boundaries. For example, Northern Indigenous food systems are often smaller in scale and rely largely on local foods sourced through hunting, trapping, fishing, gathering, and harvesting. Beyond food-generating practices, Indigenous food systems also encompass environmental governance and stewardship and involve the production, innovation, and transfer of Indigenous knowledge to maintain land-based practices (Delormier et al., 2017).

Relationships among food system components and human health in the context of climate change are dynamic and complex, in part due to the bi-directional relationship between climate change and food systems (Porter et al., 2014). While climate affects all components of the food system, food systems, in turn, can be a significant source of greenhouse gas (GHG) emissions and, thus, a driver of climate change (Fanzo et al., 2018; Friel, 2019). It is estimated that 21% to 37% of total global GHG emissions originate from food systems (Mbow et al., 2019).

Climate creates a number of challenges for food systems in Canada (Table 8.2), and these impacts are expected to increase as the climate warms. While Table 8.2 captures many examples, including some specific to Indigenous food systems, there are unique characteristics and challenges associated with various food systems throughout Canada that will mediate the impacts associated with climate change.

Table 8.2 Pathways through which climate change increases risks to food systems

CLIMATE CHANGE RISKS TO KEY FOOD SYSTEM COMPONENTS
Food production
• Increasing temperature extremes and variability, changes in precipitation patterns, and extreme weather events can damage crops, reduce agricultural productivity, and decrease yield (Easterling et al., 2007; Gornall et al., 2010; Butler, 2014b; Campbell et al., 2014; Fanzo et al., 2018; Dodd et al., 2018)
• The Canadian Prairies are projected to experience an increased risk of drought in the summer and fall, which can lead to reduced groundwater quality and quantity, and reduced water supply for irrigation of crops (Sauchyn et al., 2008; Sauchyn et al., 2020)
• Sea level rise can cause inundation of agricultural lands in coastal regions, damaging crops and creating unsuitable conditions for agricultural production. Inundation can also result in saltwater intrusion of aquifers, reducing the quality of irrigation water (Campbell et al., 2014)
• Increasing temperatures and changes in precipitation patterns may create more favourable conditions for pests, invasive species, and plant diseases (Gornall et al., 2010; Butler, 2014b; AAFC, 2015), increasing competition for resources and reducing crop productivity and quality
• Rising temperatures and increased concentrations of atmospheric CO_2 may decrease the effectiveness of some herbicides used for pest control (Porter et al., 2014)
• Increasing ozone pollution, a by-product of fossil fuel combustion, can inhibit photosynthesis, consequently reducing crop quality and productivity (Gornall et al., 2010; Butler, 2014b)
• Temperature extremes can adversely affect livestock health and decrease productivity (Butler, 2014b; Bishop-Williams et al., 2015)
• Extreme weather events may reduce land available for livestock pasture and foraging (AAFC, 2015)
• The distribution and productivity of natural and farmed fish will change as ocean and freshwater temperatures, and ocean acidification, increase (FAO, 2008; Campbell et al., 2014; Porter et al., 2014)
• Rising temperatures may create favourable conditions for aquatic diseases and invasive species (Rahel & Olden, 2008), reducing the quantity and quality of fish, shellfish, and other commercially and traditionally harvested marine animals (Larsen et al., 2014)

CLIMATE CHANGE RISKS TO KEY FOOD SYSTEM COMPONENTS
• Increasing temperatures and changing precipitation patterns are altering the quality and distribution of populations of traditionally harvested species in Canada (e.g., caribou) (CCA, 2014)
• Extreme weather events may facilitate chemical and bacterial contamination of food production sites (e.g., contaminated flood waters inundating agricultural crops) (Ziska et al., 2016)
• Increasing temperatures and changes in precipitation patterns may create favourable conditions for the growth and survival of toxigenic fungi and mycotoxin contamination of agricultural crops (Jaykus et al., 2008; Tirado et al., 2010)
• Climate change may create favorable conditions for pests, increasing the need for pesticides, which can lead to increased pesticide residues in the food supply (Lake et al., 2012)
• Increasing concentrations of atmospheric CO_2 can alter the nutritional content of some agricultural crops, decreasing concentrations of protein, iron, zinc, and other key minerals (Muncke et al., 2014; Porter et al., 2014; Ziska et al., 2016; Myers et al., 2017)
• In Northern Canada, climate change may allow for the emergence of new pathogens, viruses, and parasites that affect wildlife harvested as part of Indigenous traditional and country food systems (CCA, 2014)
• Decreasing ice thickness and coverage and water levels, as well as changing freeze-up and break-up periods, challenge the procurement of local foods for Northern Indigenous communities (Ford, 2008; Laidler et al., 2009; Wesche & Chan, 2010; Harper et al., 2015a; Wesche et al., 2016; Ford et al., 2019
Food processing
• Increasing temperatures and extreme heat events may increase the risk of food spoilage and/or contamination in processing facilities, which have food safety implications (Ziska et al., 2016)
• Traditional food storage, preservation, and preparation practices may be at risk; for example, permafrost thaw may affect the stability and safety of traditional in-ground freezers used by many Northern Indigenous communities (CCA, 2014)
• Reduced or variable availability of potable water may challenge food processing operations (Campbell et al., 2014)
• Extreme weather events (e.g., flooding) may disrupt energy supplies, labour availability, and processing facility infrastructure critical to processing operations (Ziska et al., 2016)

CLIMATE CHANGE RISKS TO KEY FOOD SYSTEM COMPONENTS
• Climate change impacts may affect the availability, quality, and cost of raw materials and inputs in the food production sector, from both international and domestic sources (Edwards et al., 2011; Wong & Schuchard, 2011)
Food distribution
• Temperature extremes, permafrost thaw, changes in precipitation patterns, changes in freeze–thaw cycles, and extreme weather events can cause physical damage and disruption to transportation infrastructure (Palko & Lemmen, 2017)
• Extreme weather events can damage distribution and storage facility infrastructure (e.g., grocery stores, food banks) (Biehl et al., 2018) and disrupt energy supplies, labour availability, and technological infrastructure critical for food distribution (Ziska et al., 2016; Biehl et al., 2018)
Food preparation and consumption
• Increasing temperatures may change food preparation behaviours (e.g., barbeques, picnics), increasing the risk of exposure to food-borne illness (Ziska et al., 2016; Levison et al., 2018)
• Increasing ocean temperature and changes in salinity increase the risk of pathogens in seafood, which is often consumed uncooked (e.g., oysters) (Jaykus et al., 2008; Tirado et al., 2010; Ziska et al., 2016)
Source: Adapted from Schnitter & Berry, 2019

8.4 Climate Change, Food Security, and Health in Canada

8.4.1 Food Security in Canada

The baseline level of food security contributes to the vulnerability of households to the food-related health impacts of climate change. Therefore, it is important to understand the baseline prevalence, distribution, determinants, and magnitude of food security in Canada. Approximately 12.7% of Canadian households experience some level of household food insecurity (Tarasuk & Mitchell, 2020). This prevalence is likely an underestimate, as the survey does not capture those living in First Nations communities (on-reserve), full-time members of the Canadian Forces, individuals in prisons, those living in some remote Northern communities, or individuals who are under-housed or homeless (Jessiman-Perreault & McIntyre, 2017).

Inequities exist with respect to how food security is distributed and experienced across Canada. Such inequities contribute to ongoing health disparities across the country (see Chapter 9: Climate Change and Health Equity). Household food insecurity is most prevalent in the territories and the Maritime provinces (Figure 8.2), and urban households experience food insecurity to a slightly greater degree (13%) than rural households (11%) (Tarasuk et al., 2016; Tarasuk & Mitchell, 2020). Household food insecurity is more common in households with children and those with lone parents, with lone female-headed households being most vulnerable (Tarasuk & Mitchell, 2020). The likelihood of severe food insecurity increases with decreasing household income (Statistics Canada, 2012). In 2017–2018, approximately 60% of Canadian households whose primary income source was social assistance reported experiencing food insecurity (Tarasuk & Mitchell, 2020). Household food insecurity is significantly higher among households where the respondent identified as Indigenous (28.2%) or Black (28.9%) (Tarasuk & Mitchell, 2020). Unemployment, lower education (less than a high school diploma), recent immigration (within five years), and self-identification as 2SLGBTQQIA+ (two-spirit, lesbian, gay, bisexual, transgender, queer, questioning, intersex and asexual) also increase the risk of household food insecurity (PHAC, 2018).

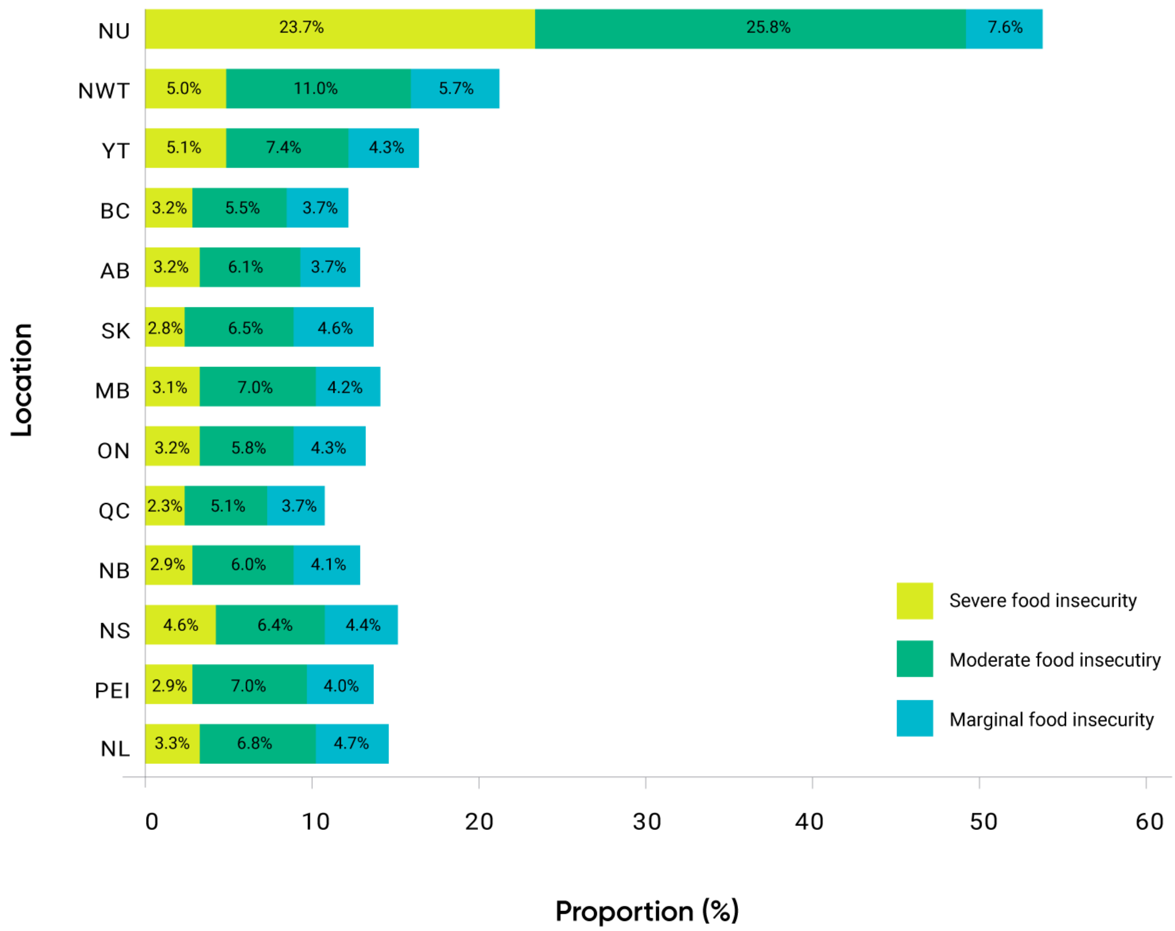


Figure 8.2 Baseline household food insecurity status in Canada by province and territory, which can underpin vulnerability to food-related climate change impacts on health. Source: Adapted from Tarasuk & Mitchell, 2020; data from Statistics Canada, 2018.

Indigenous households, in remote and Northern communities in particular, are often significantly challenged by food insecurity, which is often rooted in ongoing colonial legacies (Box 8.1). Indeed, the prevalence of food insecurity is 3.7 times higher among Inuit adults, 2.7 times higher among First Nations adults (living off reserve), and 2.2 times higher among Métis adults than among non-Indigenous adults (PHAC, 2018) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). On-reserve data indicates that just over half (50.8%) of First Nations adults live in food insecure households, and 43.2% of households with children were classified as food insecure (FNIGC, 2018). With over 68% of households experiencing some level of food insecurity (Rosol et al., 2011; Huet et al., 2012; Fillion et al., 2014), Inuit living in Nunavut have a higher prevalence of food insecurity than any other Indigenous Peoples living in a high-income country (CCA, 2014).

Box 8.1 Food colonization increases climate change vulnerability for Indigenous Peoples

Indigenous food systems are particularly vulnerable to climate change. The existing higher prevalence of food insecurity for many Indigenous Peoples contributes to climate change vulnerability, which is often rooted in ongoing colonial legacies. Indeed, Indigenous Peoples in Canada score far worse on virtually every health indicator than the general public, a situation that has been directly attributed to historical and ongoing processes of colonization (Delormier et al., 2017; Greenwood et al., 2018). Food colonization is a unique food security concern for Indigenous Peoples (Cidro et al., 2018) and has played a leading role in the disruption and undermining of Indigenous food systems (Morrison, 2011; Whyte, 2016).

Colonization has resulted in the widespread loss of connection and access to the lands that supported Indigenous food systems (e.g., through hunting, gathering, fishing, cultivation, and trading) (Desmarais & Wittman, 2014). Colonization and the resulting disruption of Indigenous food systems were by and large intentional, paving the way for an imposed food system that has contributed to the health disparities experienced by Indigenous Peoples in Canada, including higher rates of food insecurity and chronic diseases (Desmarais & Wittman, 2014; Grey & Patel, 2015). In the Indigenous food security movement, underlying structures of this ongoing colonialism are identified as the most critical determinant of poor health outcomes (Martens et al., 2016). The decrease in consumption of healthy land-based foods, such as wild meats, fish, plants, and berries, due to environmental displacement, dispossession, restrictive policies, and cultural change, is a direct result of this process (Rudolph & McLachlan, 2013; Delormier et al., 2017). Food insecurity, primarily with respect to traditional foods, has resulted in loss of Indigenous knowledge and, in turn, has affected the nutritional, emotional, and spiritual health of Indigenous Peoples in Canada.

Studies have shown that Indigenous food systems are central to Indigenous health and well-being (Desmarais & Wittman, 2014) and that increased intake of traditional foods improves Indigenous Peoples' diet quality and health (Johnson-Down & Egeland, 2010; Gagné et al., 2012; Batal et al., 2017). Traditional foods contribute to health and well-being because of their frequently higher nutritional value, the sense of identity acquired through their traditional harvesting, preparation, and sharing practices, and the increased levels of physical activity needed for their procurement (Harper et al., 2015a; Batal et al., 2017). For instance, studies conducted with the Gwich'in people in British Columbia (Kermoal & Altamirano-Jiménez, 2016) and in the Northwest Territories (Parlee et al., 2005) found that berry picking connects women to their spiritual, emotional, mental, and physical selves, in addition to providing significant nutritional value.

Women, youth, and children are identified as particularly vulnerable to the impacts related to loss of access and control over traditional lands that support Indigenous food systems (Lemke & Delormier, 2017; Neufeld et al., 2020). The Indigenous knowledge that has been passed on in support of identity, language, and purpose has been disrupted at an intergenerational level (Delormier et al., 2017; Lemke & Delormier, 2017). Rudolph & McLachlan (2013) maintain that "food insecurity and diet-related disease within Indigenous communities are thus best understood in the context of historical injustice." Taken together, and considering the important role that Indigenous food systems play in Indigenous Peoples' health and well-being, climate change impacts on Indigenous food systems have wide-ranging impacts on Indigenous Peoples, Indigenous knowledge systems, and Indigenous Rights.

While some individual and household characteristics are associated with food insecurity trends (e.g., socio-economic status, household living arrangement, Indigenous identity), it is important to note that population groups are not homogeneous and that food security status is not static. Each individual uniquely experiences a range of intersecting social, political, economic, and environmental factors that contribute to differential food security status over time (Kapilashrami & Hankivsky, 2018), and therefore different and changing vulnerability to climate change impacts on food systems. In some cases, these factors may intersect in ways that compound vulnerability to food insecurity in the context of climate change, creating disproportionate impacts on some population groups. Food insecurity has close linkages to other indicators of material and social disadvantage (Tarasuk & Mitchell, 2020). In many cases, disadvantage can further enhance vulnerability to climate-related health risks by creating difficulties that hinder individuals from taking measures to protect themselves and adapt (see Chapter 9: Climate Change and Health Equity).

8.4.2 Food Security as a Public Health Issue

Food security is an important public health challenge that will be affected, mediated, and modified by climate change. Household food insecurity is associated with many adverse physical and mental health outcomes, including nutritional deficiencies, cardiovascular disease, diabetes, oral health issues, and depression (Table 8.3) (McLeod & Veall, 2006; Muldoon et al., 2013; Tarasuk et al., 2016; Jessiman-Perreault & McIntyre, 2017). Malnutrition due to food insecurity can increase the body's susceptibility to disease, which can, in turn, limit an individual's ability to access and use food. This can further exacerbate food insecurity and malnutrition and establish a vicious cycle of food insecurity and poor health (Aberman & Tirado, 2014). Furthermore, one study in Ontario demonstrated that food insecurity can indirectly stress the health care system, as adults experiencing food insecurity require more health care services and are more likely to become high-cost health care users compared to adults who are food secure (Figure 8.3) (Tarasuk et al., 2015; Li et al., 2016; Tarasuk et al., 2016). Given these implications for the health sector, food security in a changing climate is an important public health challenge.

Table 8.3 Examples of health and social challenges associated with food insecurity that could be exacerbated by climate change

CATEGORY	HEALTH AND SOCIAL CHALLENGES
Maternal health and birth outcomes	• Inadequate nutrition during pregnancy can have negative health impacts on both the mother and child. • Maternal food insecurity is associated with an increased risk of birth defects. • Household food insecurity can adversely affect infant and young child feeding behaviours and limit the sustainability of breastfeeding.
Child development	• Food insecurity can impede both physical and cognitive growth and development in early life. • Food insecurity is associated with poorer general health in children. • Food insecurity is associated with iron deficiency anemia and has been linked to the development of a variety of chronic conditions, including asthma and depression.
Health status and chronic disease	• People who are food insecure are more likely to experience a myriad of chronic conditions, including both mental and physical health challenges. • Food insecure individuals self-report higher levels of poorer health, type 2 diabetes, heart disease, high blood pressure, and food allergies. • Food insecurity poses additional barriers to chronic disease management, which increases the likelihood of adverse outcomes.
Mental health and emotional well-being	• Food insecurity affects social and mental well-being, which can increase the likelihood of depression, distress, and social isolation (see Chapter 4: Mental Health and Well-Being). • Child hunger has been identified as a risk factor for depression and suicidal symptoms in adolescence and early adulthood.
Health care costs	• Food insecurity leads to increased health care costs and increases the probability that adults will become high-cost health care users. • In Ontario, total annual health care costs were 23%, 49%, and 121% higher for adults in marginally, moderately, and severely food insecure households, respectively.

Source: Adapted from Li et al., 2016

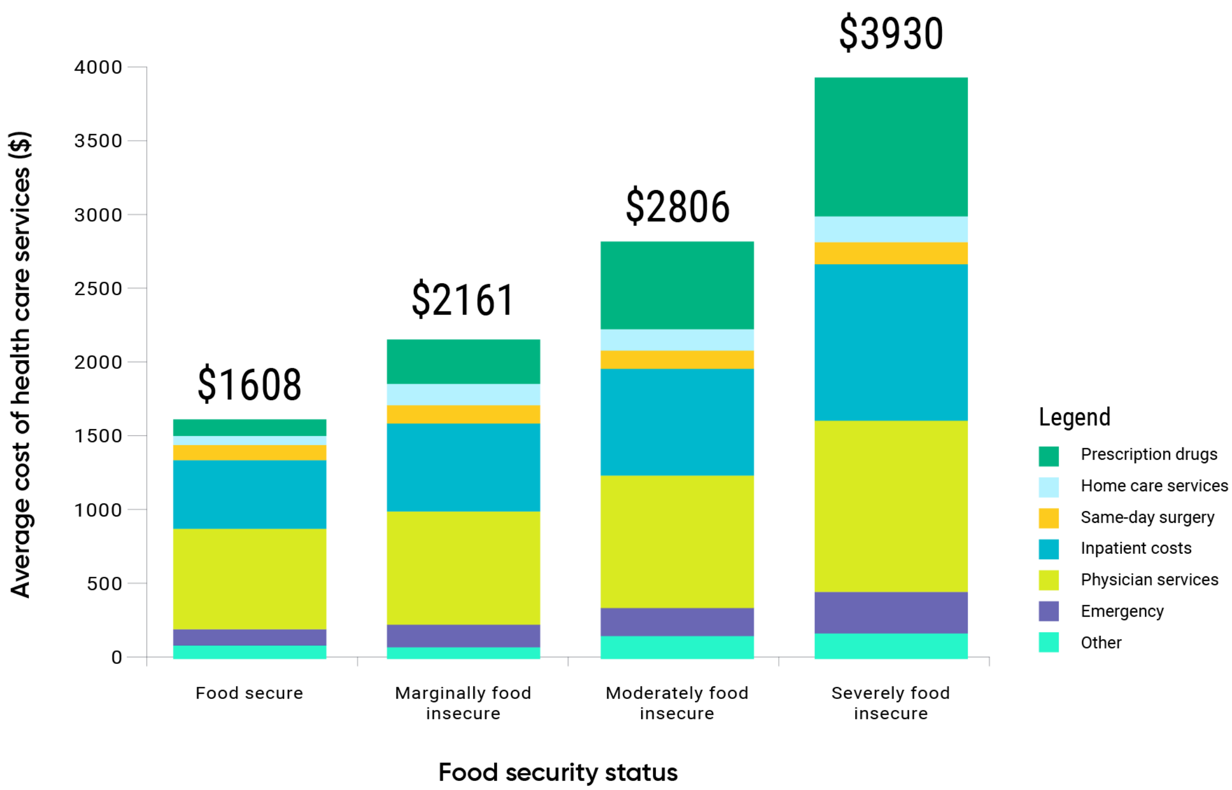


Figure 8.3 Average health care costs incurred over 12 months by Ontario adults (18 to 64 years of age), according to household food insecurity status. Source: Tarasuk et al., 2015.

8.4.3 Climate Change Impacts on the Pillars of Food Security

Climate change poses risks to food systems (see section 8.3 Climate Change Impacts on Food Systems in Canada) through complex interactions that influence the pillars of food security — availability, accessibility, utilization, and stability — which can lead to negative health outcomes among Canadians. Threats to these pillars are discussed below.

8.4.3.1 Climate Change Impacts on Food Availability

There are three primary elements associated with food availability: production, distribution, and exchange of food (Ericksen, 2008). Climate change can disrupt each of these elements (Figure 8.1). For example, crop yields are highly sensitive to changes in temperature and water availability. Air temperatures higher than 30°C are associated with reduced yields for rain-fed crops (Myers et al., 2017). Temperature variability and extremes can also damage crops, especially if these events occur during critical stages of crop development (Easterling et al., 2007; Gornall et al., 2010). In 2012, for example, following a summer of extreme heat and drought, fruit trees in Ontario bloomed earlier than seasonal norms. Temperatures then dropped, causing a frost event that resulted in an 80% loss of apple crops and a 50% loss of strawberry crops in Ontario (ECCC, 2017). It is projected that, in Eastern and Central Canada, there will be an increase in the frequency of winter bud kill and late killing-frost events (Campbell et al., 2014), which will negatively affect agricultural food production.

Canada is also expected to experience an increase in frequency and severity of extreme weather events (Bush & Lemmen, 2019), which can hinder agriculture and livestock production and also disrupt food distribution and exchange. For example, a powerful winter storm in January 2020 caused the City of St. John's, Newfoundland and Labrador, to declare a state of emergency, ordering all businesses, including grocery stores, to close. Grocery stores re-opened after four days; however, high consumer demand, combined with a disrupted regional food supply chain, resulted in many stores selling out of food and turning away customers who had been waiting for hours to purchase basic food staples (Roberts & Cooke, 2020).

Climate change is expected to affect the diversity of available food globally, which has important health implications. Springmann et al. (2016) determined that a total of 529,000 deaths worldwide (78 per million, base year: 2010) could occur between 2010 and 2050 due to climate-related reductions in food availability and changes in fruit, vegetable, and red meat consumption. In this model, climate-related changes in diet (i.e., decreased fruit and vegetable consumption) were projected to result in twice as many deaths as climate-related reductions in caloric intake. For Canada, the study projected that between 25 and 33 deaths per million will occur in 2050 due to climate-related changes in diet and weight, almost all of which are attributable to reductions in fruit and vegetable consumption (Springmann et al., 2016). Should Canada's population grow to a projected 44 million inhabitants (Statistics Canada, 2020), an additional 1100 to 1450 deaths might be expected in 2050. The adoption of GHG mitigation strategies could decrease the number of deaths worldwide due to climate-related changes in food availability in 2050 by 29% to 71%; however, excess deaths would remain even under negative emissions scenarios (Springmann et al., 2016).

8.4.3.2 Climate Change Impacts on Food Accessibility

Food accessibility relates to the affordability, allocation, and socio-cultural preferences for food (Figure 8.1) (Ericksen, 2008), and can be affected by climate change through indirect, but well-known, pathways. Several studies have projected the impact of climate change on world food prices (Easterling et al., 2007; Lake et al., 2012). For example, global models project that, under the Representative Concentration Pathway (RCP) 6.0 emission scenario, cereal prices will increase by 1% to 29% by 2050 (Mbow et al., 2019). Other staples, such as rice and sugar, are projected to increase in price by as much as 80% compared to their reference levels without climate change (Schmidhuber & Tubiello, 2007). Canada's Food Price Report identified climate change as a significant driver of food price increases since 2016. Climate change impacts, including changing weather patterns, droughts, wildfires, reduced access to fresh water, and rising sea levels, are projected to affect Canadian food systems and contribute to a 3% to 5% increase in overall food prices in 2021 (Charlebois et al., 2020; Charlebois et al., 2021).

As food prices rise, households may lack the economic means to purchase adequate, healthy, and preferred foods. Indeed, increased food prices can force consumers, especially those living on low incomes who are already at risk of food insecurity, to purchase lower-cost energy-dense processed foods, which contribute to excess sodium, sugar, and saturated fat intake and may have negative nutrition and health consequences (Lock et al., 2009; Lake et al., 2012). Substituting nutritious foods with inexpensive energy-dense processed foods can lead to an increased incidence of nutrient deficiencies and non-communicable diseases, such as obesity and type 2 diabetes (Gibson et al., 2004; Lake et al., 2012; Marushka et al., 2017; Kenny et al., 2018).

Food accessibility is also a function of physical access to food, which can be affected by climate change and extreme weather events, in particular (Palko & Lemmen, 2017). For instance, high winds, extreme precipitation, flooding, and extreme heat events can disrupt public transportation systems, which many urban dwellers rely on to access retail food distribution sites (Palko & Lemmen, 2017). These effects may be particularly pronounced for those with disabilities and those living in neighbourhoods categorized as "food deserts," where households are primarily relying on a low income and have little or no nearby access to stores or restaurants that provide healthy and affordable foods (Biehl et al., 2018).

8.4.3.3 Climate Change Impacts on Food Utilization

Food security extends beyond the supply and demand dynamics of markets to the use of food (Figure 8.1), including important aspects related to food safety (see section 8.5 Climate Change Impacts on Food Safety in Canada) and the nutritional and socio-cultural value of food (see section 8.4.3.3.1 Climate Change Impacts on Nutrient Availability) (Ericksen, 2008; Myers et al., 2017).

Climate change will influence the nutritional value and nutrient composition of diets through its influence on the pillars of food security, as well as its impact on the conditions under which food is produced, distributed, and individually chosen (The Royal Society, 2009; Lake et al., 2012). As discussed below, such changes have implications for overall human health and nutrition through possible effects on nutrient availability, biodiversity-related impacts on nutrient access, and dietary transitions and substitutions.

8.4.3.3.1 Climate Change Impacts on Nutrient Availability

Globally, increasing carbon dioxide (CO_2) concentrations associated with climate change are projected to alter the nutrient content and density of agricultural and seafood products, which can affect food security (Macdiarmid & Whybrow, 2019). Experiments growing crops (e.g., wheat, rice, legumes) in controlled environments have found that zinc, iron, and protein concentrations are reduced by 3% to 15% when grown in conditions with elevated CO_2 (550 to 690 ppm) (Myers et al., 2014; Myers et al., 2017). Phytate content was also reduced, which could offset some of the zinc and iron losses, as phytates typically reduce micronutrient bioavailability (Myers et al., 2014; Myers et al., 2017). Nevertheless, when these nutrient changes are applied to contemporary diets globally, it is projected that hundreds of millions of people will be placed at risk of zinc, iron, and/or protein deficiencies, and the existing deficiencies of an estimated two billion people will be exacerbated (Myers et al., 2017).

Increasing CO_2 concentrations are also changing the nutritional value of important forage for pollinator species (Myers et al., 2017). Although the net effect of climate change on pollinators remains unclear, studies indicate that a reduction in animal pollination would decrease yields of numerous pollinator-dependent food crops that provide important macro- and micronutrients to humans (Myers et al., 2017). Pollinator declines over the long term could reduce dietary intake of fruits, vegetables, nuts, and seeds in many countries, leading to increased child mortality and birth defects from vitamins A, E, and B6 (folate) deficiencies, and increased risks of heart disease, stroke, type 2 diabetes, and certain cancers (Myers et al., 2017). Varying soils and growing conditions, as well as methods of harvesting, processing, and storing food crops, can also influence nutrient composition. For example, selenium content varies by geography according to the soil mineral content (Lake et al., 2012).

The health impacts of reduced nutrient densities on food security, however, will depend on overall dietary diversity, as well as country-specific enrichment and fortification policies (CFIA, 2014). Similar to impacts in other higher-income countries, the impact will likely be lower in Canada, where many staple foods, including wheat flour, are fortified with essential micronutrients such as iron and folic acid (CFIA, 2014). Nevertheless, health impacts may be more pronounced in specific regions of Canada, such as Northern communities, where challenges accessing a diverse diet including fruits, vegetables, and whole grains already exist. Further research is therefore needed to understand how climate-related changes in nutrient availability will affect food security in Canada.

8.4.3.3.2 Impacts of Climate-Related Biodiversity Loss on Nutrient Access

The impacts of climate change on biodiversity loss will increase risks to food and nutrient access (Rose et al., 2001; Romero-Lankao et al., 2014). Biodiversity reflects the number and variety of living organisms and plays a key role in boosting ecosystem productivity, resilience, and sustainability — in turn, offering many benefits to humans and animals, such as soil formation and retention, pollination, climate regulation, and resources for foods and pharmaceuticals (IPBES, 2018).

While agriculture products provide the majority of dietary energy (i.e., calories), seafood is an important source of nutrients, such as protein, fat, minerals, and vitamins, for many populations, including Canadians (Myers et al., 2017; Marushka et al., 2019). Global estimates suggest that climate-related declining fish harvests (IPCC, 2019a) will leave 845 million people vulnerable to deficiencies in iron, zinc, and vitamin A, and 1.4 billion people vulnerable to deficiencies of vitamin B12 and omega-3 long-chain polyunsaturated fatty acids by 2050 (Golden et al., 2016). Those who are in low-resource settings will be at greater risk of nutrient deficiencies because of their limited access to alternatives, such as other sources of animal protein, supplements, and nutritionally fortified or enriched foods (Myers et al., 2017).

The impacts of biodiversity loss are inequitably distributed among human populations. In Canada, Indigenous Peoples who depend on the land for sustenance are particularly vulnerable to climate-related biodiversity loss (Rose et al., 2001; Richmond & Ross, 2009; Anderson et al., 2018; Kenny et al., 2018; Boulanger-Lapointe et al., 2019). For instance, drawing on observations of declining food species in 36 Indigenous communities spanning Nunavut, the Inuvialuit Settlement Region, and Nunatsiavut, Rosol et al. (2016) explored the likely nutritional impact of possible future diet substitutions. In some cases, substitutions resulted in similar nutrient intake, while other alternatives were of lower nutritional value. For example, if Inuit in the region of Kivalliq replaced 50% of their fish intake with duck (gram-for-gram), vitamin D intake would decrease by 94%, while iron and zinc intake would both increase (Rosol et al., 2016). Similarly, the diets of several First Nations in British Columbia rely on locally harvested seafood, meaning that their nutritional health is highly vulnerable to potential climate-related declines in seafood abundance (Box 8.2) (Rosol et al., 2016; Marushka et al., 2017; Watts et al., 2017; Rapinski et al., 2018). Indigenous Peoples may respond to these changes by purchasing more retail food; however, this response may increase health risks, as shifts from locally harvested to retail food often result in increased consumption of processed foods that are higher in fat, refined sugar, and sodium (Marushka et al., 2019). Furthermore, in many remote Indigenous communities, retail foods are expensive and limited in quantity, quality, and diversity — and do not support cultural continuity, which is a critical determinant of Indigenous Peoples' health — thus complicating effective options for adaptation response (Marushka et al., 2019). Along with the effects on diet quality, these declines in locally harvested food also have detrimental impacts on mental health outcomes, cultural practices, language, self-determination, and social cohesion (Batal et al., 2017; Marushka et al., 2019) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada and Chapter 4: Mental Health and Well-Being).

Box 8.2 Climate change impacts on marine environments among coastal First Nations communities in British Columbia

Locally harvested seafood is a critical component of the diet and health of coastal First Nations within British Columbia. Climate change is projected to exacerbate existing stressors (e.g., colonial fisheries regulations, environmental degradation, socio-economic inequalities) on the access to and quality of this Indigenous food system, which has implications for the health and nutrition of First Nations Peoples in this region (Marushka et al., 2019).

For instance, one study estimated that traditional seafood consumption provided coastal First Nations with the daily Dietary Reference Intake recommendations of omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (74% to 184%) and vitamin B12 (84% to 152%), and substantial levels of niacin (28% to 55%), selenium (29% to 55%), vitamin D (15% to 30%), and protein (14% to 30%). By 2050, climate change projections for these coastal communities are projected to reduce the intake of essential nutrients by 21% under a "strong mitigation" (RCP2.6) scenario and 31% under a "business-as-usual" (RCP8.5) climate change emission scenario (Marushka et al., 2019). The relative impact of these changes varied among sex and age groups, based on their average seafood consumption (Marushka et al., 2019). Analysis suggested that substituting chicken, canned tuna, and bread would not replace the nutrients lost due to climate-related seafood declines, suggesting that market foods cannot easily replace the nutritional value of traditional foods (Marushka et al., 2019).

In an effort to promote food security and sovereignty (Box 8.1), strategies to adapt to climate change adaptation that improve seafood harvest potential and access rights to coastal First Nations communities are critical (Box 8.6). In response to the need for Indigenous self-determined adaptation (Section 8.6), the First Nations Health Authority, under Health Canada's HealthADAPT program, is establishing the WATCH: We All Take Care of the Harvest (Safe and Secure Harvesting of Marine Foods in the Context of Climate Change) program, which will result in the development of local- and Indigenous-relevant adaptation strategies to reduce the impacts of climate change on Indigenous marine food systems and enhance the resilience of First Nations communities in British Columbia (Health Canada, 2019).

8.4.3.3.3 Impacts of Dietary Transitions and Substitutions on Nutrient Use

Climate change can exacerbate existing and emerging nutritional stresses, including the current nutrition transition affecting populations in and outside of Canada. The nutrition transition, which is linked to globalization and urbanization, is a shift from traditional diets toward foods higher in calories, fats, and sugars, accompanied by a rise in sedentary lifestyles (Wheeler & Von Braun, 2013; Breewood, 2018). A diet high in energy-dense processed foods rich in calories, salt, sugar, and saturated fat, and low in whole grains, nuts, seeds, legumes, fruits, and vegetables, is a leading risk factor for death and disability in Canada (IHME, 2016; Bacon et al., 2019).

Globally, the nutrition transition is contributing to a dual burden of overnutrition (e.g., obesity) and undernutrition, along with increased risks of non-communicable and infectious disease (FAO et al., 2018). Some of these health effects may be more pronounced for specific population subgroups. Monitoring of, and support for, populations that are disproportionately affected is needed, particularly for lower-income households that are most affected by rising food prices; those already at nutritional risk, such as women, children, and seniors; and those in remote geographical areas, including many Indigenous Peoples (Ford & Beaumier, 2011; Lake et al., 2012; Bunce et al., 2016; Collings et al., 2016). More research is also needed on the nature, extent, and magnitude of climate change impacts on the nutrition transition.

8.4.3.4 Climate Change Impacts on Food Stability

Longer-term food security requires that food be available, accessible, and used by people in a sustained and stable manner over time (FAO, 2008). Climate change can decrease the stability of food systems, which has a direct impact on all pillars of food security (Figure 8.1). For example, climate change increases the spatial and temporal variability in food production patterns, which affects food availability. Food prices may also fluctuate to a greater degree, which will have implications for accessibility. Many knowledge gaps exist in terms of how climate change will influence the volatility and stability of global food systems and food security, especially with respect to food access and use (Myers et al., 2017).

8.5 Climate Change Impacts on Food Safety in Canada

8.5.1 Climate Change, Food Safety, and Food-Borne Pathogens

Food safety can be compromised at any point along food system pathways (Figure 8.1). Given the estimated four million cases of food-borne illness per year, microbial food safety is an important public health concern in Canada (Thomas et al., 2013). Food-borne illnesses are acquired through the ingestion of contaminated food, and symptoms can range from diarrhea and vomiting to more severe illness (e.g., Guillain-Barré syndrome, hemolytic uremic syndrome) and death. In Canada, five pathogens (norovirus, *Clostridium perfringens*, *Campylobacter* spp., *Salmonella* spp., and *Bacillus cereus*) account for over 90% of food-borne illnesses for which the causative agent is known (Table 8.5) (Thomas et al., 2013). At least four of these pathogens are known to be climate sensitive (Kovats et al., 2004; Fleury et al., 2006; Lake et al., 2009; Valcour et al., 2016; Wu et al., 2016; Lake, 2017; Park et al., 2018).

Indeed, in many cases, climatic conditions are directly linked to food-borne illness, as pathogen occurrence in foods is affected in the short and long term by climate variables, including temperature, precipitation, extreme weather events, and ocean warming and acidification (Semenza et al., 2012a; Liu et al., 2013; Hellberg & Chu, 2015; Lake, 2017; Lake & Barker, 2018). Increasing temperature and extreme weather events rank in the top three of 19 economic, environmental, and social factors influencing food safety in Canada (Charlebois & Summan, 2015). The precise magnitude of climate change impacts on the burden of food-borne disease in Canada is uncertain, due to a paucity of research; however, given that many food-borne pathogens are climate sensitive (Lake et al., 2009; Tirado et al., 2010; Semenza et al., 2012a; Semenza et al., 2012b; Liu et al., 2013; Hellberg & Chu, 2015; Wu et al., 2016; Lake, 2017; Lake & Barker, 2018), the overall food-borne disease burden both current and emerging (previously rare) pathogens is expected to increase. For instance, mathematical models suggest that climate change will increase the burden of specific pathogens in food in Canada (e.g., *V. parahaemolyticus* in oysters) (Smith et al., 2015) (Box 8.4).

Table 8.4 Climate change impacts on the occurrence of food-borne pathogens and the current annual cases per 100,000 in Canada

PATHOGEN	SYMPTOMS[a]	ANNUAL CASES PER 100,000 (2006)[b]	CLIMATE INFLUENCE ON PATHOGEN OCCURRENCE[c]
Norovirus	Nausea, vomiting, diarrhea, stomach cramps, low-grade fever, chills, headache, muscle aches, fatigue	3,223.79	Decreased air temperature, extreme weather events (e.g., heavy precipitation, flooding)
Clostridium perfringens	Diarrhea, pain and cramps, stomach bloating, increased gas, nausea, weight loss, loss of appetite, muscle aches, fatigue. In rare cases, severe dehydration, hospitalization, death	544.50	Uncertain, but might thrive in drought conditions
Campylobacter spp.	Fever, nausea, vomiting, stomach pain, diarrhea. In rare cases, hospitalization, long-lasting health effects, death	447.23	Changes in the timing or length of seasons, increased air temperature, precipitation, flooding
Salmonella spp., non-typhoidal	Chills, fever, nausea, diarrhea, vomiting, stomach cramps, headache. In rare cases, hospitalization, long-lasting health effects, death	269.26	Changes in the timing or length of seasons, extreme weather events, increased air temperature
Bacillus cereus	Diarrhea, vomiting. In rare cases, hospitalization, long-lasting health effects, death	111.60	Changes in the timing or length of seasons, drought
Verotoxigenic *Escherichia coli* non-O157	Diarrhea. In rare cases, hospitalization, long-lasting health effects, death	63.15	Changes in the timing or length of seasons, extreme weather events, increased air temperature

PATHOGEN	SYMPTOMS[a]	ANNUAL CASES PER 100,000 (2006)[b]	CLIMATE INFLUENCE ON PATHOGEN OCCURRENCE[c]
Verotoxigenic *Escherichia coli* O157	Diarrhea. In rare cases, hospitalization, long-lasting health effects, death	39.47	Changes in the timing or length of seasons, extreme weather events, increased air temperature
Toxoplasma gondii	Minimal to mild illness with fever. In rare cases, inflammation of the brain, infection of other organs, birth defects	28.10	Extreme weather events, increased air temperature
V. parahaemolyticus	Diarrhea, stomach cramps, nausea, vomiting, fever, headache. In rare cases, liver disease	5.53	Extreme weather events, increased air temperature, increased sea surface temperature
Listeria monocytogenes	Fever, nausea, cramps, diarrhea, vomiting, headache, constipation, muscle aches. In severe cases, stiff neck, confusion, headache, loss of balance, miscarriage, stillbirth, premature delivery, meningitis, death	0.55	Extreme weather events, increased air temperatures, precipitation
Vibrio vulnificus	Diarrhea, stomach cramps, nausea, vomiting, fever, and headache. In rare cases, liver disease	< 0.01	Extreme weather events, increased air temperatures, increased sea surface temperature

a. Government of Canada, 2019.

b. Thomas et al., 2013.

c. Hellberg & Chu, 2015; Yan et al., 2016; Ziska et al., 2016.

Source: Smith & Fazil, 2019

The relationship between climate change and food-borne illness can be estimated using short-term seasonal trends as a proxy. Many studies in temperate regions similar to Canada have linked food-borne contamination and disease incidence with seasonal trends (Semenza et al., 2012a; Semenza et al., 2012c). A review analyzing studies of food-borne illness in temperate countries identified consistent summer peaks for disease caused by *Campylobacter* spp., *Salmonella* spp., verotoxigenic *Escherichia coli* infection, *Cryptosporidium* (bi-modal peak with spring and summer highs), and giardiasis (Lal et al., 2012). In New Brunswick, the incidence of Campylobacter, *E. coli*, *Giardia*, and *Salmonella* infections were greater in the spring and/or summer months (Valcour et al., 2016). In Alberta and Newfoundland and Labrador, ambient air temperatures were positively associated with *Campylobacter* spp., pathogenic *E. coli*, and *Salmonella* spp. infections (Fleury et al., 2006). Non-cholera Vibrio spp. infections have been associated with rising air and water temperatures and prolonged summer seasons (Semenza, et al., 2012a; Semenza et al., 2012c). Recently, it has been proposed that non-cholera Vibrio spp. can act as an indicator of climate change in marine systems due to their climate sensitivity (Baker-Austin et al., 2017).

Risks of climate-related food-borne illness are expected to vary across Canada, due in part to regional and local consumption preferences; for example, risks from seafood-associated pathogens will likely be greater in regions with high seafood consumption (e.g., coastal regions). Inuit are at increased risk of climate-related impacts on food safety, due in part to climate-sensitive traditional food practices, such as the consumption of raw meats, which are sensitive to even slight changes in food storage and transport temperatures (Pardhan-Ali et al., 2012a; King & Furgal, 2014; Harper et al., 2015a; Harper et al., 2015b; Jung & Skinner, 2017; Rapinski et al., 2018; Harper et al., 2019). Furthermore, climate change may introduce new microbial contamination into Northern regions through changes to wildlife ranges (Jenkins et al., 2013), permafrost thaw, and other environmental changes (Harper et al., 2015a). Additional research is needed on climate-related food safety risks that are unique to First Nations, Inuit, and Métis peoples, as well as Northern communities (Hedlund et al., 2014).

8.5.1.1 Food System Pathways Through Which Climate Change Affects Food Safety

Climate change affects the growth, survival, abundance, and range of pathogens throughout food systems, including during food production, processing, distribution, preparation, and consumption (Semenza et al., 2012a; Semenza et al., 2012c). An overview of how climate change can affect microbial food safety at each step of food systems, using *E. coli* in lettuce as an example, is provided in Box 8.3.

Box 8.3 Climate change impacts throughout food systems can increase public health risks: *Escherichia coli* O157 in lettuce as an example of a climate-sensitive food-borne pathogen

E. coli O157 is a zoonotic enteric pathogen that colonizes the gut of domestic livestock, such as cattle, and subsequently is shed in feces. Across North America, this pathogen has been implicated in an increasing number of outbreaks associated with produce, including fruits, leafy vegetables, and sprouts (Rangel et al., 2005; Heiman et al., 2015; Coulombe et al., 2020). Lettuce is the most common produce commodity associated with *E. coli* O157 outbreaks (Heiman et al., 2015).

Figure 8.4 presents a conceptual model of how climate change can increase lettuce contamination, thus creating public health risks. Lettuce can be exposed to *E. coli* through the transfer of contaminated feces or manure through air, groundwater, soil, and surface water reservoirs. Climate and weather variables, such as the timing and intensity of precipitation and temperature changes, can affect the level and prevalence of *E. coli* O157 throughout the production period through to harvest (Table 8.6). This, along with human handling and consumption practices, has a direct impact on the public health burden of infections with *E. coli* O157.

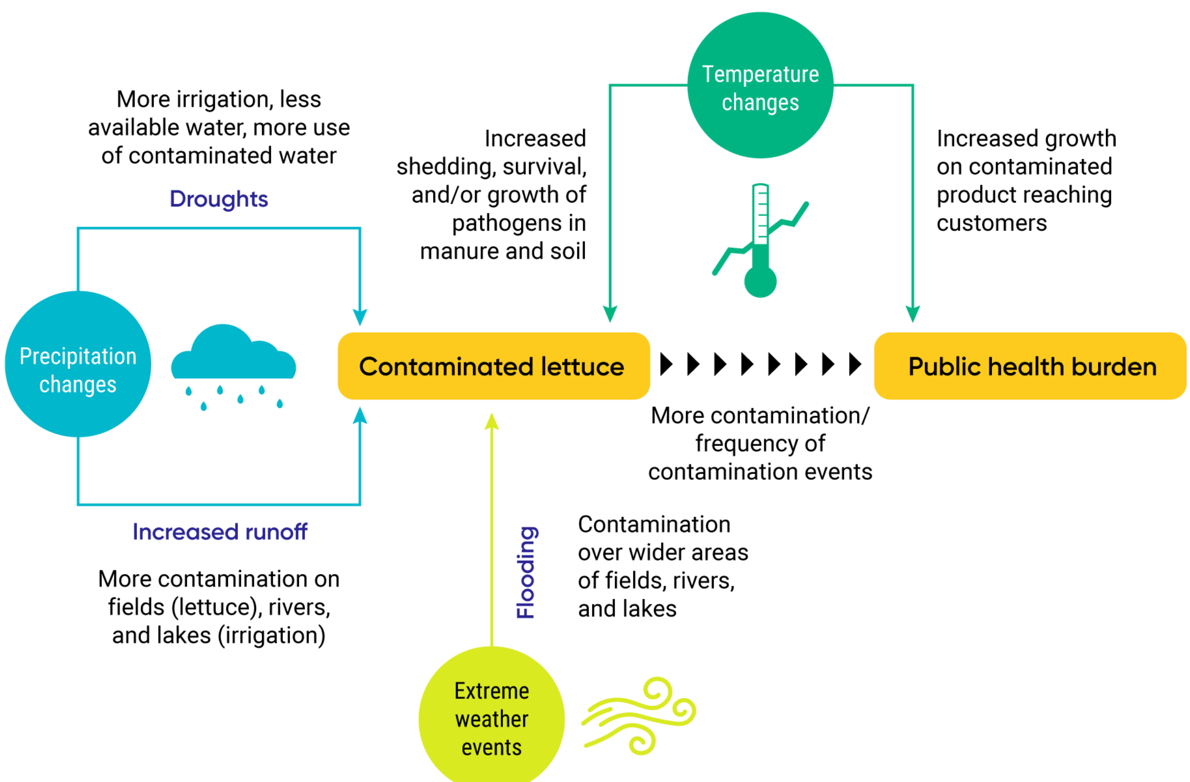


Figure 8.4 Climate-related contamination pathways of lettuce grown in Canada from pathogens shed from livestock.

Table 8.5 Selected components of lettuce contamination pathways that are affected by climate change

DRIVERS OF RISK	AIR TEMPERATURE	SURFACE WATER TEMPERATURE	PRECIPITATION	RELATIVE HUMIDITY (RH)
Shedding of pathogens by livestock	Conflicting evidence that shedding rates and amounts are influenced by air temperature and heat stress	Not applicable	Not applicable	Not applicable
Pathogen persistence in feces and manure	Growth and death rates are influenced by temperature	Not applicable	Heavy rain can leach or wash pathogens from feces and manure into the environment, including soil that might be used to grow lettuce	Persistence and growth are favoured by high RH
Pathogen occurrence and persistence in soil	Growth and death rates are influenced by temperature	Not applicable	Longer elapsed time between manure application and rain is associated with less leaching; heavy rain can leach or wash pathogens from soil into the environment; amount of rainfall dictates frequency of irrigation with potentially contaminated water that is applied to lettuce; precipitation can result in wet deposition of airborne pathogens	Persistence and growth are favoured by high RH
Pathogen occurrence in groundwater	Not applicable	Not applicable	Heavy rain can leach pathogens into groundwater, which then might be used for irrigation, processing, etc.	Not applicable

DRIVERS OF RISK	AIR TEMPERATURE	SURFACE WATER TEMPERATURE	PRECIPITATION	RELATIVE HUMIDITY (RH)
Pathogen occurrence and persistence in surface water	Higher temperatures can drive more cattle to surface water and increase direct deposition	Persistence in water bodies may be influenced by surface temperature	Increased precipitation favours runoff into water bodies but also dilutes surface water; heavy rainfall can affect turbidity and re-suspend pathogens from sediment in water used for irrigation, processing, etc.	Not applicable
Pathogen occurrence and persistence on plants at harvest	Higher temperatures necessitate more frequent irrigation; growth and death rates are influenced by temperature	Not applicable	Heavy rains favour transmission of pathogens from soil to lettuce through splashing or flooding; irrigation soon after heavy rainfall events is more likely to be affected by contaminated runoff; droughts increase irrigation needs; precipitation can result in wet deposition of airborne pathogens on lettuce	Persistence and growth are favoured by high RH
Pathogen occurrence at processing	Not applicable	Increased surface water temperature can encourage pathogen growth in water used for food processing, if improperly treated	Rainfall can contaminate water used for lettuce processing if inadequately treated	Not applicable

DRIVERS OF RISK	AIR TEMPERATURE	SURFACE WATER TEMPERATURE	PRECIPITATION	RELATIVE HUMIDITY (RH)
Pathogen persistence from processing through consumer storage	Growth rates are influenced by temperature; increased air temperatures can affect safe storage temperatures, thus encouraging pathogen growth	Not applicable	Extreme events can cause power outages, resulting in deficiencies in cold-chain management, and encourage pathogen growth	Not applicable
Consumer handling and preparation	Longer growing and, thus, longer consumption seasons increase annual exposure to Canadian-grown lettuce	Not applicable	Not applicable	Not applicable

The relationship between climate variables and lettuce contamination is complex; therefore, uncertainty exists about projected health risks due to climate change. For example, flooding and irrigation are two factors that may increase lettuce contamination, yet they are influenced by precipitation in opposite ways: increased rainfall could increase risks of contamination due to flooding or reduce risks due to less irrigation. More detailed analyses that capture the system's complexity in a particular context or location are required to understand how changes in precipitation will ultimately affect public health risks. Such analyses could include mathematical models, which could quantify the relative impacts of each risk driver on public health in the studied location and identify points throughout food systems where climate change adaptation measures could be most effective. By integrating climate change projections, the model could also allow various adaptation options to be tested (Romero-Lankao et al., 2014; ECCC, 2018).

8.5.1.1.1 Climate Change Impacts on Food Safety via Food Production

Food production (e.g., farming, aquaculture) is the stage of food systems where pathogens are most likely to be introduced and propagated through to food products. Climate change will create both challenges and opportunities for Canadian food production (Warren & Lemmen, 2014) and, therefore, may increase risks to food safety. For example, growing seasons may be extended and suitable land for agriculture may expand northward as temperatures rise (Schmidhuber & Tubiello, 2007; Gornall et al., 2010; Butler, 2014a; Warren & Lemmen, 2014; AAFC, 2015). At the same time, however, as climate conditions warm, pathogens can be introduced and become established in these new production regions via increased food production activity, range expansion of wildlife and insect vectors, and improved pathogen growth conditions (Séguin, 2008; Smith & Fazil, 2019).

Climate change can affect the release of pathogens from livestock into the environment (Smith & Fazil, 2019). Some livestock animals are known, or suspected to, carry and shed greater numbers of enteric pathogens during periods of elevated air temperatures (Venegas-Vargas et al., 2016). Increased temperatures expected with climate change may result in increased pathogen shedding (Keen et al., 2003; Pangloli et al., 2008), thus affecting pathogen abundance in the surrounding environment, crops, and, consequently, food. Increased temperature stress or alterations in livestock housing conditions (e.g., indoor versus outdoor environments) as a result of climate change could also drive increased antimicrobial use in food-producing animals, which could increase antimicrobial-resistant food-borne illnesses in humans (WHO, 2017; MacFadden et al., 2018).

Pathogens released into the environment can be transported via precipitation and directly contaminate food sources, such as crops or livestock facilities. The frequency and intensity of precipitation events is expected to increase for many regions in Canada as temperatures rise (Bush & Lemmen, 2019), increasing concerns about contamination. Without intervention, this contamination could work its way through all stages of food systems, ultimately contributing to the burden of food-borne illness. One study in Ontario, for example, found temporal associations between human giardiasis incidence and pathogen presence in manure in livestock reservoirs, river water level and flow rate, and precipitation (Brunn et al., 2019). As the climate continues to change, combinations of drought followed by extreme precipitation could increase these contamination events, as dry, compact soil has an increased runoff potential (Yusa et al., 2015).

Many wildlife and insect vectors, such as rodents, deer, flies, and beetles, contribute to food-borne pathogen transmission and therefore can affect food safety. Climate conditions can directly affect these vectors (Agunos et al., 2014). For example, climatic variables are known to affect fly population density (Goulson et al., 2005; Ngoen-Klan et al., 2011), and flies can be carriers of *Campylobacter* (Hald et al., 2008). In Ontario, a 28% to 30% increase in incidence of illness due to *Campylobacter* in humans is projected by 2050 due to climate-related changes in fly population size and activity (Cousins et al., 2019).

Warming water temperatures have been linked to seafood contamination and incidence of food-borne diseases. For example, modelling studies suggest that risks from *V. parahaemolyticus* in British Columbia could increase by 41% to 45% by the 2060s (Box 8.4) (Smith et al., 2015). In addition to *V. parahaemolyticus*, the abundance of *V. cholerae* detected along Canadian coasts has increased significantly over time (Banerjee et al., 2018). *V. cholerae* is a highly lethal pathogen (causing cholera) previously restricted to tropical regions, but its abundance could increase in Canadian waters with climate change.

Box 8.4 Projected impacts of climate change on *V. parahaemolyticus* in British Columbia oysters

Human exposure to *V. parahaemolyticus*, which occurs primarily through the consumption of raw oysters that contain the bacterium, causes gastroenteritis (Government of Canada, 2019). Approximately 2.33% of *V. parahaemolyticus* strains are pathogenic (FDA, 2005). Several of these pathogenic strains are present in seawater at and above 15°C and are known to concentrate in oysters that ingest the bacteria as they filter food from the water (Cabello et al., 2005; Konrad et al., 2017). Water temperature is the key environmental variable to which *V. parahaemolyticus* is sensitive (Young et al., 2015); thus, the prevalence and concentration of the bacteria vary seasonally and are expected to increase in many regions as air and water temperatures rise with climate change (Parveen et al., 2008; Grimes et al., 2009; Julie et al., 2010; Broberg et al., 2011; FAO & WHO, 2011).

A large portion of Canadian oyster production is located on the coast of British Columbia, with many operations in the Strait of Georgia between Vancouver Island and the British Columbia mainland (Comeau & Suttle, 2007). Despite careful harvesting and processing protocols intended to reduce the risk of contaminated oysters reaching consumers, projected changes in environmental conditions due to climate change in areas where oysters are farmed are likely to increase the presence and concentrations of *V. parahaemolyticus* and, therefore, the risk of human exposure and illness. These effects on oyster farming operations in British Columbia have been estimated via mathematical modelling, which is summarized in Table 8.6 (Smith et al., 2015).

Model results suggest that public health impacts from *V. parahaemolyticus* in oysters harvested in British Columbia, calculated in terms of disability-adjusted life-years (DALYs), could increase by 41% to 45% by the 2060s (Smith et al., 2015). In 2006, the burden of food-borne illness attributed to *V. parahaemolyticus* was 5.53 cases per 100,000 Canadians. The majority of these cases were assumed to be attributable to undercooked or raw shellfish; thus, if the projected relative increase in the burden of disease from *V. parahaemolyticus* in oysters applies similarly to other shellfish, then the public health burden could increase to eight cases per 100,000 Canadians in 40 years. Box 8.5 discusses adaptation options to reduce health risks from *V. parahaemolyticus*. Further development of models of *V. parahaemolyticus* and seafood risk may increase knowledge of the risks from climate change and support seasonal prediction capabilities and other health sector responses.

Table 8.6 Modelling the projected health risks of climate change impacts on *V. parahaemolyticus* in oysters

MODEL ELEMENT	DESCRIPTION
Location	• Chrome Island in the Strait of Georgia, British Columbia, Canada
Season	• Harvest spread equally among all months of the year
Pathogen	• *V. parahaemolyticus*, 2.33% of which are pathogenic (FDA, 2005)
Oyster species	• Farmed Pacific oyster, *Crassostrea gigas*
Environmental parameters affecting growth	• Water temperature pre-harvest, air temperature at harvest (oysters held at ambient air temperature two to 11 hours post-harvest), and temperature during refrigeration affect levels of V. parahaemolyticus
Climate change factors	• Increase of mean harvest water temperature by 0.024°C per year • Increase of daily maximum air temperature by 0.04°C or 0.08°C per year
Human exposure	• Dose–response model used with mass of oysters consumed per serving and number of servings per year
Health outcomes	• Rate of infection with gastrointestinal illness and DALYs attributed to *V. parahaemolyticus* in oysters
Results	• DALYs associated with *V. parahaemolyticus* in oysters harvested in British Columbia are estimated to increase by 41% to 45% by the 2060s • This would correspond to an increase to eight cases per 100,000 Canadians from *V. parahaemolyticus* in all shellfish by the 2060s

Source: Adapted from Smith et al., 2015

8.5.1.1.2 Climate Change Impacts on Food Safety via Food Processing and Distribution

Climate variables also affect the occurrence, growth, and survival of pathogens throughout food processing and distribution. Any pre-existing contamination can proliferate if food is mishandled during these steps (e.g., inappropriate food storage temperature, cross-contamination), and additional contamination can be introduced through, for example, the use of contaminated water during processing (see Chapter 7: Water Quality, Quantity, and Security). Extreme weather events associated with climate change, such as flooding, high winds, or precipitation can result in power outages that disrupt temperature controls (e.g., refrigeration), creating opportunities for pathogen growth and resulting in impacts on food safety and food-borne illnesses.

Air temperature is a key food safety risk during food processing and distribution. The prevalence of poultry contaminated with *Campylobacter* in Canadian processing and retail environments has been positively correlated with air temperatures (Smith & Fazil, 2019). Humidity and precipitation also affect the occurrence of pathogens throughout processing and distribution. For example, some micro-organisms, such as fungi, can produce mycotoxins that cause adverse human health effects, and these micro-organisms can proliferate under certain temperature and humidity conditions during the processing of corn and cereal grain products (Duarte et al., 2010). In Canada, warmer and wetter conditions due to climate change could encourage fungi growth and mycotoxin production (Patriarca & Fernández Pinto, 2017).

Nearly 30% of retail food consumed in Canada is imported from other countries (Statistics Canada, 2009); therefore, any climate-related changes to the occurrence or growth of pathogens during food production in other countries, or during food distribution to Canada, could affect the health of Canadians. Cases of food-borne illness caused by pathogens previously exotic or rare to Canada could increase in incidence with climate change (Smith & Fazil, 2019). Canadian food importers, along with federal, provincial, and local public health agencies, should enhance the monitoring of global trends and incidence of food-borne illness to anticipate potential new threats to Canadian food systems. Environmental scanning platforms, such as the Canadian Food Safety Information Network, may assist with such monitoring, as they include tools to identify local or global food safety issues (CFIA, 2018). Additionally, international initiatives, such as the European Food Safety Authority's Climate Change and Emerging Risks for Food Safety project, which lists climate-related emerging risks in European food systems (EFSA et al., 2020), may be helpful in informing and monitoring existing and emerging food safety risks relevant to Canada. Given the interconnected nature of the global food system, and the complex effects climate change has on food systems, monitoring may become increasingly challenging and may need to expand in order to appropriately capture the diverse impacts of climate change on food safety in Canada.

8.5.1.1.3 Climate Change Impacts on Food Safety via Food Preparation and Consumption

Climate change impacts on food-borne illnesses at the preparation and consumption stages fall into three categories: climate-related behavioural changes by individuals that increase pathogen exposure via food; increased pathogen survival and growth on foods during transport or storage; and potential indirect climate-related changes to human susceptibility and/or exposure to food-borne illness.

Human behaviour, such as food mishandling events, can lead to cross-contamination or undercooking of food products, thus increasing the risk of food-borne illness. Seasonal increases in food mishandling by consumers are attributable to higher-risk cooking methods (e.g., barbeque used in the summer may increase risk of cross-contamination if the same utensils are used for raw and cooked meats) and consumption patterns (e.g., picnics in warm temperatures where foods are less likely to be stored at safe temperatures) (Ravel et al., 2010; Liu et al., 2013; Milazzo et al., 2017). In Canada, the contamination of meat products with *Salmonella* spp. does not increase in the summer season, compared to the rest of the year (Smith & Fazil, 2019); however, human cases of illness caused by *Salmonella* do increase in the summer (Fleury et al., 2006; Ravel et al., 2010; Valcour et al., 2016), suggesting that behavioural factors and/or susceptibility could drive the seasonality of illness rates (Ravel et al., 2010). Climate change could also influence food preferences and consumption patterns, which may have implications for human health. For example, an extended growing season, due to climate change, could provide longer access to fresh produce, which is at increased risk for pathogen contamination due to higher temperatures and changes to precipitation, thus increasing the risk of food-borne illness. In fact, the rate of *E. coli* outbreaks linked to raw produce (e.g., lettuce) has increased over the last several decades (Rangel et al., 2005; Heiman et al., 2015).

Storing foods at cold temperatures at which pathogens cannot grow is one of the main strategies to maintain food safety. Even a 1°C increase in average ambient temperatures, which has already been surpassed in Canada due to climate change (see Chapter 1: Climate Change and Health Linkages), can result in significant food safety concerns (Smith et al., 2015). Furthermore, the projected increase in extreme weather events and resulting power transmission disruptions due to climate change (Warren & Lemmen, 2014) will introduce potential disruptions in the cold chain at the consumer level with subsequent increases in food safety risk. In Northern Canada, safe food storage in ground freezers used by some Indigenous Peoples is threatened by increasing temperatures and permafrost thaw (CCA, 2014).

Finally, other adverse health effects caused or exacerbated by climate change can increase an individual's susceptibility to food-borne illnesses. For example, immunocompromised individuals are at increased risk of an infectious illness, including from food-borne pathogens (Pouillot et al., 2015). Furthermore, malnutrition arising from food insecurity, extreme weather events (e.g., extreme heat events, flooding), and poor air quality can cause adverse health impacts on Canadians, which could compound vulnerability to food-borne illness (Kipp et al., 2019).

8.5.2 Climate Change Impacts on Food Safety via Chemical Contaminants

Food-related chemical hazards occur when chemicals are present in foods at levels that negatively affect human health when consumed (CFIA, 2014). Chemical contaminants include a wide range of compounds, such as persistent organic pollutants (POPs) (e.g., industrial chemicals, pesticides), heavy metals (e.g., arsenic, copper, cadmium, lead, mercury, tin), and polycyclic aromatic hydrocarbons (PAHs). These chemical contaminants are introduced into plants and animals through environmentally mediated pathways, such as atmospheric deposition and uptake from contaminated soil, water, or other organisms. For example, when chemical contaminants are deposited at or near sites of food production or harvesting, such as fish breeding grounds, livestock pastures, or agricultural lands, they can be introduced into food systems via contaminated water or soil (Thomson & Rose, 2011). Levels of chemical contaminants in commercial foods are monitored through regular surveillance activities by Health Canada and the Canadian Food Inspection Agency. Chemical contaminants may be detected in commercial foods; however, concentrations are generally low and not associated with adverse health impacts. Canada's national food chemical safety program has various tools (e.g., monitoring and surveillance programs, guidance on maximum safe concentration levels, and consumption advice) to help ensure exposure to food chemical contaminants is as low as possible.

There is growing evidence that climate change could increase human exposure to chemical contaminants, as climate variables, such as temperature, precipitation, wind, hydrological systems, ice and snow coverage, and extreme weather events can affect the transport, distribution, concentration, persistence, and bioaccumulation of chemical contaminants (Dewailly et al., 2000; Jaykus et al., 2008; Rose et al., 2011; Marvin et al., 2013; CCA, 2014; Manciocco et al., 2014; Government of Canada, 2016; Ziska et al., 2016).

8.5.2.1 Climate Change Impacts on Contaminants Throughout Food Systems

Environmental contaminants are chemicals that accidentally or deliberately enter the environment, often, but not always, as a result of human activities. Some of these contaminants may have been manufactured for industrial use and, because they are very stable, they do not break down easily. If released into the environment, these contaminants may enter the food chain. Other environmental contaminants are naturally occurring chemicals, but industrial activity may increase their mobility or increase the amount available to circulate in the environment, allowing them to enter the food chain at higher levels than would otherwise occur. Levels detected in food sold in Canada are generally low. These contaminants have varying toxicity and health effects (Government of Canada, 2016). For example, food-borne exposure to POPs has been linked to cancer, negative effects on the immune system, and developmental and reproductive problems (Schecter & Gasiewicz, 2003; Pardue et al., 2005; Government of Canada, 2016; Weihe et al., 2016). Exposure to food-borne heavy metals, such as lead and mercury, can affect the nervous system and cause cognitive, behavioural, and motor impairments (ATSDR, 1999; Thomson & Rose, 2011; Boucher et al., 2012; ATSDR, 2020; Dewailly et al., 2000; USEPA, 2021). More than 80% of fish consumption advisories in Canada and the United States are at least partially attributed to methylmercury (Eagles-Smith et al., 2016), which bioaccumulates in aquatic organisms and can cause severe health effects when consumed by humans in sufficiently high quantities or over prolonged periods of time (Alava et al., 2018). Biotoxins in the food system that can cause health risks to Canadians, and that are linked to climate change, are discussed in more detail in Chapter 7: Water Quality, Quantity, and Security.

Multiple factors contribute to the potential risk and severity of illness resulting from chemical contaminant exposure, including an individual's genetic predisposition and other health conditions, the contaminant type and concentration, and the extent of exposure over time (Ziska et al., 2016). Risks are increased in children and seniors, since their organ systems have a reduced ability to process and eliminate contaminants (Lopez & Goldoftas, 2009; Ferguson et al., 2017).

8.5.2.1.1 Climate Change Impacts on Food Safety via Chemical Contamination During Food Production

In Canada, the impact climate change has on food safety via chemical contamination is not well understood, and the extent of increased risk has not been quantified. For example, additional research is required to monitor whether climate change will increase concentrations of contaminants to levels that may be associated with adverse health effects. International evidence suggests that climate change is likely to increase the risk of chemical contamination during food production through several pathways (Thomson & Rose, 2011) (Table 8.7).

Table 8.7 Examples of environmental chemical contaminants, potential adverse health effects,[2] and mechanisms through which climate change may increase global food safety risks

CHEMICAL CONTAMINANT	EXAMPLE ADVERSE HEALTH EFFECTS	CLIMATIC EVENT	IMPACTS OF CLIMATIC EVENT	POTENTIAL FOOD SYSTEM RISKS
Arsenic	*Acute:* nausea; vomiting; diarrhea; cardiovascular effects; adverse brain effects *Chronic*: dermal effects; numbness in hands and feet; skin, bladder, and lung cancer	Flooding	Transport from contaminated sites to agricultural land	Uptake into foods grown in contaminated sites (e.g., agricultural crops, livestock grazing sites)
		Drought	Need to use wastewater for irrigation	More contaminants applied to crops
Cadmium	Kidney and bone damage; cancer	Freshwater warming	Increased uptake and bioavailability	Higher concentration in the food chain
Polychlorinated biphenyls (PCBs)	Cancer; endocrine disruption; immune, neurological, and reproductive effects	Oceanic warming	Increased Arctic algal growth	Higher concentration in food chain
		Warmer, drier summers	Need to use wastewater for irrigation	More contaminants applied to crops
Dioxins and dioxin-like PCBs	Skin lesions; cancer; endocrine disruption; immune, neurological, and reproductive effects	Flooding	Transport from contaminated sites to agricultural land	Uptake into milk, eggs, and other animal products

2 The examples of health effects associated with chemical contamination in this table are generally associated with much higher concentrations of contaminants than levels to which Canadian populations are typically exposed. While exposure to some contaminants may increase as a result of climate change in Canada, ongoing monitoring and surveillance is needed to determine whether levels would increase high enough to be associated with adverse health effects.

CHEMICAL CONTAMINANT	EXAMPLE ADVERSE HEALTH EFFECTS	CLIMATIC EVENT	IMPACTS OF CLIMATIC EVENT	POTENTIAL FOOD SYSTEM RISKS
Lead	Hematological, gastrointestinal, cardiovascular, renal, neurological, and reproductive effects; impaired metabolism of vitamin D in children	Flooding	Transport from contaminated sites to agricultural land	Uptake into pastoral foods
Mercury/ methylmercury	Impaired neurological development; impaired peripheral vision; sensory disturbances; coordination loss; impaired speech, hearing, and walking; muscle weakness	Oceanic warming	Increased Arctic algal growth and methylation	Higher concentration in fish
		Wildfires	Release of sequestered mercury from soil	Increased uptake in foods via atmospheric deposition
Polycyclic aromatic hydrocarbons (PAHs)	Cancer	Floods	Transport from contaminated sites to agricultural land	Uptake into pastoral foods
		Wildfires	Increased formation of PAH	Increased uptake in food via atmospheric deposition
		Warmer drier summers	Need to use wastewater for irrigation	More contaminants applied to crops

Source: Adapted from Thomson & Rose, 2011

Increasing temperatures associated with climate change are expected to exacerbate the risks posed by POPs, which are already of concern due to their negative health effects (WHO, 2008). Projected warming will enhance the transfer of POPs from oceans, lakes, and rivers to air, which will subsequently extend the potential for long-range transport of POPs (Ma et al., 2011). Climate change is also expected to influence soil properties and thereby increase the bioavailability of POPs and heavy metals and increase their bioaccumulation in food chains (Boxall et al., 2009; Manciocco et al., 2014). Similar trends are anticipated for PAHs in a changing climate (Miraglia et al., 2009).

Increasing extreme weather events associated with climate change will also affect the distribution of chemical hazards in the environment. Heavy precipitation and flooding can transport chemicals from direct sources (e.g., mines and tailing ponds), as well as contaminated soils, to new locations where food is produced (Lake et al., 2005; Boxall et al., 2009; Miraglia et al., 2009; Umlauf et al., 2011; Lake et al., 2015). European studies have found that regular flooding of industrial river catchments increase polychlorinated dibenzo-p-dioxins dibenzofurans (PCDD/Fs) and polychlorinated biphenyl (PCB) levels in soil and grass, which can then be transferred to food (Umlauf et al., 2011; Lake et al., 2015). Similarly, researchers found high levels of POPs in soil from flooded pastureland and in the milk of animals that grazed on the land (Umlauf et al., 2005), as well as high levels of cadmium and lead in wheat, lettuce, and potatoes (Lake et al., 2005). Wildfires have also been identified as a pathway for food source contamination, as they release PAHs and other contaminants (e.g., dioxins, cadmium, and mercury) into the air, which can then travel long distances before they are deposited (Armitage et al., 2011). If these chemicals are deposited into water bodies or on agricultural or pastureland, they could be introduced into food systems. Additional research on the impact of wildfires on chemical contamination of food is needed.

Rising water temperatures also exacerbate levels of seafood contaminants (e.g., nickel, copper, cadmium, lead, and zinc) and risks to aquatic organisms (Ma et al., 2011; Manciocco et al., 2014). For example, rising water temperatures can increase PCB metabolites and copper toxicity in rainbow trout (Boeckman & Bidwell, 2006; Khan et al., 2006; Buckman et al., 2007; Manciocco et al., 2014). Increasing water temperatures also affect concentrations of methylmercury in fish and mammals (Carrie et al., 2010) as a result of increased metabolic rates and mercury uptake (Booth & Zeller, 2005; Ziska et al., 2016).

Climate change is projected to increase the incidence of livestock and aquatic pests, parasites, and microbes (Lafferty et al., 2004; Ziska et al., 2016), which could encourage greater use of pesticides, herbicides, veterinary treatments, and aquaculture drugs (Boxall et al., 2009; Tirado et al., 2010; AAFC, 2015; Ziska et al., 2016). This increased incidence is projected to be exacerbated as chemicals used for pest management, such as pesticides and herbicides, become less effective as concentrations of CO_2 increase (Ziska et al., 2016). Such changes could lead to increased chemicals from pesticides, herbicides, and veterinary drugs entering food systems, with negative implications for human health (Boxall et al., 2009; Miraglia et al., 2009; Manciocco et al., 2014; Delcour et al., 2015).

Greater demand for water resources to maintain agricultural activities is expected as a result of changing precipitation patterns and the projected increase in droughts in many regions of the world (Jiménez Cisneros et al., 2014). Indeed, some regions are already experiencing stress on water resources and increasingly turning to wastewater reuse to meet irrigation needs. Wastewater can contain chemicals, such as PAHs and PCBs, which can therefore enter the food chain when used to irrigate agricultural crops (Al Nasir & Batarseh, 2008; Rose et al., 2011). Although wastewater is not commonly used in Canada for crop irrigation, stressed water resources and response measures could lead to food safety risks in the future and should be monitored. Further, policies and regulations for wastewater use and other water management practices vary by country, which has implications for the safety of foods being imported into Canada (Lake et al., 2012).

8.5.2.1.2 Climate Change Impacts on Food Safety via Chemical Contamination During Food Preparation and Consumption

While there is limited research examining how climate change could affect chemical contamination during food preparation and consumption, human behaviours may change in response to climate change in ways that could increase chemical exposures. For example, processing foods (e.g., drying, smoking) and cooking foods at high temperatures (e.g., grilling, frying, roasting, baking) are common sources of food contamination by PAHs and heterocyclic amines (Sugimura et al., 2004; Zelinkova & Wenzl, 2015). Consequently, the potential increase in barbequing associated with more frequent and prolonged warm days could increase exposure to chemicals from barbequed foods (Séguin, 2008).

Some Indigenous communities in Canada have developed alternative gardening and food preservation measures in an effort to adapt to climate change. Such activities may be necessary to support individual and community food security and sovereignty but may have unintended implications for human health. A study of food-related climate adaptation activities implemented, or planned to be implemented, across three First Nations communities in British Columbia and one Inuit community in Nunavut, revealed several food safety concerns (Steiner & Neathway, 2019). These included PAH contamination from food smoking, chemical contamination from the use of tires or treated wood as planters, and chemical and microbial risks from the use of greywater for crop irrigation (Steiner & Neathway, 2019). More research is needed to understand how such climate change adaptation measures may affect food safety and human health.

8.5.2.2 Climate Change Challenges Related to Chemical Hazards in Foods in the Arctic and Sub-Arctic

Persistent contaminants are found throughout Northern ecosystems, largely from transport from lower latitudes through air, water, and terrestrial routes (Kuhnlein & Chan, 2000; Rigét et al., 2016; Brown et al., 2018), and from local sources (e.g., mining sites). For example, accelerated temperature rise and the consequent melting of glaciers, snow, and sea ice can enhance POP transfer between trophic levels, and increase food safety risks for Arctic populations (Ma et al., 2011; Manciocco et al., 2014). Chemical contaminants deposited and trapped in glaciers via airborne transportation may be deposited in glacier-fed lakes and water bodies as glaciers melt, increasing exposure to humans and wildlife (Bogdal et al., 2009).

In Northern regions, locally harvested foods can be a significant route of contaminant exposure (Ratelle et al., 2018), particularly for Indigenous Peoples, as Indigenous food systems in the Arctic and sub-Arctic often include large quantities of locally harvested fish, birds, and marine mammals. Fish and marine mammals are primary sources of mercury and PCBs (NCP, 2013; Rigét et al., 2016; Brown et al., 2018; Chukmasov et al., 2019). Similarly, POPs and heavy metals have been found in all components of the Arctic ecosystem (Fillion et al., 2014). Once an organism absorbs a contaminant, the contaminant can bioaccumulate in the organism or be transferred to other organisms, posing potential health risks to those who consume the organism in significant quantities or over an extended period of time (Dewailly et al., 2000; NCP, 2013).

Variations in contaminant body burdens commonly reflect differences in dietary habits and traditional lifestyles (AMAP, 2015; Government of Canada, 2017). For example, POP and metal levels in Inuit women are generally higher for those in coastal communities in Nunavik and Nunavut, where there is a higher consumption of marine mammals, compared with Inuit women from Nunatsiavut (in Northern Labrador) and the Inuvialuit Settlement Region (in the Northwest Territories) (Government of Canada, 2017). Results of the *Inuit Health Survey (2007–2008)* suggest that Inuit men tend to eat traditional foods more frequently and in larger quantities than Inuit women (Egeland, 2010). The body burden of POPs and metals were therefore often higher in Inuit men than women, sometimes as much as two-or three-fold. Likewise, older adults typically consume more traditional foods than younger adults, and generally have higher contaminant body burdens of POPs and metals (Government of Canada, 2017). Globally, coastal Indigenous Peoples consume on average 15 times more seafood per capita than non-Indigenous people (Cisneros-Montemayor et al., 2016), and thus may be at increased risk of climate-related alterations in contaminant concentrations in food systems.

With warmer temperatures leading to earlier sea ice breakup, the toxicity of some contaminants in the water column may increase (Gaden et al., 2012). High levels of mercury and PCBs in Arctic fish have been linked to enhanced algal growth from warmer water temperatures (Carrie et al., 2010). Climate-related shifts in prey type and abundance could also affect contaminant exposure in marine mammals, by affecting foraging times and success. Earlier spring sea ice breakup can allow marine animals to forage earlier and for longer periods and allow access to foraging areas that were inaccessible under previous breakup regimes (Gaden et al., 2012).

Exposure to PCBs and mercury in top predatory species may increase with climate change, as Arctic sea ice retreats and releases accumulated chemicals to marine environments (Gaden et al., 2012; Alava et al., 2018). One study projected that the concentration of methylmercury and PCBs in animals at high trophic levels could increase by 8% and 3% by 2100 under a high emissions scenario (RCP8.5) and a no climate change scenario, respectively (Alava et al., 2018). Another study found a 3% to 5% increase in methylmercury uptake in marine organisms for each 1°C rise in water temperature (Booth & Zeller, 2005). In addition to food safety risks, the nutritional value of fish (e.g., omega-3 fatty acids) may also change due to interactions between climate change and contaminants and effects on fish metabolism (Alava et al., 2017). Climate change may, therefore, increase exposure to chemical contaminants in, and change the nutritional quality of, important food sources harvested by Indigenous Peoples (Undeman et al., 2010). Consumption of traditional foods have significant importance for the health and well-being of Indigenous Peoples (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Guidance from the Government of Canada's *Canadian Arctic Contaminants Assessment Report* and the Arctic Monitoring and Assessment Programme suggest that the nutritional benefits from consumption of traditional foods outweigh potential risks associated with chemical contamination, with few exceptions (Chukmasov et al., 2019). As the climate changes, it will be important to enhance research efforts and increase understanding of the impacts of climate change on food safety via chemical contamination.

8.6 Adaptation to Reduce Health Risks

Adaptation is a key component of the response to climate change in Canada and globally and has been identified as an urgent need to protect health (see Chapter 10: Adaptation and Health System Resilience). Responsibility for adaptation in Canada is divided between federal and provincial/territorial governments (Berry et al., 2014a; Henstra, 2017). Many adaptation measures focused on food security and food safety fall within the jurisdiction of public health, which is both a federal issue that crosses provincial and territorial borders, and a sub-national issue that falls under provincial health jurisdiction (Austin et al., 2018). Each province and territory has its own organizational structure, policy direction, and priorities for delivering public health services, determining how adaptation to the effects of climate change on food security and food safety is approached (Clarke & Berry, 2012). Regional and local public health authorities also play a critical role in maintaining food safety through health protection, promotion, screening, and surveillance (Berry et al., 2018).

Adaptation at the food–health nexus will require intersectoral collaboration (e.g., health, environment, agriculture, transportation), and coordination across multiple levels of government and with civil society (Hess et al., 2012; Berry et al., 2014a; Smith et al., 2014). Food systems are complex webs of interdependent factors that affect food safety and food security and are often transboundary in nature (e.g., involving human behaviour, trade, and regulation) (Challinor et al., 2017). Adaptation policy responses that lack high levels of coordination across sectors risk being redundant, fragmented, or maladaptive (Magnan et al., 2016; Austin et al., 2018).

Recognizing the diversity of adaptation opportunities for food systems, this chapter examines two types of adaptation: climate-centred adaptations, which have a narrow and substantial focus on responding to food-related impacts of biophysical hazards associated with climate change; and vulnerability-centred adaptations, which have a broad and integrative focus on the societal, cultural, environmental, political, and economic factors (i.e., social determinants of health), that create and exacerbate vulnerability to food-related impacts of climate change (Ebi, 2009; Dupuis & Biesbroek, 2013; Ford et al., 2018). To address climate-related health risks relevant to food security and safety in Canada both climate- and vulnerability-centred adaptations are needed.

8.6.1 Climate-Centred Adaptation Options

8.6.1.1 Climate Change and Health Vulnerability and Adaptation Assessments

Vulnerability and adaptation assessments (V&As) concerning climate change and health provide an evidence-based assessment of the key health risks posed by climate change, identify high-risk populations and regions, evaluate the effectiveness of existing interventions, and outline adaptation opportunities (Berry et al., 2014a; Buse, 2018). These assessments are critical to building public health preparedness for climate change (Charron et al., 2008; Hansen & Hoffman, 2011; Berry et al., 2014a; PHAC, 2017; Berry et al., 2018). Regional and local health authorities across Canada are increasingly conducting V&As; however, the degree to which climate-related impacts on food security and food safety are assessed varies.

Provincially and territorially, responsibility for completion of V&As reflects mandates for climate change adaptation and the jurisdictional landscape for health services. Under the Ontario Public Health Standards, for example, health units are required to assess the health impacts of climate change. Several health units have, therefore, completed V&As, including Grey Bruce Health Unit (Grey Bruce Health Unit, 2017), Middlesex-London Health Unit (Berry et al., 2014b), and Simcoe Muskoka District Health Unit (Levison et al., 2017), all of which address risks of food-borne illness. Both assessments from Middlesex-London Health Unit and Simcoe Muskoka District Health Unit also explicitly consider the multiple dimensions of food security. The City of Toronto's report, *Exploring Health and Social Impacts of Climate Change in Toronto* (Medical Officer of Health, 2013) considers food security and food safety in the context of power outages during extreme weather events and insufficiency of food storage standards as temperatures warm. In 2017, Toronto Public Health launched a Food Vulnerability Assessment (Zeuli et al., 2018a) to assess the resilience of Toronto's food system under three extreme weather scenarios. Although food security risks were relatively low, they were associated with extreme weather events. The city identified a need to develop food resilience plans for neighbourhoods already experiencing food insecurity, which could be exacerbated by climate change. The report included recommendations to develop poverty-reduction strategies that address unequal food access (Zeuli et al., 2018a).

There are challenges in developing robust, actionable food-related V&As. Climate change and health V&As rely on surveillance data to assess associations between health outcomes and climatic conditions. While surveillance systems are in place to identify food-borne illnesses, the majority of cases of food-borne illness are undiagnosed or unreported (Berry et al., 2014a; Harper et al., 2015c; Thomas et al., 2015). Furthermore, while there have been advances in climate projections and impact analysis, particularly in localized downscaled projections, uncertainty regarding projections of food-borne disease in Canada due to climate change remains high. As a result, many V&As do not quantify how climate change may affect food-related risks, and, where future trends are examined, they involve only general extrapolations indicating the potential direction of change (Ebi et al., 2018). Furthermore, links among climate change, food quality, and water quality remain understudied (PHAC, 2017). Therefore, there is a need for future studies to examine how projected climate changes will affect food security and food safety (Smith & Fazil, 2019), and how future demographic and socio-economic factors will affect the distribution and incidence of such risks in Canada.

Several programs have been initiated in response to these gaps. For instance, the Public Health Agency of Canada's Preventative Public Health Systems and Adaptation to a Changing Climate Program is focused on working with public health stakeholders to expand research on climate change impacts and to support adaptations, including surveillance and response to emerging food-borne diseases. In addition, Health Canada's climate change and health adaptation capacity-building program, HealthADAPT, has funded 10 projects across Canada that aim to improve the knowledge base about the health impacts of climate change and develop strategic adaptation plans to address risks by conducting V&As. Partners in these projects include provincial and territorial health ministries, local health units, and the First Nations Health Authority in British Columbia. Several of these projects will examine climate change impacts on food-borne diseases.

8.6.1.2 Adaptation Planning

Climate change adaptation strategies and action plans play important roles in linking evidence to decision-making, articulating policy goals and objectives, and establishing pathways for adaptation action (Olazabal et al., 2019). Adaptation plans are a key component in laying the groundwork for adaptation action in all levels of government in Canada, minimizing climate-related impacts on food security and food safety, and maximizing resilience-building efforts. However, achieving tangible benefits from these groundwork efforts necessitates effective and timely implementation (Lesnikowski et al., 2011; Lesnikowski et al., 2016).

Discussions about intersections among climate change, food security, and health are often better developed in strategic adaptation plans for Indigenous communities, where changing environmental conditions are affecting Indigenous food systems (Box 8.5). For example, Newfoundland and Labrador's climate change plan highlights the links between temperature and sea ice changes, on one hand, and decreased access to Inuit hunting areas, on the other, and implications for Inuit food security, safety, and mental health outcomes (Municipal Affairs and Environment, 2019). Food is also a key priority in territorial adaptation planning, where cross-sectoral adaptation actions are being designed to integrate health, conservation, economy, and culture. In many provincial climate change adaptation strategies, however, climate-related impacts on agricultural production are framed as an economic, rather than a public health, issue. In Nova Scotia, for example, adaptation activities in the Department of Agriculture focus on crop diversification, soil and water management, pest control, and flood risk management, but do not make explicit linkages with public health risks related to food security and food safety (Nova Scotia Environment, 2014).

Despite its importance, municipal climate change planning is highly uneven across Canada (Guyadeen et al., 2019). Examples of municipal adaptation plans that address growing climate change risks to food include Toronto's Climate Change and Health Strategy, which sets out several actions that build on the Toronto Food Strategy, including identifying the need for infrastructure to support food system sustainability, encouraging low-carbon diets, and assessing climate change impacts on food security and food safety (TPH, 2015). The City of Surrey, in British Columbia's agriculturally productive lower mainland, has examined how changing temperatures and precipitation will affect agricultural losses and increase the risk of food-borne illness. The city's Agricultural Plan was updated in 2013 to reflect changing climatic conditions (Planning and Development Department, 2013). Surrey's Climate Adaptation Strategy aims to improve local resilience to climate-related disruptions in global food prices and supply chains by encouraging crop diversification and supporting local research on climate-resilient agricultural practices. The strategy also draws linkages with long-term flood risk management and land-use planning mechanisms to improve food production in urban spaces. At the regional level, Metro Vancouver's Food Action Plan Task Force is working to identify how municipalities throughout the region are contributing to a resilient regional food system, and how local food-production capacity can be increased (Metro Vancouver, 2016). Some small towns and rural areas are also examining how local food systems will be affected by climate change. The City of Castlegar, British Columbia, conducted a Sensitivity Assessment for Food and Agriculture that examined how climate change will stress local food production (City of Castlegar, 2010). The assessment proposed several actions to improve the adaptive capacity of Castlegar's food system to climate change, including citizen-based monitoring of crop production and awareness-raising about food storage techniques.

In Quebec, the city of Montréal is conducting a study on the potential for urban commercial agriculture on the island of Montréal that supports food system resilience, with the goal of developing a commercial urban agriculture strategy and action plan (Ville de Montréal, 2018). However, in the general context of climate change planning, municipal policies regarding food production and consumption have commonly been adopted with the goal of reducing GHG emissions, and only recently are Canadian cities beginning to integrate food production and consumption into adaptation planning. For instance, some local adaptation strategies now recognize that higher summer temperatures and power outages due to extreme weather events pose a threat to food safety by increasing the risk of food-borne illness (Halifax Regional Municipality, 2010; City of Windsor, 2012; City of Montréal, 2015; City of Toronto, 2019). Municipal strategies that consider food security in the context of climate change often focus on increasing the self-sufficiency of local and regional food systems; food systems can be a nexus that provides opportunities to achieve synergies between adaptation and GHG mitigation policies (City of Toronto Environment Office, 2008; City of Surrey, 2013; Zeuli et al., 2018b).

To support adaptation by Indigenous communities, the First Nations Adapt Program and the Climate Change Preparedness in the North Program, administered by Crown-Indigenous Relations and Northern Affairs Canada, funds Indigenous-led climate change risk assessments and supports the development of adaptation options (CIRNAC, 2018; CIRNAC, 2019). Many of the funded projects have focused on climate-related impacts on health and/or food security. Examples include projects led by the Blood Band in Alberta to increase awareness about the impact of climate change on community food security; in British Columbia, the Splatsin First Nation's risk assessment on the impact of flooding on food resources; the Government of Yukon Department of Environment's research on the relationships among climate change, traditional foods, and Yukoners' diets; and a permafrost vulnerability assessment and map of traditional harvest areas conducted by the Jean Marie River First Nation with Yukon College. The Climate Change and Health Adaptation Program, administered by Indigenous Services Canada, also funds community-driven projects to build adaptive capacity for the health impacts of climate change, including a number of projects on food security.

Efforts are underway at all governmental levels to address climate-related impacts on food production and security. Opportunities exist to learn from leading projects and partners that explicitly address risks to health and that expand protection of Canadians from future climate change impacts. These actions would encourage collaborative partnerships across sectors and inform more effective adaptation action, contributing to greater resilience in the population.

8.6.1.2.1 Adaptation Leadership in Northern Canada to Address Risks to Food Security and Safety

In Northern Canada, adaptation planning is taking place at regional to community levels. Formal planning efforts share a common perspective on climate-related health impacts as a cross-cutting challenge and emphasize the need to understand and respect relationships among health, conservation, culture, and the economy. The integration of Western science and Indigenous knowledge is a key principle found across planning documents, although a dominance of scientific framings and government planning approaches has been noted (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada) (Bates, 2007; Cameron et al., 2015; Labbé et al., 2017; Flynn et al., 2018). Key food-related impacts of climate change addressed in many Northern adaptation plans include changes in the availability and accessibility of traditional foods, increased contaminants, more unpredictable weather and sea ice conditions, and impacts on mental health outcomes from challenges in preserving Indigenous practices and skills embedded in land-based activities.

At the regional level, the Pan-Territorial Adaptation Strategy (Government of Nunavut et al., 2011) has encouraged cooperation among the territorial governments to understand climate change risks and propose appropriate policy response measures. Inuit Tapiriit Kanatami's National Inuit Climate Change Strategy (ITK, 2019) aims to enhance coordination of Inuit regional adaptation planning efforts and develop strong linkages between global advocacy and participation in local efforts. The plan identifies five priority action areas: knowledge and capacity development; health, well-being, and the environment; food systems; energy; and infrastructure. Additionally, the National Inuit Committee on Health convenes an Inuit Food Security Working Group, which coordinates efforts around nutrition, food security, and health in Inuit regions.

Strategic frameworks and action plans have also been adopted or are currently being developed at territorial and local levels. For example, the Northwest Territories Climate Change Strategic Framework and its associated Action Plan (2019 to 2023) detail several adaptation actions that specifically target food security and health, such as monitoring Indigenous food sources, conducting surveillance of species distribution, geo-mapping food system contamination, monitoring drinking water quality, developing a health advisory alert system, and exploring the potential for cultivation of new crops in community gardens as the growing season lengthens (Government of Northwest Territories, 2018). The Framework and Action Plan highlight that Indigenous knowledge should be used to obtain baseline data to monitor environmental and health trends and to identify future research needs. Both the Government of the Northwest Territories Sustainable Livelihoods Action Plan for 2019 to 2023 and the Nunavut Food Security Strategy and Action Plan for 2014 to 2016 also recognize that climate change poses a key risk to food accessibility in the region and state the importance of ensuring access to country foods to achieve community food security.

The Government of Nunavut's strategic document *Upagiaqtavut – Setting the Course: Climate Change Impacts and Adaptation in Nunavut* emphasizes community involvement, decision-making by consensus, collaboration, resourcefulness, and respect for the environment. The document proposes several outreach and research activities, including planning toolkits, incorporating climate change topics into school curricula, and encouraging knowledge-sharing from Elders to youth. A number of community-specific actions to increase food access were developed through community adaptation planning exercises with federal and territorial government support, including delivering hunter apprenticeship programs, repairing or replacing dangerous trails to provide access to hunting and fishing areas, improving access to navigation technology and equipment, establishing community freezers, and creating awareness programs for safe food storage. Based on the results of these projects, a Local Adaptation Planning in Nunavut Toolkit was released in 2011 to support communities preparing their own adaptation plans (Bowron & Davidson, 2011).

The Government of Yukon is developing a territorial adaptation strategy that builds on past adaptation work. The Climate Change and Public Health Project (2013–2014) identified current and projected climate change health impacts in Yukon, along with priorities and gaps in knowledge and resources (Government of Yukon, 2014). Regarding food policy more broadly, the territory established an Interdepartmental Food Security Working Group to propose pathways forward for addressing food security across the portfolios of the Departments of Environment; Health and Social Services; Economic Development; Community Services; Energy, Mines and Resources; and Education. The territory is also developing a local food strategy, intended to encourage regional production and consumption of food and to reduce reliance on food transported from outside of Yukon. Various actions have been proposed to increase Yukon's food system resilience, including the expansion of community markets, funding for irrigation system upgrades and specialized farming equipment, and the design of school programs to engage students on issues of food sustainability in Yukon, all of which will also enhance climate change adaptive capacity.

8.6.1.3 Surveillance

Surveillance systems are critical components of adaptation to the health impacts of climate change (Ebi & Semenza, 2008; Lam et al., 2019), as they provide ongoing monitoring of health outcomes through the collection, analysis, and interpretation of data. While most surveillance systems in Canada related to food safety do not currently include climate variables and were not implemented to support climate change adaptation, it is possible to use climate information and surveillance results to better understand risks to health and evaluate adaptation options (Box 8.5). For example, Smith et al. (2019) used national surveillance data from the Canadian Integrated Program for Antimicrobial Resistance Surveillance to show a correlation between air temperature and precipitation, on one hand, and microbial food-borne contamination, on the other. Similar studies have used surveillance data to identify associations between enteric infections and temperature (Ravel et al., 2010; David et al., 2017). New opportunities to enhance existing surveillance systems exist. For example, there are opportunities to integrate climate variables into the FoodNet Canada Surveillance System that tracks enteric disease risks throughout the farm-to-fork continuum in regions of urban–rural interface (e.g., retail foods, farm, water) (PHAC, 2017). Nevertheless, challenges for surveillance remain. For example, the proportion of enteric infections attributable to food consumption versus water and other sources of infection remains unknown (Butler et al., 2016), and the true burden of food-borne illness is underestimated due to under-diagnosis and under-reporting (Harper et al., 2015c; Thomas et al., 2015).

The ability of surveillance systems to provide early warning of the emergence of new or existing climate-sensitive diseases needs to be further investigated and strengthened (Ford et al., 2014), particularly for high emissions scenarios (e.g., RCP 8.5) (Costello et al., 2009; Ebi et al., 2018) and for risks that may emerge from outside food systems (e.g., via trade) (Lake, 2017). Climate change could make current food-related surveillance systems inadequate, underpinning the importance of horizon scanning to anticipate new threats (Lake, 2017).

National household food insecurity data are collected in the Canadian Community Health Survey, so that temporal changes in the prevalence of household food insecurity can be detected. However, the survey's results provide an incomplete picture of the state of food security in Canada with each survey cycle, as some provinces and territories can opt out of its food security component, and several population groups, including First Nations living on reserves and those living in long-term care homes and prisons, are excluded (PROOF, 2018). Furthermore, the ability to examine fine-scale demographic, temporal, and spatial details with these data is limited (PROOF, 2018). Such data have not been used to examine the impacts of climate and climate change on food security in Canada (Ebi et al., 2017; Ford et al., 2019; Lam et al., 2019). Because the survey has limited ability to capture the multi-dimensional nature of food security among First Nations, Inuit, and Métis Peoples, alternative food security measurement approaches must be developed, rooted in cultural values and Indigenous knowledge, and focusing on consumption of traditional and retail foods and on the role of sharing networks in underpinning food access (Ready, 2016; Ford et al., 2019).

Existing surveillance systems are insufficient to detect the occurrence and spread of climate-related health risks for many Indigenous Peoples in Canada (Harper et al., 2015b; Sawatzky et al., 2018; Lam et al., 2019), thus increasing their vulnerability to future impacts (Ford et al., 2010; Harper et al., 2015a). Gaps in surveillance have been documented in Indigenous communities, and these gaps exist for a range of reasons, such as missing data, differing interactions with health care systems, and high costs of patient follow-up needed to provide data (Ford et al., 2010; Harper et al., 2011; Pardhan-Ali et al., 2012a; Pardhan-Ali et al., 2012b; Pardhan-Ali et al., 2013; Ford et al., 2014; Harper et al., 2015a; Harper et al., 2015b; Harper et al., 2015c). Indigenous knowledge is critical for robust climate change and health surveillance efforts (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Several studies demonstrate the effectiveness of Indigenous knowledge for community-based monitoring and surveillance systems to monitor and respond to climate-related changes in access to Indigenous land-based activities, species distribution, food safety, and associated health impacts (e.g., food security, nutrition, personal safety and injury, food-borne pathogens, and new and re-emerging infectious diseases) (Berner et al., 2016; Blangy et al., 2018; Sawatzky et al., 2018; Kipp et al., 2019; Lam et al., 2019).

Box 8.5 Adaptation actions to reduce emerging *V. parahaemolyticus* risks in oysters

The health risks from *V. parahaemolyticus* in oysters harvested in Canada are projected to increase due to climate change (see Box 8.3). Adaptation efforts are required to prevent these risks from increasing the burden of food-borne illness.

Improved ability to predict emerging risks from *V. parahaemolyticus* could be used for early warnings, to target the timing and location of public health interventions and to inform new health-related industry practices. For example, under a predicted strong El Niño–Southern Oscillation event, adaptation efforts could include adjustments in industry practices and regulatory policy, especially for seafood that is consumed raw, such as oysters. Other options include more stringent post-harvest temperature controls to limit pathogen growth. However, during a 2004 *V. parahaemolyticus* outbreak in Alaska, pathogen levels at harvest posed significant health risks, despite post-harvest controls (Martinez-Urtaza et al., 2010). *V. parahaemolyticus* levels at harvest were reduced by an order of magnitude the following year by adopting a new practice in which oysters were held 15 to 30 m deeper in the water and, therefore, at colder temperatures, for one month before harvest (Martinez-Urtaza et al., 2010). Alternatively, post-harvest processes such as mild heat, high hydrostatic pressure, and freezing can reduce levels of *V. parahaemolyticus* and other pathogens, such as *V. cholerae* and *V. vulnificus*. These processes generally retain the raw oysters' sensory characteristics that consumers prefer. As risks to health increase with a warming climate, these adaptation options provide opportunities to protect Canadians.

8.6.1.4 Risk Communication and Education

Awareness of climate change risks has a powerful influence on the initiation and development of adaptation programs and the adoption of adaptive behaviours (Grothmann & Patt, 2005; Moser, 2014; Ford & King, 2015). There are a number of examples in which health authorities have undertaken activities to increase education and awareness of climate change impacts on food and to promote individual behavioural change. In Quebec, the *Mon climat, ma santé* website was designed to increase public awareness of climate-related health impacts. The website provides an introduction to the concept of food insecurity and discusses various ways that climate change will affect food production and consumption in Canada and globally. The website promotes food security in a changing climate, emphasizing buying local foods, community gardening, and holding events such as cooking workshops to teach citizens how to reduce food waste (INSPQ, n.d.). At a city level, in Montréal, a 2017 pilot project in the neighbourhood of Notre-Dame-de-Grâce aimed to improve emergency preparedness through community resilience workshops. Citizens were encouraged to assemble 72-hour emergency kits that included recipes suited to emergency situations and food (City of Montreal, 2018). Additionally, the federal government has funded many projects through First Nations Adapt, Climate Change Preparedness in the North, and HealthADAPT programs that include risk communication and community-based education. The Young Hunters Program in Arviat, Nunavut, for example, uses SmartIce technology to monitor sea ice thickness and keep the community informed about travel conditions. By including youth in data collection, young community members simultaneously learn about sea ice and wildlife safety. The First Nation of Nacho Nyak Dun in Yukon provides information to the community on climate change and food security by conducting knowledge-gathering activities, and then developing and translating information into the Northern Tutchone language.

8.6.2 Vulnerability-Centred Adaptations

8.6.2.1 Tackling the Root Causes of Vulnerability

The people who are disproportionately affected by climate change impacts on food security and food safety are those who are socio-economically disadvantaged and who already experience high burdens of ill health, such as people living on a low income, seniors, members of racialized communities, households headed by single women, and persons with disabilities (Smith et al., 2014; FAO, 2016). Adaptation actions that address societal conditions underlying climate-health vulnerability can enhance food security and food safety, as well as contributing to health equity and overall community resilience (see Chapter 9: Climate Change and Health Equity). For instance, for Indigenous Peoples, this includes supporting and promoting Indigenous food sovereignty (Box 8.6). Opportunities for action discussed in existing literature are diverse and commonly examined in the context of Indigenous food systems; they include investing in social safety nets to respond to food emergencies (e.g., soup kitchens), poverty alleviation, truth and reconciliation, education, inclusive governance, and cultural promotion (Ford et al., 2013; Skinner et al., 2013; Fillion et al., 2014; Ford et al., 2014; Organ et al., 2014; Ford et al., 2016; Rosol et al., 2016). These actions have multiple health co-benefits and can strengthen important determinants of health, including food security.

Box 8.6 Indigenous food sovereignty as a climate change solution

The Indigenous food sovereignty movement is rising in response to the imposition of Western industrial food systems, as Indigenous nations seek to reclaim their well-being through the revitalization of traditional food systems (Whyte, 2016; Delormier et al., 2017). Indigenous food sovereignty connotes an alternative food system that involves Indigenous knowledge and mutually beneficial relationships to the land, contrasting with many large-scale mainstream food systems characterized by industrialism, capitalism, and globalism. Indigenous food sovereignty seeks the integration of political, social, economic, ecological, and spiritual aspects of food. It asserts that Indigenous communities have the right to preserve their cultural traditions and practices surrounding the production, harvesting, and sharing of food (Lemke & Delormier, 2017). Indigenous food sovereignty conveys a "restorative framework for health and community development," as well as healing relationships with each other, the land, animals, and plants (Morrison, 2011). Four central principles have been associated with Indigenous food sovereignty (Morrison, 2011):

- Food is sacred and cannot be constrained by colonial laws and policies; its value is instead upheld by acting on long-standing sacred responsibilities to land, animals, and plants.
- Participation in the day-to-day practice of nurturing healthy relationships with land and each other is essential to maintaining Indigenous food sovereignty.
- Self-determination — the freedom to make decisions regarding food to support healthy people and communities — is critical.
- There is a need for broad policy reform to reconcile Indigenous food systems with colonial laws and policies.

Addressing Indigenous food sovereignty, as opposed to security, is a challenging task. It involves the analysis of the root causes of health disparities experienced by Indigenous Peoples as they relate to food systems, including the imposition of colonial food systems. The need for the revitalization of traditional food practices is a vital component of food sovereignty and necessitates the recognition of Aboriginal and treaty rights (Government of Canada, 2020) so that access to traditional lands may be secured.

In Indigenous systems, food is conceptualized as a gift, a source of life. It plays a central role in ceremonies, identity, and culture, and is an integral component of the web of relationships between people and the land (Whyte, 2016). Access to traditional foods is an essential element of Indigenous culture, language, and well-being at the individual and community level. Such access depends on the maintenance of both physical and spiritual relationships to the land.

The linkage between Indigenous knowledge and food is a critical consideration when examining food security in the context of climate change. Knowledge of food systems is taught, and relationships with food are perpetuated, through social engagements within and among families, communities, and other societies. When the Western agri-food system model supplanted the traditional food system, the transmission of Indigenous knowledge was greatly diminished (Grey & Patel, 2015; Kermoal & Altamirano-Jiménez, 2016). Diets are healthier in those areas where traditional foods are eaten more often (Johnson-Down & Egeland, 2010; Gagné et al., 2012; Chan et al., 2019). Furthermore, there is a gendered component to the impact of food insecurity. Women traditionally hold specialized knowledge about food systems, including its production, harvesting, preparation, and safety, and actively promote the nutritional and medicinal properties of food, as well as contributing to the stewardship of the land (Lemke & Delormier, 2017).

Mainstreaming or integrating climate change considerations and information on risks to food security and food safety into existing policies and programs can also help to address underlying causes of vulnerability. Some jurisdictions are taking such actions already. The Government of Nunavut's Food Security Strategy and Action Plan, developed in collaboration with the Nunavut Tunngavik Inc., Inuit organizations, non-governmental organizations, and the private sector, accounts for climate change impacts on food accessibility and promotes food-related skills important for adaptation (NFSC, 2014). Similarly, other territorial adaptation plans emphasize the importance of supporting health and wellness activities to build community resilience to multiple stresses, including climate change. Other measures to address food insecurity focus on increasing the self-sufficiency of local and regional food systems, which, in turn, can increase climate resilience (Sonnino, 2016; Dorward et al., 2017). Calgary's Food System Assessment and Action Plan incorporates local climate projections, addresses adaptation challenges and opportunities throughout food systems, and showcases local examples of urban farming (City of Calgary, 2012). Municipalities across Canada are increasingly encouraging the creation of community gardens, permitting the keeping of chickens within city boundaries, supporting farmer's markets and community agriculture programs, and growing urban food forests.[3] Such actions can contribute to community climate resilience and have many health co-benefits.

8.6.2.2 Strengthening Health Systems

Strengthening health systems to improve the management of current and future risks from climate change is central to adaptation (Ford et al., 2014; Watts et al., 2015) (see Chapter 10: Adaptation and Health System Resilience). Public health authorities play a critical role in maintaining health and well-being, through health protection, promotion, screening, and surveillance related to food safety (Charron et al., 2008). There is limited knowledge of the effectiveness of current measures to reduce health risks from the potential food-related impacts of climate change (Yusa et al., 2015).

Given the interdependent relationships among food systems, health, and climate change, food can be an important intervention point for climate action and health equity within the health care system. For example, Nourish: The Future of Food in Health Care, a collaborative initiative led by the McConnell Foundation with partners across Canada, has worked to empower health care leaders to take greater actions on climate change and health equity issues through interventions with food (Nourish, n.d.).The Nourish Innovator Program, which ran from December 2016 to May 2019, brought innovators from 25 Canadian hospitals and health authorities together to collaborate on a series of projects that leveraged the power of food to achieve impact in three cross-cutting areas: climate, equity, and community well-being. National collaborative projects

3 Located in urban areas and mimicking a natural ecosystem, urban food forests consist of perennial trees and edible plants (Clark & Nicholas, 2012).

included initiatives related to traditional and cultural food programs, sustainable menus, value-based and local food procurement in health care, and measuring patient food experiences.

8.6.3 Adaptation Progress and Future Challenges

Adaptation efforts are underway at federal, provincial, territorial, municipal, community, household, and individual levels to respond to the food-related impacts of climate change, although analysis in this chapter indicates more action is needed. Continued monitoring and evaluation of adaptation will be essential for tracking progress in responding to risks and learning from actions, necessitating the development of new methods, approaches, and datasets (Ford et al., 2016; ECCC, 2018; Berrang-Ford et al., 2019; Lesnikowski et al., 2019).

Barriers impeding efforts to reduce risks to health from climate change impacts on food security and safety include uncertainty of climate change impacts; lack of financial resources; insufficient social capital; prioritization of more immediate public health challenges; fragmented institutional arrangements; and jurisdictional challenges (Huang et al., 2011; Clarke & Berry, 2012; Paterson et al., 2012; Yusa et al., 2015; Roser-Renouf et al., 2016; Austin et al., 2018; Austin et al., 2019). There are also potential limits to adaptation, although little scholarship has assessed these limits in a climate–health context in general (Ebi & Hess, 2017; de Coninck et al., 2018) or for food security and food safety in particular. Associated debates around loss, damage, and compensation are relevant in Canada, particularly for Indigenous Peoples, who face an unequal and inequitable burden of impact, but have not yet been examined (Ford, 2009; Landauer & Juhola, 2019).

Another challenge to adaptation is that, in climate change policy planning, food security tends to be framed as primarily an economic and/or GHG emissions mitigation issue, rather than as a social, cultural, or public health challenge that needs to be addressed. Food policies and programs in response to climate change are, therefore, being developed primarily under sustainability, mitigation, or resilience policy initiatives and often lack strong linkages to public health issues and concerns.

8.7 Knowledge Gaps and Recommendations

8.7.1 Food Security

The existing literature on climate change and food security generally focuses on food availability, and research generally places a disproportionately large emphasis on climate change impacts on food production, rather than other components of the food system (Nelson et al., 2016). As a result, there is limited understanding of the impacts climate change will have on non-production components of food systems (i.e., food processing, distribution, preparation, and consumption) (Porter et al., 2014), and on human health. Further, studies have tended to concentrate on single-factor changes that might affect food systems, rather than delving into the more complex and multi-layered features of food security that require integration of environmental, political, economic, and social factors. As a result, a number of knowledge gaps exist, particularly regarding food system components most vulnerable to climate change, the consequences for human health, and the most effective adaptation strategies (Schnitter & Berry, 2019).

The severity and significance of climate change effects on food security, as well as the capacity to adapt, will vary across the country. Although a number of studies have explored climate change impacts on food security in Northern Canada, knowledge gaps persist in that region. Further, improving understanding of the main risks and vulnerabilities facing populations in regions south of 60 degrees north latitude, including rural and remote communities as well as urban centres, requires targeted analysis. Regional and local food system assessments and analyses are needed to identify unique vulnerabilities and inform appropriate adaptation strategies, with particular consideration for individuals who will face disproportionate impacts and may already face nutritional risk and food insecurity (e.g., low-income households, Indigenous Peoples, households headed by single women).

Given the integrated nature of food systems, disruption of one component of the food system can disrupt critical operations of other components. Consequently, future research examining the climate change, food security, and human health nexus from a food system perspective would help identify critical vulnerabilities and points of adaptation intervention. A food system perspective also encourages the collaboration of all food system actors. Indeed, many adaptation actions that contribute to a resilient food system fall outside of the jurisdiction of the health sector and will require a multi-sectoral response (Schnitter & Berry, 2019).

To understand risks to food security from climate change, specific knowledge is needed, including research to:

- identify processing and distribution facilities in Canada that are most vulnerable to disruption from extreme weather events and prioritize the most vulnerable sites for resilience-building activities;
- map food transportation and distribution networks across Canada and identify important facilities to assess climate change risks and implement adaptation actions;
- investigate how food distribution systems might adapt to short-term disruptions and longer-term challenges caused by climate change;

- examine climate change impacts on nutrition in a Canadian context, including examining the impact elevated CO_2 concentrations will have on nutritional content of key crops and studying potential climate-related diet shifts and implications for Canadians, and analyzing potential food substitutions and implications for dietary guidelines;
- evaluate and monitor the effectiveness of current measures to reduce health risks from impacts of climate change on food insecurity;
- enhance research and understanding of key factors that contribute to food insecurity, including analysis of compounding, intersecting vulnerability factors and the impact climate change will have on this relationship; and
- increase research and understanding of the impacts climate change may have on food security specifically for First Nations, Inuit, and Métis peoples.

8.7.2 Food Safety

Several Canadian and international studies have used surveillance data to link climate variables and/or climate change to incidence of enteric diseases. Fewer studies have directly associated climate change with food safety by, for example, linking climate to the occurrence of pathogens in foods or to illness directly attributed to food consumption. It is difficult to estimate the precise effect of climate change on food safety, as many food-borne pathogens can also be acquired via contaminated water consumption, direct contact with animals, and human-to-human transmission. Enhanced and integrated monitoring and surveillance of animals, the environment (including water), and foods for pathogens would help to address important knowledge gaps. Several food safety surveillance systems are established in Canada to monitor food-borne diseases; nevertheless, most of these surveillance systems do not currently include climate variables. An opportunity exists to integrate climate variables into food safety surveillance systems to be able to monitor trends in climate-related food-borne illness.

Food safety-related issues are under-represented in the climate-health literature relative to other health indicators (Springmann et al., 2016). More studies are needed to project the impacts of climate change and adaptation measures on food safety in Canada. Risk modelling work conducted thus far indicates that food-borne disease risks are projected to increase with climate change for several combinations of foods, pathogens, and regions (Smith et al., 2015). These types of mathematical models can be populated with data from enhanced surveillance programs that include climate variables, as well as new primary research on the evidence for pathogen behaviours under simulated climate scenarios, to derive risk projections for more food safety issues. Diseases previously considered exotic or rare to Canada should be reconsidered in light of climate changes expected in Canada (Greer et al., 2008). Cross-disciplinary research using various methodological tools can provide useful insights and forecast disease transmission patterns under specific climatic conditions (Greer et al., 2008).

More research is also required to fully understand the impact of climate change and variability on the fate of chemical contaminants in the environment. While ocean warming and acidification will affect the bioaccumulation of contaminants in aquatic species and the structure and distribution of food webs, additional research is needed to understand the changing physical biochemical basis and the changing geographical distribution of aquatic species. Furthermore, to address climate-related environmental changes, integrated surveillance of water, soils, and foods for contaminants and chemical residues; crops for pesticide residues; animal products for veterinary residues; and emerging animal and human diseases is essential (WHO, 2008; Tirado et al., 2010). The data generated from this research can be used to identify emerging problems and food contamination trends and to contribute to risk assessments (Moulton & Schramm, 2017).

To understand risks to food safety from climate change, specific knowledge is needed, including research to:

- regularly review Canadian food inspection regulations and policies to ensure that they are robust enough to cover emerging food safety issues, both in Canada and in countries from which food is imported;
- investigate how climate change adaptation measures may affect food safety and human health — for example, examine potential food safety issues and associated adaptations related to traditional preparation and storage methods used by Indigenous Peoples and how climate change may influence these practices;
- enhance and expand existing food safety surveillance systems to include climate variables and to integrate monitoring of animals and the environment;
- enhance models and derive risk projections for food-borne illnesses in the context of climate change; and
- examine the impact of climate change on the fate of chemical contaminants in the environment.

8.8 Conclusions

This chapter explores the linkages among climate change, food systems, and human health, as well as how society can adapt to reduce potential health risks in Canada. Several important themes have emerged and reveal the various challenges and opportunities for addressing the impacts of climate change on food security and food safety for human health outcomes in Canada, including:

- the pervasiveness of climate change impacts on all food system components, throughout the production, processing, distribution, preparation, and consumption phases, and the subsequent challenges for human health;
- the need to consider both the direct and indirect climate-related impacts on food systems, food security, and food safety on human health;
- the vulnerability of specific populations (e.g., low-income communities, Indigenous Peoples, marginalized communities, children, and older adults) to risks associated with food safety and food security in the context of climate change;
- the importance of acknowledging the multiple and intersecting ways environmental, social, political, and economic determinants affect health in the context of food systems, food security, and food safety;
- the globalization of food systems, causing climate change impacts on food security and health to be experienced at both a global and local level; and
- the variability of food safety and food security risks to health by region, and the resulting need for adaptation models to account for unique place-based experiences (driven by consumption patterns, cultural norms, preference, climate, etc.), while accounting for socio-economic barriers and other social determinants of health in order to build capacity for resilience.

As challenges to food systems, food security, and food safety present potentially severe threats to human health in and outside of Canada (Confalonieri et al., 2007; Friel et al., 2011; Bradbear & Friel, 2013; Porter et al., 2014; Bowen & Ebi, 2015; Wang & Horton, 2015; Springmann et al., 2016), it is crucial to gain greater understanding of risks from climate change and of opportunities to protect people. Despite existing knowledge gaps, efforts to address the health risks associated with climate change impacts on food systems are already underway in Canada. Evaluating and monitoring the effectiveness of these activities can elucidate important learnings and contribute to the implementation of actions across the country. Collaboration, spanning across all sectors and levels of government, will be critical to adapt effectively to climate change impacts on food security and safety in Canada.

8.9 References

Aberman, N.-L., & Tirado, C. (2014). Impacts of climate change on food utilization. In B. Freedman (Ed.), *Global Environmental Change* (pp. 717–724). Dordrecht, Netherlands: Springer. <https://doi.org/10.1007/978-94-007-5784-4_124>

Agency for Toxic Substances & Disease Registry (ATSDR). (1999). *Toxicological Profile for Mercury.* Retrieved from <https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=115&tid=24>

Agency for Toxic Substances & Disease Registry (ATSDR). (2020). *ToxGuide for lead.* Retrieved from <https://www.atsdr.cdc.gov/toxguides/toxguide-13.pdf>

Agriculture and Agri-Food Canada (AAFC). (2015). *Impact of climate change on Canadian agriculture.*

Agunos, A., Waddell, L., Léger, D., & Taboada, E. (2014). A systematic review characterizing on-farm sources of Campylobacter spp. for broiler chickens. *PLoS ONE*, 9(8), e104905. <https://doi.org/10.1371/journal.pone.0104905>

Alava, J. J., Cheung, W. W. L., Ross, P. S., & Sumaila, U. R. (2017). Climate change-contaminant interactions in marine food webs: Toward a conceptual framework. *Global Change Biology*, *23*(10), 3984–4001. <https://doi.org/10.1111/gcb.13667>

Alava, J. J., Cisneros-Montemayor, A. M., Sumaila, U. R., & Cheung, W. W. L. (2018). Projected amplification of food web bioaccumulation of MeHg and PCBs under climate change in the Northeastern Pacific. *Scientific Reports*, *8*(1), 13460. https://doi.org/10.1038/s41598-018-31824-5

Al Nasir, F., & Batarseh, M. I. (2008). Agricultural reuse of reclaimed water and uptake of organic compounds: Pilot study at Mutah University wastewater treatment plant, Jordan. *Chemosphere*, *72*(8), 1203–1214. https://doi.org/https://doi.org/10.1016/j.chemosphere.2008.01.064

Anand, S. S., Hawkes, C., de Souza, R. J., Mente, A., Dehghan, M., Nugent, R., … Popkin, B. M. (2015). Food consumption and its impact on cardiovascular disease: importance of solutions focused on the globalized food system: a report from the workshop convened by the World Heart Federation. *Journal of the American College of Cardiology*, *66*(14), 1590–1614. <https://doi.org/10.1016/j.jacc.2015.07.050>

Anderson, D., Ford, J. D., & Way, R. G. (2018). The impacts of climate and social changes on cloudberry (bakeapple) picking: a case study from southeastern Labrador. *Human Ecology*, *46*(6), 849–863. <https://doi.org/https://dx.doi.org/10.1007/s10745-018-0038-3>

Arctic Monitoring and Assessment Programme (AMAP). (2015). *AMAP Assessment 2015: Human health in the Arctic*. Oslo, Norway. <https://doi.org/10.3402/ijch.v75.33949>

Armitage, J. M., Quinn, C. L., & Wania, F. (2011). Global climate change and contaminants—an overview of opportunities and priorities for modelling the potential implications for long-term human exposure to organic compounds in the Arctic. *Journal of Environmental Monitoring*, *13*(6), 1532–1546. <https://doi.org/10.1039/C1EM10131E>

Arnell, N. W., Brown, S., Gosling, S. N., Gottschalk, P., Hinkel, J., Huntingford, C., … Zelazowski, P. (2016). The impacts of climate change across the globe: A multi-sectoral assessment. *Climatic Change*, *134*, 457–474. <https://doi.org/10.1007/s10584-014-1281-2>

Austin, S. E., Ford, J. D., Berrang-Ford, L., Biesbroek, R., & Ross, N. A. (2019). Enabling local public health adaptation to climate change. *Social Science & Medicine*, *220*, 236–244. <https://doi.org/10.1016/j.socscimed.2018.11.002>

Austin, S. E., Ford, J. D., Berrang-Ford, L., Biesbroek, R., Tosun, J., & Ross, N. A. (2018). Intergovernmental relations for public health adaptation to climate change in the federalist states of Canada and Germany. *Global Environmental Change*, *52*, 1–22. <https://doi.org/10.1016/j.gloenvcha.2018.07.010>

Bacon, S., Campbell, N., Raine, K., Tsuyuki, R., Khan, N., Arango, M., & Kaczorowski, J. (2019). Canada's new Healthy Eating Strategy: Implications for health care professionals and a call to action. *Canadian Pharmacists Journal/Revue des Pharmaciens du Canada*, *152*(3), 151–157. <https://doi.org/10.14288/hfjc.v12i1.275>

Baker-Austin, C., Trinanes, J., Gonzalez-Escalona, N., & Martinez-Urtaza, J. (2017). Non-Cholera Vibrios: The Microbial Barometer of Climate Change. *Trends in microbiology*, *25*(1), 76–84. https://doi.org/10.1016/j.tim.2016.09.008

Banerjee, S. K., Rutley, R., & Bussey, J. (2018). Diversity and dynamics of the Canadian coastal Vibrio community: an emerging trend detected in the temperate regions. *Journal of Bacteriology, 200*(15), e00787-17. https://doi.org/10.1128/jb.00787-17

Batal, M., Johnson-Down, L., Moubarac, J. C., Ing, A., Fediuk, K., Sadik, T., … Willows, N. (2017). Sociodemographic associations of the dietary proportion of ultra-processed foods in First Nations peoples in the Canadian provinces of British Columbia, Manitoba, Alberta and Ontario. *International Journal of Food Sciences and Nutrition*, *69*(6), 753–761. <https://doi.org/10.1080/09637486.2017.1412405>

Bates, P. (2007). Inuit and scientific philosophies about planning, prediction, and uncertainty. *Arctic Anthropology*, *44*(2), 87–100. <https://doi.org/10.1353/arc.2011.0065>

Beaudin-Reimer, B. (2020). Perspectives from Métis Harvesters in Manitoba on Concerns and Challenges to Sustaining Traditional Harvesting Practices and Knowledge: A Distinctions-Based Approach to Indigenous Food Sovereignty. In P. Settee, & S. Shukla (Eds.), *Indigenous Food Systems: Concepts, Cases, and Conversations* (pp. 229). Toronto, ON: Canadian Scholars.

Berner, J., Brubaker, M., Revitch, B., Kreummel, E., Tcheripanoff, M., & Bell, J. (2016). Adaptation in Arctic circumpolar communities: food and water security in a changing climate. *International Journal of Circumpolar Health*, *75*(1), 33820. <https://doi.org/10.3402/ijch.v75.33820>

Berrang-Ford, L., Biesbroek, R., Ford, J. D., Lesnikowski, A., Tanabe, A., Wang, F. M., … Heymann, S. J. (2019). Tracking global climate change adaptation among governments. *Nature Climate Change*, *9*, 440–449.

Berry, P., Clarke, K., Fleury, M. D., & Parker, S. (2014a). Human health. In F.J. Warren & D.S. Lemmen (Eds.), *Canada in a changing climate: sector perspectives on impacts and adaptation* (pp. 191–232). Ottawa, ON: Government of Canada.

Berry, P., Enright, P. M., Shumake-Guillemot, J., Villalobos Prats, E., & Campbell-Lendrum, D. (2018). Assessing health vulnerabilities and adaptation to climate change: a review of international progress. *International Journal of Environmental Research and Public Health*, *15*(12), 2626. <https://doi.org/10.3390/ijerph15122626>

Berry, P., Paterson, J., & Buse, C. (2014b). *Assessment of vulnerability to the health impacts of climate change in Middlesex-London*. London, ON.

Biehl, E., Buzogany, S., Baja, K., & Neff, R. (2018). Planning for a resilient urban food system: a case study from Baltimore City, Maryland. *Journal of Agriculture, Food Systems, and Community Development*, *8*(B), 39–53. <https://doi.org/10.5304/jafscd.2018.08B.008>

Bishop-Williams, K. E., Berke, O., Pearl, D. L., Hand, K., & Kelton, D. F. (2015). Heat stress related dairy cow mortality during heat waves and control periods in rural Southern Ontario from 2010–2012. *BMC Veterinary Research*, *11*(1), 291. <https://doi.org/10.1186/s12917-015-0607-2>

Blangy, S., Bernier, M., Bhiry, N., Jean-Pierre, D., Aenishaenslin, C., Bastian, S., … Rousse, D. (2018). OHMi-Nunavik: A multi-thematic and cross-cultural research program studying the cumulative effects of climate and socio-economic changes on Inuit communities. *Ecoscience*, *25*(4), 311–324. <https://doi.org/10.1080/11956860.2018.1542783>

Boeckman, C., & Bidwell, J. (2006). The effects of temperature, suspended solids, and organic carbon on copper toxicity to two aquatic invertebrates. *Water, Air, & Soil Pollution*, *171*(1–4), 185–202. <https://doi.org/10.1007/s11270-005-9036-3>

Bogdal, C., Schmid, P., Zennegg, M., Anselmetti, F. S., Scheringer, M., & Hungerbuhler, K. (2009). Blast from the past: melting glaciers as a relevant source for persistent organic pollutants. *Environmental Science & Technology*, *43*(21), 8173–8177. <https://doi.org/10.1021/es901628x>

Booth, S., & Zeller, D. (2005). Mercury, food webs, and marine mammals: implications of diet and climate change for human health. *Environmental Health Perspectives*, *113*(5), 521–526. <https://doi.org/10.1289/ehp.7603>

Boucher, O., Jacobson, S. W., Plusquellec, P., Dewailly, E., Ayotte, P., Forget-Dubois, N., Jacobson, J. L., & Muckle, G. (2012). Prenatal methylmercury, postnatal lead exposure, and evidence of attention deficit/hyperactivity disorder among Inuit children in Arctic Québec. *Environmental health perspectives*, *120*(10), 1456–1461. <https://doi.org/10.1289/ehp.1204976>

Boulanger-Lapointe, N. N., Gerin-Lajoie, J., Collier, L. S., Desrosiers, S., Spiech, C., Henry, G. H. R., … Cuerrier, A. (2019). Berry plants and berry picking in Inuit Nunangat: Traditions in a changing socio-ecological landscape. *Human Ecology*, *47*(1), 81–93. <https://doi.org/10.1007/s10745-018-0044-5>

Bowen, K. J., & Ebi, K. L. (2015). Governing the health risks of climate change: towards multi-sector responses. *Current Opinion in Environmental Sustainability*, *12*, 80–85. <https://doi.org/10.1016/j.cosust.2014.12.001>

Bowron, B., & Davidson, G. (2011). *Climate change adaptation planning: A Nunavut toolkit*. Ottawa, ON. Retrieved from <https://www.climatechangenunavut.ca/sites/default/files/nunavut_toolkit_final_2011_0.pdf>

Boxall, A. B. A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P. D., … Williams, R. J. (2009). Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. *Environmental Health Perspectives*, *117*(4), 508–514. <https://doi.org/10.1289/ehp.0800084>

Bradbear, C., & Friel, S. (2013). Integrating climate change, food prices and population health. *Food Policy*, *43*, 56–66. <https://doi.org/10.1016/J.FOODPOL.2013.08.007>

Breewood, H. (2018). *What is the nutrition transition? Foodsource: building blocks*. Retrieved from <https://www.tabledebates.org/building-blocks/what-nutrition-transition>

Broberg, C. A., Calder, T. J., & Orth, K. (2011). *Vibrio parahaemolyticus* cell biology and pathogenicity determinants. *Microbes and Infection*, *13*(12–13), 992–1001. <https://doi.org/10.1016/j.micinf.2011.06.013>

Brown, T. M., Macdonald, R. W., Muir, D., & Letcher, R. J. (2018). The distribution and trends of persistent organic pollutants and mercury in marine mammals from Canada's Eastern Arctic. *The Science of the Total Environment*, *618*, 500–517. <https://doi.org/10.1016/j.scitotenv.2017.11.052>

Brunn, A., Fisman, D. N., Sargeant, J. M., & Greer, A. L. (2019). The influence of climate and livestock reservoirs on human cases of Giardiasis. *EcoHealth, 16*(1), 116–127. <https://doi.org/10.1007/s10393-018-1385-7>

Buckman, A. H., Fisk, A. T., Parrott, J. L., Solomon, K. R., & Brown, S. B. (2007). PCBs can diminish the influence of temperature on thyroid indices in rainbow trout (*Oncorhynchus mykiss*). *Aquatic Toxicology*, *84*(3), 366–378. <https://doi.org/https://doi.org/10.1016/j.aquatox.2007.06.016>

Bunce, A., Ford, J., Harper, S., Edge, V., Namanya, D. B., Berrang-Ford, L., … Lwasa, S. (2016). Vulnerability and adaptive capacity of Inuit women to climate change: a case study from Iqaluit, Nunavut. *Natural Hazards*, *83*(3), 1419–1441. <https://doi.org/10.1007/s11069-016-2398-6>

Buse, C. G. (2018). Why should public health agencies across Canada conduct climate change and health vulnerability assessments? *Canadian Journal of Public Health*, *109*(5–6), 782–785. <https://doi.org/10.17269/s41997-018-0118-6>

Bush, E., & Lemmen, D. S. (Eds.). (2019). *Canada's changing climate report*. Ottawa, ON: Environment and Climate Change Canada.

Butler, A. J., Pintar, K. D. M., & Thomas, M. K. (2016). Estimating the relative role of various subcategories of food, water, and animal contact transmission of 28 enteric diseases in Canada. *Foodborne Pathogens and Disease*, *13*(2), 57–64. <https://doi.org/10.1089/fpd.2015.1957>

Butler, C. (2014a). *Climate change and global health*. Oxsfordshire, United Kingdom: Centre for Agriculture and Bioscience International. <https://doi.org/10.1079/9781780642659.0011>

Butler, C. (2014b). Food and water and climate change. In B. Freedman (Ed.), *Global Environmental Change* (pp. 629-648). Springer.

Cabello, A., Espejo, R., & Romero, J. (2005). Tracing in oysters (*Tiostrea chilensis*) using a Green Fluorescent Protein tag. *Journal of Experimental Marine Biology and Ecology, 327*(2), 157–166. <https://doi.org/10.1016/j.jembe.2005.06.009>

Cameron, E., Mearns, R., & McGrath, J. T. (2015). Translating climate change: adaptation, resilience, and climate politics in Nunavut, Canada. *Annals of the Association of American Geographers*, *105*(2), 274–283. <https://doi.org/10.1080/00045608.2014.973006>

Campbell, I. D., Durant, D. G., Hunter, K. L., & Hyatt, K. D. (2014). Food production. In F. J. Warren & D. S. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (pp. 99–134). Ottawa, ON: Natural Resources Canada.

Canadian Food Inspection Agency (CFIA). (2014). Food safety hazards. *Imported and Manufactured Food Program Inspection Manual*. Ottawa, ON.

Canadian Food Inspection Agency (CFIA). (2018). *Canadian Food Safety Information Network (CFSIN)*. Retrieved from <https://www.inspection.gc.ca/science-and-research/cfsin/eng/1525378586176/1525378959647>

Carrie, J., Wang, F., Sanei, H., Macdonald, R. W., Outridge, P. M., & Stern, G. A. (2010). Increasing contaminant burdens in an Arctic fish, Burbot (*Lota lota*), in a warming climate. *Environmental Science & Technology*, *44*(1), 316–322. <https://doi.org/10.1021/es902582y>

Challinor, A. J., Adger, W. N., & Benton, T. G. (2017). Climate risks across borders and scales. *Nature Climate Change*, (7), 621–623. <https://doi.org/10.1038/nclimate3380>

Chan, L., Batal, M., Sadik, T., Tikhonov, C., Schwartz, H., Fediuk, K., … Berti, P. (2019). *FNFNES Final Report for Eight Assembly of First Nations Regions: Draft Comprehensive Technical Report*. Ottawa, ON: Assembly of First Nations, University of Ottawa, & Université de Montréal.

Charlebois, S., McGuinty, E., Keselj, V., Music, J., Guisto, A., Kevany, K., … Moksyakov, A. (2020). Canada's *Food Price Report* 2020 (10th ed.). Dalhousie University, & University of Guelph. Retrieved from <https://www.foodincanada.com/wp-content/uploads/2019/12/Canada-Food-Price-Report-Eng-2020.pdf>

Charlebois, S., & Summan, A. (2015). A risk communication model for food regulatory agencies in modern society. *Trends in Food Science & Technology*, *45*(1), 153–165. <https://doi.org/10.1016/j.tifs.2015.05.004>

Charron, D., Fleury, M., Lindsay, L. R., Ogden, N., & Schuster, C. J. (2008). The impacts of climate change on water-, food-, vector and rodent-borne diseases. In J. Sèguin (Ed.), *Human health in a changing climate: A canadian assessment of vulnerabilities and adaptive capacity* (pp. 171–210). Ottawa, ON: Health Canada.

Chukmasov, P., Aksenov, A., Sorokina, T., Varakina, Y., Sobolev, N., & Nieboer, E. (2019). North Pacific Baleen Whales as a Potential Source of Persistent Organic Pollutants (POPs) in the Diet of the Indigenous Peoples of the Eastern Arctic Coasts. *Toxics*, *7*(4), 65. <https://doi.org/10.3390/toxics7040065>

Cidro, J., Martens, T. R., Zahayko, L., & Lawrence, H. P. (2018). First foods as Indigenous food sovereignty: Country foods and breastfeeding practices in a Manitoban First Nations community. *Canadian Food Studies/La Revue Canadienne Des Études Sur l'alimentation*, *5*(2), 25–43.

Cisneros-Montemayor, A. M., Pauly, D., Weatherdon, L. V., & Ota, Y. (2016). A global estimate of seafood consumption by coastal indigenous peoples. *PloS One*, *11*(12), e0166681.

City of Calgary. (2012). *Calgary Eats! A Food System Assessment and Action Plan for Calgary*. Calgary, AB.

City of Castlegar. (2010). *Adapting to climate change project summary report & action plan*. Castlegar, BC.

City of Montreal. (2015). *Climate change adaptation plan for the Montreal urban agglomeration 2015-2010: Adaptation measures*. Montreal, QC.

City of Surrey. (2013). *Community Climate Action Strategy*. Surrey, BC.

City of Toronto. (2019). *Toronto's first resilience strategy*. Toronto, ON.

City of Toronto Environment Office. (2008). *Ahead of the storm: Preparing Toronto for climate change*. Toronto, ON.

City of Windsor. (2012). *City of Windsor Climate Change Adaptation Plan*. Windsor, ON.

Clarke, K. L., & Berry, P. (2012). From theory to practice: A Canadian case study of the utility of climate change adaptation frameworks to address health impacts. *International Journal of Public Health*, *57*, 167–174. <https://doi.org/10.1007/s00038-011-0292-2>

Collings, P., Marten, M. G., Pearce, T., & Young, A. G. (2016). Country food sharing networks, household structure, and implications for understanding food insecurity in Arctic Canada. *Ecology of Food and Nutrition*, *55*(1), 30–49. <https://doi.org/10.1080/03670244.2015.1072812>

Comeau, A. M., & Suttle, C. A. (2007). Distribution, genetic richness and phage sensitivity of *Vibrio spp.* from coastal British Columbia. *Environmental Microbiology, 9*(7), 1790–1800. <https://doi.org/10.1111/j.1462- 2920.2007.01299.x>

Confalonieri, U., Menne, B., Akhtar, R., Ebi, K. L., Hauengue, M., Kovats, R.., … Woodward, A. (2007). Human Health. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 391–431). Cambridge, United Kingdom: Cambridge University Press.

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., … Patterson, C. (2009). Managing the health effects of climate change. *The Lancet*, *373*, 1693. <https://doi.org/10.1016/S0140-6736(09)60935-1>

Coulombe, G., Catford, A., Martinez-Perez, A., & Buenaventura, E. (2020). Outbreaks of *Escherichia coli* O157:H7 infections linked to romaine lettuce in Canada from 2008 to 2018: An analysis of food safety context. *Journal of Food Protection, 83*(8), 1444–1462. <https://doi.org/10.4315/JFP-20-029>

Council of Canadian Academies (CCA). (2014). *Aboriginal food security in Northern Canada: an assessment of the state of knowledge*. Ottawa, ON.

Council of Canadian Academies (CCA). (2019). *Canada's top climate change risks: the expert panel on climate change risks and adaptation potential*. Ottawa, ON.

Cousins, M., Sargeant, J. M., Fisman, D., & Greer, A. L. (2019). Modelling the transmission dynamics of Campylobacter in Ontario, Canada, assuming houseflies, *Musca domestica*, are a mechanical vector of disease transmission. *Royal Society Open Science*, *6*(2), 181394. <https://doi.org/10.1098/rsos.181394>

Crown-Indigenous Relations and Northern Affiars Camada (CIRNAC). (2018). *Climate change preparedness in the North program*. Retrieved from <https://www.rcaanc-cirnac.gc.ca/eng/1481305554936/1594738066665>

Crown-Indigenous Relations and Northern Affiars Camada (CIRNAC). (2019). *First Nation adapt program.* Retrieved from <https://www.rcaanc-cirnac.gc.ca/eng/1481305681144/1594738692193>

David, J. M., Pollari, F., Pintar, K. D. M., Nesbitt, A., Butler, A. J., & Ravel, A. (2017). Do contamination of and exposure to chicken meat and water drive the temporal dynamics of Campylobacter cases? *Epidemiology and Infection*, *145*(15), 3191–3203. <https://doi.org/10.1017/S0950268817002199>

de Coninck, H., Revi, A., Babiker, M., Bertoldi, P., Buckeridge, M., Cartwright, A., … Sugiyama, T. (2018). Strengthening and Implementing the Global Response. In V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, … T. Waterfield (Eds.), *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,* (p. 132). Cambridge, United Kingdom: Cambridge University Press.

Delcour, I., Spanoghe, P., & Uyttendaele, M. (2015). Literature review: Impact of climate change on pesticide use. *Food Research International*, *68*, 7–15. <https://doi.org/https://doi.org/10.1016/j.foodres.2014.09.030>

Delormier, T., Horn-Miller, K., McComber, A. M., & Marquis, K. (2017). Reclaiming food security in the Mohawk community of Kahnawà:ke through Haudenosaunee responsibilities. *Maternal & Child Nutrition*, *13*(S3), e12556. <https://doi.org/10.1111/mcn.12556>

Desmarais, A. A., & Wittman, H. (2014). Farmers, foodies and First Nations: getting to food sovereignty in Canada. *Journal of Peasant Studies*, *41*(6), 1153–1173. <https://doi.org/10.1080/03066150.2013.876623>

Dewailly, É., Ayotte, P., Bruneau, S., Lebel, G., Levallois, P., & Weber, J. P. (2000). Exposure of the Inuit population of Nunavik (Arctic Québec) to lead and mercury. *Archives of Environmental Health: An International Journal*, *56*(4), 350–357. <https://doi.org/10.1080/00039890109604467>

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian Journal of Public Health*, *109*(3), 327–337. <https://doi.org/10.17269/s41997-018-0070-5>

Dorward, C., Smukler, S. M., & Mullinix, K. (2017). A novel methodology to assess land-based food self-reliance in the Southwest British Columbia bioregion. *Renewable Agriculture and Food Systems*, *32*(2), 112–130. <https://doi.org/10.1017/S1742170516000053>

Duarte, S. C., Pena, A., & Lino, C. M. (2010). A review on ochratoxin A occurrence and effects of processing of cereal and cereal derived food products. *Food Microbiology*, 27(2), 187–198. <https://doi.org/10.1016/j.fm.2009.11.016>

Dupuis, J., & Biesbroek, R. (2013). Comparing apples and oranges: The dependent variable problem in comparing and evaluating climate change adaptation policies. *Global Environmental Change*, *23*(6), 1476–1487. <https://doi.org/10.1016/j.gloenvcha.2013.07.022>

Eagles-Smith, C. A., Wiener, J. G., Eckley, C. S., Willacker, J. J., Evers, D. C., Marvin-dipasquale, M., … Ackerman, J. T. (2016). Mercury in western North America: A synthesis of environmental contamination, fluxes, bioaccumulation, and risk to fish and wildlife. *Science of the Total Environment*, *568*, 1213–1226. <https://doi.org/10.1016/j.scitotenv.2016.05.094>

Easterling, W., Aggarwal, P., Batima, P., Brander, K., Erda, L., Howden, S., … Tubiello, F. (2007). Food, fibre and forest products. In M. Parry, O. Canziani, J. Palutikof, P. van der Linden, & C. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 273–313). Cambridge, United Kingdom: Cambridge University Press.

Ebi, K. L. (2009). Public health responses to the risks of climate variability and change in the United States. *Journal of Occupational and Environmental Medicine*, *51*(1), 4–12. <https://doi.org/10.1097/JOM.0b013e31816fd67b>

Ebi, K. L., Berry, P., Hayes, K., Boyer, C., Sellers, S., Enright, P. M., & Hess, J. J. (2018). Stress testing the capacity of health systems to manage climate change-related shocks and stresses. *International Journal of Environmental Research and Public Health*, *15*(11), 2370. <https://doi.org/10.3390/ijerph15112370>

Ebi, K. L., & Hess, J. J. (2017). The past and future in understanding the health risks of and responses to climate variability and change. *International Journal of Biometeorology*, *61*(S1), 71–80. <https://doi.org/10.1007/s00484-017-1406-1>

Ebi, K. L., Ogden, N. H., Semenza, J. C., & Woodward, A. (2017). Detecting and attributing health burdens to climate change. *Environmental Health Perspectives*, *125*(8), 085004. <https://doi.org/10.1289/EHP1509>

Ebi, K. L., & Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine*, *35*(5), 501–507. <https://doi.org/10.1016/j.amepre.2008.08.018>

Edwards, F., Dixon, J., Friel, S., Hall, G., Larsen, K., Lockie, S., … Hattersley, L. (2011). Climate change adaptation at the intersection of food and health. *Asia Pacific Journal of Public Health*, *23*(2), 91S-104S. <https://doi.org/10.1177/1010539510392361>

Egeland, G. M. (2010). *Inuit Health Survey 2007-2008*. Montreal, QC. Retrieved from <https://www.mcgill.ca/cine/files/cine/adult_report_nunavut.pdf>

Environment and Climate Change Canada (ECCC). (2017). *High and dry in the East.*

Environment and Climate Chance Canada (ECCC). (2018). *Canadian centre for climate modelling and analysis*. Retrieved from <http://climate-modelling.canada.ca/data/data.shtml>

Ericksen, P. J. (2008). Conceptualizing food systems for global environmental change research. *Global Environmental Change*, *18*(1), 234–245. <https://doi.org/10.1016/j.gloenvcha.2007.09.002>

European Food Safety Authority (EFSA), Maggiore, A., Afonso, A., Barrucci, F., & Sanctis, G. D. (2020). Climate change as a driver of emerging risks for food and feed safety, plant, animal health and nutritional quality. *EFSA Supporting Publications*, *17*(6), 1881E. doi:10.2903/sp.efsa.2020.EN-1881

Fanzo, J., Davis, C., McLaren, R., & Choufani, J. (2018). The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security*, *18*, 12–19. <https://doi.org/10.1016/J.GFS.2018.06.001>

Ferguson, A., Penney, R., & Solo-Gabriele, H. (2017). A review of the field on children's exposure to environmental contaminants: a risk assessment approach. *International Journal of Environmental Research and Public Health*, *14*(3), 265. <https://doi.org/10.3390/ijerph14030265>

Fillion, M., Laird, B., Douglas, V., Van Pelt, L., Archie, D., & Chan, H. M. (2014). Development of a strategic plan for food security and safety in the Inuvialuit settlement region, Canada. *International Journal of Circumpolar Health*, *73*(1), 25091. <https://doi.org/10.3402/ijch.v73.25091>

First Nations Information Governance centre (FNIGC). (2018). *National Report of the First Nations Regional Health Survey Phase 3: Volume 2*. Ottawa, ON.

Fleury, M., Charron, D. F., Holt, J. D., Allen, O. B., & Maarouf, A. R. (2006). A time series analysis of the relationship of ambient temperature and common bacterial enteric infections in two Canadian provinces. *International Journal of Biometeorology*, *50*(6), 385–391. <https://doi.org/10.1007/s00484-006-0028-9>

Flynn, M., Ford, J. D., Pearce, T., Harper, S. L., & Team, I. R. (2018). Participatory scenario planning and climate change impacts, adaptation and vulnerability research in the Arctic. *Environmental Science & Policy*, *79*, 45–53. <https://doi.org/10.1016/j.envsci.2017.10.012>

Food and Agriculture Organization of the United Nations (FAO). (1996). Rome declaration on world food security and World Food Summit Plan of Action. In *World Food Summit* (pp. 1–25). <https://doi.org/10.1163/ilwo-iiin2>

Food and Agriculture Organization of the United Nations (FAO). (2008). *Climate change and food security: A framework document*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). (2015). *Climate change and food systems: Global assessments and implications for food security and trade*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). (2016). *Climate change and food security: Risks and responses*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO), International Fund for Agriculture Development (IFAD), United Nations Children's Fund (UNICEF), World Food Programme (WFP), & World Health Organization (WHO). (2018). *The state of food security and nutrition in the world: Building climate resilience for food security and nutrition*. Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO), & World Health Organization (WHO). (2011). *Risk assessment of* Vibrio parahaemolyticus *in seafood: interpretive summary and technical report*. Rome, Italy.

Food and Drug Administration (FDA). (2005). *Quantitative risk assessment on the public health impact of pathogenic* Vibrio parahaemolyticus *in raw oysters*. Retrieved from <https://www.fda.gov/food/cfsan-risk-safety-assessments/quantitative-risk-assessment-public-health-impact-pathogenic-vibrio-parahaemolyticus-raw-oysters>

Ford, J. D. (2008). Vulnerability of Inuit food systems to food insecurity as a consequence of climate change: a case study from Igloolik, Nunavut. *Regional Environmental Change*, *9*, 83–100. <https://doi.org/10.1007/s10113-008-0060-x>

Ford, J. D. (2009). Dangerous climate change and the importance of adaptation for the Arctic's Inuit population. *Environmental Research Letters*, *4*(2), 024006. <https://doi.org/10.1088/1748-9326/4/2/024006>

Ford, J. D., & Beaumier, M. (2011). Feeding the family during times of stress: experience and determinants of food insecurity in an Inuit community. *The Geographical Journal*, *177*(1), 44–61. <https://doi.org/http://dx.doi.org/10.1111/j.1475-4959.2010.00374.x>

Ford, J. D., Berrang-Ford, L., King, M., & Furgal, C. (2010). Vulnerability of Aboriginal health systems in Canada to climate change. *Global Environmental Change*, *20*(4), 668–680. <https://doi.org/10.1016/j.gloenvcha.2010.05.003>

Ford, J. D., Clark, D. G., & Naylor, A. W. (2019). Food insecurity in Nunavut: Are we going from bad to worse? *Canadian Medical Association Journal*, *191*(20), E550–E551. <https://doi.org/10.1503/cmaj.190497>

Ford, J. D., Falk, K., Tesar, C., & Jacobsen, R. B. (2018). Adaptation and resilience. In *Adaptation Actions for a Changing Arctic: Perspectives from the Baffin Bay/Davis Strait region* (pp. 307–328). Oslo, Norway: Arctic Monitoring and Assessment Programme (AMAP).

Ford, J. D., & King, D. (2015). A framework for examining adaptation readiness. *Mitigation and Adaptation Strategies for Global Change*, *20*, 505–526. 10.1007/s11027-013-9505-8

Ford, J. D., Lardeau, M.-P., Blackett, H., Chatwood, S., & Kurszewski, D. (2013). Community food program use in Inuvik, Northwest Territories. *BMC Public Health*, *13*(1), 970. <https://doi.org/10.1186/1471-2458-13-970>

Ford, J. D., Tilleard, S., Berrang-Ford, L., Araos, M., Biesbroek, R., Lesnikowski, A., … Bizikova, L. (2016). Opinion: Big data has big potential for applications to climate change adaptation. *Proceedings of the National Academy of Sciences*, *113*(39), 10729–10732. <https://doi.org/10.1073/pnas.1614023113>

Ford, J. D., Willox, A. C., Chatwood, S., Furgal, C., Harper, S., Mauro, I., & Pearce, T. (2014). Adapting to the effects of climate change on Inuit health. *American Journal of Public Health*, *104*(S3), e9–e17. <https://doi.org/10.2105/AJPH.2013.301724>

Friel, S. (2019). It's a consumptagenic world. In N. Krieger (Ed.), *Climate Change and People's Health* (pp. 57–112). New York, NY: Oxford University Press. <https://doi.org/doi:10.1093/oso/9780190492731.001.0001>

Friel, S., Bowen, K., Campbell-Lendrum, D., Frumkin, H., McMichael, A. J. J., & Rasanathan, K. (2011). Climate change, noncommunicable diseases, and development: the relationships and common policy opportunities. *Annual Review of Public Health*, *32*, 133–147. <https://doi.org/10.1146/annurev-publhealth-071910-140612>

Friel, S., & Ford, L. (2015). Systems, food security and human health. *Food Security*, *7*(2), 437–451. <https://doi.org/10.1007/s12571-015-0433-1>

Gaden, A., Ferguson, S. H., Harwood, L., Melling, H., Alikamik, J., & Stern, G. A. (2012). Western Canadian Arctic ringed seal organic contaminant trends in relation to sea ice break-up. *Environmental Science & Technology*, *46*(8), 4427–4433. <https://doi.org/10.1021/es204127j>

Gagné, D., Blanchet, R., Lauziere, J., Vaissière, É., Vézina, C., Ayotte, P., … Turgeon O'Brien, H. (2012). Traditional food consumption is associated with higher nutrient intakes in Inuit children attending childcare centres in Nunavik. *International Journal of Circumpolar Health*, *71*(1), 18401. <https://doi.org/10.3402/ijch.v71i0.18401>

Gibson, K., Kneen, C., & Houghton, J. (2004). *Making the connection: food security and public health*. The Community Nutritionists Council of BC. Retrieved from <https://bcfoodsecuritygateway.ca/wp-content/uploads/sites/2/2015/11/Making_the_Connection.pdf>

Golden, C. D., Allison, E. H., Cheung, W. W. L., Dey, M. M., Halpern, B. S., McCauley, D. J., … Myers, S. S. (2016). Nutrition: fall in fish catch threatens human health. *Nature*, *534*(7607), 317–320. <https://doi.org/10.1038/534317a>

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K., & Wiltshire, A. (2010). Implications of climate change for agricultural productivity in the early twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1554), 2973–2989. <https://doi.org/10.1098/rstb.2010.0158>

Goulson, D., Derwent, L. C., Hanley, M. E., Dunn, D. W., & Abolins, S. R. (2005). Predicting calyptrate fly populations from the weather, and probable consequences of climate change. *Journal of Applied Ecology*, *42*(5), 795–804. <https://doi.org/10.1111/j.1365-2664.2005.01078.x>

Government of Canada. (2016). *Environmental Contaminants*. Retrieved from <https://www.canada.ca/en/health-canada/services/food-nutrition/food-safety/chemical-contaminants/environmental-contaminants.html>

Government of Canada. (2017). *Canadian Arctic Contaminants Assessment Report: Human Health Assessment 2017* (M. S. Curren, Ed.). Ottawa, ON. Retrieved from <https://unh.app.box.com/file/412682049405>

Government of Canada. (2019). *Diseases and conditions*. Retrieved from <https://www.canada.ca/en/public-health/services/diseases.html>

Government of Canada. (2020). *Treaties and agreements*. Retrieved from <https://www.rcaanc-cirnac.gc.ca/eng/1100100028574/1529354437231>

Government of Northwest Territories. (2018). *2030 NWT climate change strategic framework*. Retrieved from <https://www.enr.gov.nt.ca/en/services/climate-change/2030-nwt-climate-change-strategic-framework>

Government of Nunavut, Government of Northwest Territories, & Government of Yukon. (2011). *Pan-territorial adaptation strategy: Moving forward on climate change adaptation in Canada's north*. Retrieved from <https://www.northernadaptation.ca/sites/default/files/Pan-Territorial_Adaptation_Strategy.pdf>

Government of Yukon. (2014). *Climate Change & public health*. Whitehorse, YK.

Greenwood, M., de Leeuw, S., & Lindsay, N. (2018). Challenges in health equity for Indigenous peoples in Canada. *The Lancet*, *391*(10131), 1645–1648. <https://doi.org/10.1016/S0140-6736(18)30177-6>

Greer, A., Ng, V., & Fisman, D. (2008). Climate change and infectious diseases in North America: the road ahead. *Canadian Medical Association Journal*, *178*(6), 715. <https://doi.org/10.1503/CMAJ.081325>

Gregory, P., Ingram, J., & Brklacich, M. (2005). Climate change and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *360*(1463), 2139–2148. <https://doi.org/10.1098/rstb.2005.1745>

Grey Bruce Health Unit. (2017). *Climate change and public health in Grey Bruce Health Unit: current conditions and future projections*. Owen Sound, ON.

Grey, S., & Patel, R. (2015). Food sovereignty as decolonization: Some contributions from Indigenous movements to food system and development politics. *Agriculture & Human Values*, *32*(3), <https://doi.org/431–444. 10.1007/s10460-014-9548-9>

Grimes, D. J., Johnson, C. N., Dillon, K. S., Flowers, A. R., Noriea, N. F., 3rd, & Berutti, T. (2009). What genomic sequence information has revealed about Vibrio ecology in the ocean--a review. *Microbial ecology*, *58*(3), 447–460. <https://doi.org/10.1007/s00248-009-9578-9>

Grothmann, T., & Patt, A. (2005). Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change*, *15*(3), 199–213. <https://doi.org/https://doi.org/10.1016/j.gloenvcha.2005.01.002>

Guyadeen, D., Thistlethwaite, J., & Henstra, D. (2019). Evaluating the quality of municipal climate change plans in Canada. *Climatic Change*, *152*, 121–143. <https://doi.org/10.1007/s10584-018-2312-1>

Hald, B., Skovgård, H., Pedersen, K., & Bunkenborg, H. (2008). Influxed insects as vectors for *Campylobacter jejuni* and *Campylobacter coli* in Danish broiler houses. *Poultry Science*, *87*(7), 1428–1434. <https://doi.org/10.3382/ps.2007-00301>

Halifax Regional Municipality. (2010). *HRM climate SMART community action guide to climate change and emergency preparedness*.

Halseth, R. (2015). *The nutritional health of the First Nations and Métis of the Northwest Territories: A review of current knowledge and gaps*. Prince George, BC. Retrieved from <http://www.nccah-ccnsa.ca/Publications/Lists/Publications/Attachments/141/2015_04_21_RPT_DietNutritionNWT_EN_Web.pdf>

Hansen, L. J., & Hoffman, J. R. (2011). Assessing vulnerability to climate change. In *Climate Savvy* (pp. 55–69). Island Press. <https://doi.org/10.5822/978-1-59726-988-9_5>

Harper, S. L., Berrang-Ford, L., Carcamo, C., Cunsolo, A., Edge, V. L., Ford, J. D., … Namanya, D. B. (2019). The Indigenous Climate–Food–Health Nexus. In L. R. Mason, & J. Rigg (Eds.), *People and Climate Change: Vulnerability, Adaptation, and Social Justice* (pp. 184-207). Oxford University Press.

Harper, S. L., Edge, V. L., Ford, J., Cunsolo, A., Wood, M., Team, I. R., … Namanya, D. B. (2015a). Climate-sensitive health priorities in Nunatsiavut, Canada. *BMC Public Health*, *15*(1), 605. <https://doi.org/10.1186/s12889-015-1874-3>

Harper, S. L., Edge, V. L., Ford, J., Thomas, M. K., Pearl, D. L., Shirley, J., … McEwen, S. A. (2015b). Acute gastrointestinal illness in two Inuit communities: burden of illness in Rigolet and Iqaluit, Canada. *Epidemiology and Infection*, *143*(14), 3048–3063. <https://doi.org/10.1017/S0950268814003744>

Harper, S. L., Edge, V. L., Ford, J., Thomas, M. K., Pearl, D. L., Shirley, J., … McEwen, S. A. (2015c). Healthcare use for acute gastrointestinal illness in two Inuit communities: Rigolet and Iqaluit, Canada. *International Journal of Circumpolar Health*, *74*, 26290. <https://doi.org/10.3402/ijch.v74.26290>

Harper, S. L., Edge, V. L., Schuster-Wallace, C. J., Ar-Rushdi, M., & McEwen, S. A. (2011). Improving Aboriginal health data capture: evidence from a health registry evaluation. *Epidemiology and Infection*, *139*(11), 1774—1783. <https://doi.org/10.1017/s095026881000275x>

Health Canada. (2019). *Climate Change and Health Adaptation Capacity Building Program (HealthADAPT)*. Retrieved from <https://www.canada.ca/en/health-canada/news/2019/04/backgrounder-climate-change-and-health-adaptation-capacity-building-program-healthadapt.html>

Health Canada. (2020). *Determining food security status*. Retrieved from <https://www.canada.ca/en/health-canada/services/food-nutrition/food-nutrition-surveillance/health-nutrition-surveys/canadian-community-health-survey-cchs/household-food-insecurity-canada-overview/determining-food-security-status-food-nutrition-surveillance-health-canada.html>

Hedlund, C., Blomstedt, Y., & Schumann, B. (2014). Association of climatic factors with infectious diseases in the Arctic and subarctic region – a systematic review. *Global Health Action*, *7*(1), 24161. <https://doi.org/10.3402/gha.v7.24161>

Heiman, K. E., Mody, R. K., Johnson, S. D., Griffin, P. M., & Gould, L. H. (2015). *Escherichia coli* O157 outbreaks in the United States, 2003–2012. *Emerging Infectious Diseases*, *21*(8), 1293. <https://doi.org/10.3201/eid2108.141364>

Hellberg, R. S., & Chu, E. (2015). Effects of climate change on the persistence and dispersal of foodborne bacterial pathogens in the outdoor environment: A review. *Critical Reviews in Microbiology*, *42*(4), 548–572. <https://doi.org/10.3109/1040841X.2014.972335>

Henstra, D. (2017). Climate adaptation in Canada : Governing a complex policy regime. *Review of Policy Research*, *34*(3), 378–399. <https://doi.org/10.1111/ropr.12236>

Hess, J. J., McDowell, J. Z., & Luber, G. (2012). Integrating climate change adaptation into public health practice: using adaptive management to increase adaptive capacity and build resilience. *Environmental Health Perspectives*, *120*(2), 171–179. <https://doi.org/10.1289/ehp.1103515>

High Level Panel of Experts (HLPE). (2017). *Nutrition and food systems*. Rome, Italy. Retrieved from <http://www.fao.org/3/i7846e/i7846e.pdf>

Huang, C., Vaneckova, P., Wang, X., FitzGerald, G., Guo, Y., & Tong, S. (2011). Constraints and barriers to public health adaptation to climate change: a review of the literature. *American Journal of Preventive Medicine*, *40*(2), 183–190. <https://doi.org/10.1016/J.AMEPRE.2010.10.025>

Huet, C., Rosol, R., & Egeland, G. M. (2012). The prevalence of food insecurity is high and the diet quality poor in Inuit communities. *The Journal of Nutrition*, *142*(3), 541–547. <https://doi.org/10.3945/jn.111.149278>

Ingram, J. (2009). Food system concepts. In R. Rabbinge & A. Linneman (Eds.), *European food systems in a changing world* (pp. 9–15). ESF-COST.

Institute for Health Metrics and Evaluation (IHME). (2016). *Global burden of disease arrow diagram.*

Institut national de santé publique du Québec (INSPQ). (n.d.). *Mon Climat, Ma Santé*. Retrieved from <http://www.monclimatmasante.qc.ca/>

Intergovernmental Panel on Climate Change (IPCC). (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change* (V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, … T. Waterfield, Eds.). Retrieved from <https://www.ipcc.ch/sr15/>

Intergovernmental Panel on Climate Change (IPCC). (2019a). *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (P. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. Roberts, … J. Malley, Eds.). Retrieved from <https://www.ipcc.ch/srccl/>

Intergovernmental Panel on Climate Change (IPCC). (2019b). *Special Report on the Ocean and Cryosphere in a Changing Climate* (H.-O. Pörtner, D. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, … N. Weyer, Eds.). Retrieved from <https://www.ipcc.ch/srocc/>

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (2018). *The regional assessment report on biodiversity and ecosystem services for the Americas* (J. Rice, C. S. Seixas, M. E. Zaccagnini, M. Bedoya- Gaitán, N. Valderrama, C. B. Anderson, … J. S. Farinaci, Eds.). Germany: Bonn.

Inuit Tapiriit Kanatami (ITK). (2019). *National Inuit Climate Change Strategy*. Retrieved from <https://www.itk.ca/wp-content/uploads/2019/06/ITK_Climate-Change-Strategy_English.pdf>

Jaykus, L., Woolridge, M., Frank, J., Miraglia, M., McQuatters-Gollop, A., Tirado, C., … Friel, M. (2008). *Climate change: Implications for food safety*. Rome, Italy.

Jenkins, E. J., Castrodale, L. J., de Rosemond, S. J. C., Dixon, B. R., Elmore, S. A., Gesy, K. M., … Thompson, R. C. A. (2013). Tradition and transition: parasitic zoonoses of people and animals in Alaska, Northern Canada, and Greenland. *Advances in Parasitology*, *82*, 33–204. <https://doi.org/10.1016/B978-0-12-407706-5.00002-2>

Jessiman-Perreault, G., & McIntyre, L. (2017). The household food insecurity gradient and potential reductions in adverse population mental health outcomes in Canadian adults. *SSM - Population Health*, *3*, 464–472. <https://doi.org/10.1016/j.ssmph.2017.05.013>

Jiménez Cisneros, B. E., Oki, T., Arnell, N. W., Benito, G., Cogley, J. G., Doll, P., … Mwakalila, S. S. (2014). Freshwater Resources. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 229–269). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Johnson-Down, L., & Egeland, G. M. (2010). Adequate nutrient intakes are associated with traditional food consumption in Nunavut Inuit children aged 3–5 years. *The Journal of Nutrition*, *140*(7), 1311–1316. <https://doi.org/10.3945/jn.109.117887>

Julie, D., Solen, L., Antoine, V., Jaufrey, C., Annick, D., & Dominique, H.-H. (2010). Ecology of pathogenic and non-pathogenic *Vibrio parahaemolyticus* on the French Atlantic coast. Effects of temperature, salinity, turbidity and chlorophyll a. *Environmental Microbiology*, *12*(4), 929–937. <https://doi.org/10.1111/j.1462- 2920.2009.02136.x>

Jung, J. K. H., & Skinner, K. (2017). Enteric Disease Outbreaks: Foodborne and waterborne illness among Canadian Indigenous populations: A scoping review. *Canada Communicable Disease Report*, *43*(1), <https://doi.org/7.10.14745/ccdr.v43i01a02>

Kapilashrami, A., & Hankivsky, O. (2018). Intersectionality and why it matters to global health. *The Lancet*, *391*(10140), 2589–2591. <https://doi.org/10.1016/S0140-6736(18)31431-4>

Keen, J. E., Laegreid, W. W., Chitko Mckown, C. G., Bono, J. L., Fox, J. M., Clawson, M., & Heaton, M. (2003). Effect of exogenous glucocorticoids and dietary change on winter and summer STEC O157 fecal shedding in naturally-infected beef cattle. In *Research Workers in Animal Diseases Conference Proceedings*.

Kenny, T.-A., Fillion, M., Simpkin, S., Wesche, S. D., & Chan, H. M. (2018). Caribou (*Rangifer tarandus*) and Inuit nutrition security in Canada. *EcoHealth*, *15*(3), 590–607. <https://doi.org/10.1007/s10393-018-1348-z>

Kermoal, N., & Altamirano-Jiménez, I. (Eds.). (2016). *Living on the land: Indigenous women's understanding of place*. Athabasca University Press.

Khan, S., Barhoumi, R., Burghardt, R., Liu, S., Kim, K., & Safe, S. (2006). Molecular mechanism of inhibitory aryl hydrocarbon receptor-estrogen receptor/Sp1 cross talk in breast cancer cells. *Molecular Endocrinology*, *20*(9), 2199–2214. <https://doi.org/10.1210/me.2006-0100>

King, U., & Furgal, C. (2014). Is hunting still healthy? Understanding the interrelationships between indigenous participation in land-based practices and human-environmental health. *International Journal of Environmental Research and Public Health*, *11*(6), 5751–5782. <https://doi.org/10.3390/ijerph110605751>

Kipp, A., Cunsolo, A., Vodden, K., King, N., Manners, S., & Harper, S. L. (2019). Climate change impacts on health and wellbeing in rural and remote regions across Canada: A synthesis of the literature. *Health Promotion and Chronic Disease Prevention in Canada*, *39*(4). <https://doi.org/10.24095/hpcdp.39.4.02>

Konrad, S., Paduraru, P., Romero-Barrios, P., Henderson, S. B., & Galanis, E. (2017). Remote sensing measurements of sea surface temperature as an indicator of *Vibrio parahaemolyticus* in oyster meat and human illnesses. *Environmental Health*, *16*(1), 92. <https://doi.org/https://dx.doi.org/10.1186/s12940-017-0301-x>

Kovats, R. S., Edwards, S. J., Hajat, S., Armstrong, B. G., Ebi, K. L., & Menne, B. (2004). The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. *Epidemiology & Infection*, *132*(3), 443–453. <https://doi.org/10.1017/s0950268804001992>

Kuhnlein, H. V, & Chan, H. M. (2000). Environment and contaminants in traditional food systems of Northern Indigenous peoples. *Annual Review of Nutrition*, *20*(1), 595–626. <https://doi.org/10.1146/annurev.nutr.20.1.595>

Labbé, J., Ford, J. D., Araos, M., & Flynn, M. (2017). The government-led climate change adaptation landscape in Nunavut, Canada. *Environmental Reviews*, *25*(1), 12–25. <https://doi.org/10.1139/er-2016-0032>

Lafferty, K. D., Porter, J. W., & Ford, S. E. (2004). Are diseases increasing in the ocean? *Annual Review of Ecology, Evolution, and Systematics*, *35*, 31–54. <https://doi.org/10.1146/annurev.ecolsys.35.021103.105704>

Laidler, G. J., Ford, J. D., Gough, W. A., Ikummaq, T., Gagnon, A. S., Kowal, S., … Irngaut, C. (2009). Travelling and hunting in a changing Arctic: assessing Inuit vulnerability to sea ice change in Igloolik, Nunavut. *Climatic Change*, *94*, 363–397. <https://doi.org/10.1007/s10584-008-9512-z>

Lake, I. R. (2017). Food-borne disease and climate change in the United Kingdom. *Environmental Health*, *16*(S1), 117. <https://doi.org/10.1186/s12940-017-0327-0>

Lake, I. R., & Barker, G. C. (2018). Climate change, foodborne pathogens and illness in higher-income countries. *Current Environmental Health Reports*, *5*(1), 187–196. <https://doi.org/10.1007/s40572-018-0189-9>

Lake, I. R., Foxall, C. D., Fernandes, A., Lewis, M., Rose, M., White, O., … Mortimer, D. (2015). The effects of flooding on dioxin and PCB levels in food produced on industrial river catchments. *Environment International*, *77*, 106–115. <https://doi.org/10.1016/J.ENVINT.2015.01.006>

Lake, I. R., Foxall, C. D., Lovett, A. A., Fernandes, A., Dowding, A., White, S., & Rose, M. (2005). Effects of river flooding on PCDD/F and PCB levels in cows' milk, soil, and grass. *Environmental Science & Technology*, *39*(23), 9033–9038. <https://doi.org/10.1021/es051433a>

Lake, I. R., Gillespie, I. A., Bentham, G., Nichols, G. L., Lane, C., Adak, G. K., & Threlfall, E. J. (2009). A re-evaluation of the impact of temperature and climate change on foodborne illness. *Epidemiology & Infection*, *137*(11), 1538–1547. <https://doi.org/0.1017/S0950268809002477>

Lake, I. R., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A. B. A., Draper, A., … Waldron, K. W. (2012). Climate change and food security: health impacts in developed countries. *Environmental Health Perspectives*, *120*(11), 1520–1526. <https://doi.org/10.1289/ehp.1104424>

Lal, A., Hales, S., French, N., & Baker, M. G. (2012). Seasonality in human zoonotic enteric diseases: a systematic review. *PLoS One*, *7*(4), e31883. <https://doi.org/10.1371/journal.pone.0031883>

Lam, S., Dodd, W., Skinner, K., Papadopoulos, A., Zivot, C., Ford, J., … Harper, S. L. (2019). Community-based monitoring of Indigenous food security in a changing climate: global trends and future directions. *Environmental Research Letters*, *14*(7), 073002. <https://doi.org/10.1088/1748-9326/ab13e4>

Landauer, M., & Juhola, S. (2019). Loss and damage in the rapidly changing Arctic. In R. Mechler, L. Bouwer, T. Schinko, S. Surminski, & J. Linnerooth-Bayer (Eds.), *Loss and Damage from Climate Change. Climate Risk Management, Policy and Governance* (pp. 425–447). Springer, Cham. <https://doi.org/10.1007/978-3-319-72026-5_18>

Larsen, J. N., Anisimov, O. A., Constable, A., Hollowed, A. B., Maynard, N., Prestrud, P., … Stone, J. M. R. (2014). Polar Regions. In V. R. Barros, C. B. Field, D. J. Dokken, M. B. Mastrandrea, K. J. Mach, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1567–1612). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Lemke, S., & Delormier, T. (2017). Indigenous Peoples' food systems, nutrition, and gender: Conceptual and methodological considerations. *Maternal & Child Nutrition*, *13*, e12499. <https://doi.org/10.1111/mcn.12499>

Lemmen, D. S., Warren, F. J., Lacroix, J., & Bush, E. (Eds.). (2008). *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Ottawa, ON: Natural Resources Canada.

Lesnikowski, A., Belfer, E., Rodman, E., Smith, J., Biesbroek, R., Wilkerson, J., … Berrang-Ford, L. (2019). Frontiers in data analytics for adaptation research: Topic modeling. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(3), e576. <https://doi.org/10.1002/wcc.576>

Lesnikowski, A., Ford, J., Berrang-Ford, L., Paterson, J., Barrera, M., & Heymann, J. (2011). Adapting to health impacts of climate change: a study of UNFCCC Annex I parties. *Environmental Research Letters*, *6*(4), 044009. <https://doi.org/10.1088/1748-9326/6/4/044009>

Lesnikowski, A., Ford, J., Biesbroek, R., Berrang-Ford, L., & Heymann, J. (2016). National-level progress on adaptation. *Nature Climate Change*, *6*(3), 261–264. <https://doi.org/10.1038/nclimate2863>

Levison, M. M., Butler, A. J., Rebellato, S., Armstrong, B., Whelan, M., & Gardner, C. (2018). Development of a climate change vulnerability assessment using a public health lens to determine local health vulnerabilities: an Ontario health unit experience. *International Journal of Environmental Research and Public Health*, *15*(10), 2237. <https://doi.org/10.3390/ijerph15102237>

Levison, M. M., Whelan, M., & Butler, A. (2017). *A changing climate: assessing health impacts and vulnerabilities due to climate change within Simcoe Muskoka*. Simcoe Muskoka District Health Unit.

Li, N., Dachner, N., Tarasuk, V., Zhang, R., Kurrein, M., Harris, T., Gustin, S., & Rasal, D. (2016). *Priority Health Equity Indicators for British Columbia: Household Food Insecurity Indicator Report.* Vancouver, BC: Provincial Health Services Authority and PROOF.

Liu, C., Hofstra, N., & Franz, E. (2013). Impacts of climate change on the microbial safety of pre-harvest leafy green vegetables as indicated by *Escherichia coli* O157 and Salmonella spp. *International Journal of Food Microbiology*, *163*(2–3), 119–128. <https://doi.org/10.1016/j.ijfoodmicro.2013.02.026>

Lock, K., Stuckler, D., Charlesworth, K., & McKee, M. (2009). Potential causes and health effects of rising global food prices. *BMJ (Clinical research ed.)*, *339*, b2403. <https://doi.org/10.1136/bmj.b2403>

Lopez, R., & Goldoftas, B. (2009). The urban elderly in the United States: health status and the environment. *Reviews on Environmental Health*, *24*(1), 47–57. <https://doi.org/10.1515/REVEH.2009.24.1.47>

Ma, J., Hung, H., Tian, C., & Kallenborn, R. (2011). Revolatilization of persistent organic pollutants in the Arctic induced by climate change. *Nature Climate Change*, *1*(5), 255–260. <https://doi.org/10.1038/nclimate1167>

Macdiarmid, J. I., & Whybrow, S. (2019). Nutrition from a climate change perspective. In A. Gallagher (Ed.), *Proceedings of the Nutrition Society* (pp. 1–8). Cambridge University Press. <https://doi.org/10.1017/S0029665118002896>

MacFadden, D. R., McGough, S. F., Fisman, D., Santillana, M., & Brownstein, J. S. (2018). Antibiotic resistance increases with local temperature. *Nature Climate Change*, *8*(6), 510–514. <https://doi.org/10.1038/s41558-018-0161-6>

Magnan, A. K., Schipper, E. L. F., Burkett, M., Bharwani, S., Burton, I., & Eriksen, S. H. (2016). Addressing the risk of maladaptation to climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *7*, 646–665. <https://doi.org/10.1002/wcc.409>

Manciocco, A., Calamandrei, G., & Alleva, E. (2014). Global warming and environmental contaminants in aquatic organisms: the need of the etho-toxicology approach. *Chemosphere*, *100*, 1–7. <https://doi.org/10.1016/j.chemosphere.2013.12.072>

Martens, T., Cidro, J., Hart, M. A., & McLachlan, S. (2016). Understanding Indigenous food sovereignty through an Indigenous research paradigm. *Journal of Indigenous Social Development*, *5*(1), 18-37.

Martinez-Urtaza, J., Bowers, J. C., Trinanes, J., & DePaola, A. (2010). Climate anomalies and the increasing risk of *Vibrio parahaemolyticus* and *Vibrio vulnificus* illnesses. *Food Research International*, *43*(7), 1780–1790. <https://doi.org/10.1016/j.foodres.2010.04.001>

Marushka, L., Batal, M., Sharp, D., Schwartz, H., Ing, A., Fediuk, K., … Chan, H. M. (2017). Fish consumption is inversely associated with type 2 diabetes in Manitoba First Nations communities. *FACETS*, *2*, 795–818. <https://doi.org/10.1139/facets-2017-0023>

Marushka, L., Kenny, T.-A. A., Batal, M., Cheung, W. W. L., Fediuk, K., Golden, C. D., … Chan, H. M. (2019). Potential impacts of climate-related decline of seafood harvest on nutritional status of coastal First Nations in British Columbia, Canada. *PLoS ONE*, *14*(2). <https://doi.org/10.1371/journal.pone.0211473>

Marvin, H. J. P., Kleter, G. A., Noordam, M. Y., Franz, E., Willems, D. J. M., & Boxall, A. (2013). Proactive systems for early warning of potential impacts of natural disasters on food safety: climate-change-induced extreme events as case in point. *Food Control*, *34*(2), 444–456. https://doi.org/https://doi.org/10.1016/j.foodcont.2013.04.037

Mbow, C., Rosenzweig, C., Barioni, L., Benton, T., Herrero, M., Krishnapillai, M., … Xu, Y. (2019). Food security. In P. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, … J. Malley (Eds.), *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Retrieved from <https://www.ipcc.ch/srccl/>

McLeod, L., & Veall, M. (2006). The dynamics of food insecurity and overall health: evidence from the Canadian National Population Health Survey. *Applied Economics*, *38*(18), 2131–2146. <https://doi.org/10.1080/00036840500427429>

Medical Officer of Health. (2013). *Exploring Health and Social Impacts of Climate Change in Toronto*. Toronto, ON.

Metro Vancouver. (2016). *Regional food system action plan*. Vancouver, BC.

Milazzo, A., Giles, L. C., Zhang, Y., Koehler, A. P., Hiller, J. E., & Bi, P. (2017). Factors Influencing Knowledge, Food Safety Practices and Food Preferences During Warm Weather of Salmonella and Campylobacter Cases in South Australia. *Foodborne Pathogens and Disease*, *14*(3), 125–131. <https://doi.org/10.1089/fpd.2016.2201>

Miraglia, M., Marvin, H. J. P., Kleter, G. A., Battilani, P., Brera, C., Coni, E., … Vespermann, A. (2009). Climate change and food safety: an emerging issue with special focus on Europe. *Food and Chemical Toxicology*, *47*(5), 1009–1021. <https://doi.org/10.1016/j.fct.2009.02.005>

Morrison, D. (2011). Indigenous food sovereignty: a model for social learning. In A. A. Desmarais, N. Wiebe, & H. Wittman (Eds.), *Food Sovereignty in Canada: Creating Just and Sustainable Food Systems* (pp. 97–113). Fernwood Publishing.

Moser, S. C. (2014). Communicating adaptation to climate change: the art and science of public engagement when climate change comes home. *Climate Change*, *5*(3), 337–358. <https://doi.org/10.1002/wcc.276>

Moulton, A. D., & Schramm, P. J. (2017). Climate change and public health surveillance. *Journal of Public Health Management and Practice*, *23*(6), 618–626. <https://doi.org/10.1097/PHH.0000000000000550>

Muldoon, K. A., Duff, P. K., Fielden, S., & Anema, A. (2013). Food insufficiency is associated with psychiatric morbidity in a nationally representative study of mental illness among food insecure Canadians. *Social Psychiatry and Psychiatric Epidemiology*, *48*(5), 795–803. <https://doi.org/10.1007/s00127-012-0597-3>

Muncke, J., Myers, J. P., Scheringer, M., & Porta, M. (2014). Food packaging and migration of food contact materials: will epidemiologists rise to the neotoxic challenge? *Journal of Epidemiology and Community Health*, *68*(7), 592–594. <https://doi.org/10.1136/jech-2013-202593>

Municipal Affairs and Environment. (2019). *The way forward on climate change in Newfoundland and Labrador*. St. John's, NL.

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., … Huybers, P. (2017). Climate change and global food systems: potential impacts on food security and undernutrition. *Annual Review of Public Health*, *38*, 259–277. <https://doi.org/10.1146/annurev-publhealth-031816-044356>

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D. B., Bloom, A. J., … Usui, Y. (2014). Increasing CO_2 threatens human nutrition. *Nature*, *510*, 139–142. <https://doi.org/10.1038/nature13179>

Nelson, M. C., Ingram, S. E., Dugmore, A. J., Streeter, R., Peeples, M. A., Mcgovern, T. H., … Smiarowski, K. (2016). Climate challenges, vulnerabilities, and food security. *PNAS*, *113*(2), 298–303. <https://doi.org/10.1073/pnas.1506494113>

Neufeld, H. T. (2020). Socio-Historical Influences and Impacts on Indigenous Food Systems in Southwestern Ontario: The Experiences of Elder Women Living On-and Off-Reserve. In P. Settee, & S. Shukla (Eds.), *Indigenous Food Systems: Concepts, Cases, and Conversations* (pp. 251). Canadian Scholars' Press.

Ngoen-Klan, R., Moophayak, K., Klong-Klaew, T., Irvine, K. N., Sukontason, K. L., Prangkio, C., … Sukontason, K. (2011). Do climatic and physical factors affect populations of the blow fly *Chrysomya megacephala* and house fly *Musca domestica*? *Parasitology Research*, *109*(5), 1279–1292. <https://doi.org/10.1007/s00436-011-2372-x>

Northern Contaminants Program (NCP). (2013). *Canadian Arctic Contaminants Assessment Report III on Persistent Organic Pollutants* (D. Muir, P. Kurt-Karakus, J. Stow, Eds.). Ottawa, ON: Northern Contaminants Program, Aboriginal Affairs and Northern Development Canada.

Nourish. (n.d.). *The Nourish Innovator Program*. Retrieved from <https://www.nourishhealthcare.ca/about-nourish>

Nova Scotia Environment. (2014). *Agriculture.*

Nunavut Food Security Coalition (NFSC). (2014). *Nunavut Food Security Strategy and Action Plan 2014-16*. Retrieved from <https://www.nunavutfoodsecurity.ca/sites/default/files/files/Resources/Strategy/NunavutFoodSecurityStrategy_ENGLISH.pdf>

Olazabal, M., Galarraga, I., Ford, J., Murieta, E. S. De, & Lesnikowski, A. (2019). Are local climate adaptation policies credible? A conceptual and operational assessment framework. *International Journal of Urban Sustainable Development*, *11*(3), 1–15. <https://doi.org/10.1080/19463138.2019.1583234>

Organ, J., Castleden, H., Furgal, C., Sheldon, T., & Hart, C. (2014). Contemporary programs in support of traditional ways: Inuit perspectives on community freezers as a mechanism to alleviate pressures of wild food access in Nain, Nunatsiavut. *Health and Place*, *30*, 251–259. <https://doi.org/10.1016/j.healthplace.2014.09.012>

O'Riordan, T., & Lenton, T. (2013). *Addressing tipping points for a precarious future*. Oxford, United Kingdom: Oxford University Press. <https://doi.org/10.5871/bacad/9780197265536.001.0001>

Palko, K., & Lemmen, D. S. (Eds.). (2017). *Climate risks and adaptation practices for the Canadian transportation sector 2016*. Ottawa, ON: Government of Canada.

Pangloli, P., Dje, Y., Ahmed, O., Doane, C. A., Oliver, S. P., & Draughon, F. A. (2008). Seasonal incidence and molecular characterization of Salmonella from dairy cows, calves, and farm environment. *Foodborne Pathogens and Disease*, *5*(1), 87–96. <https://doi.org/10.1089/fpd.2008.0048>

Pardhan-Ali, A., Berke, O., Wilson, J., Edge, V. L., Furgal, C., Reid-Smith, R., … McEwen, S. A. (2012a). A spatial and temporal analysis of notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. *International Journal of Health Geographics*, *11*(1), 17. <https://doi.org/10.1186/1476-072X-11-17>

Pardhan-Ali, A., Wilson, J., Edge, V. L., Furgal, C., Reid-Smith, R., Santos, M., & McEwen, S. A. (2012b). A descriptive analysis of notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. *BMJ Open*, *2*(4), e000732. <https://doi.org/10.1136/bmjopen-2011-000732>

Pardhan-Ali, A., Wilson, J., Edge, V. L., Furgal, C., Reid-Smith, R., Santos, M., & McEwen, S. A. (2013). Community-level risk factors for notifiable gastrointestinal illness in the Northwest Territories, Canada, 1991-2008. *BMC Public Health*, *13*(1), 63. <https://doi.org/10.1186/1471-2458-13-63>

Pardue, J., Moe, W., McInnis, D., Thibodeaux, L., Valsaraj, K., Maciasz, E., … Yuan, Q. (2005). Chemical and microbiological parameters in New Orleans floodwater following Hurricane Katrina. *Environmental Science & Technology*, *39*(22), 8591–8599. <https://doi.org/10.1021/es0518631>

Park, M. S., Park, K. H., & Bahk, G. J. (2018). Interrelationships between multiple climatic factors and incidence of foodborne diseases. *International Journal of Environmental Research and Public Health*, *15*(11), 2482. <https://doi.org/10.3390/ijerph15112482>

Parlee, B., & Berkes, F. (2005). Health of the land, health of the people: a case study on Gwich'in berry harvesting in northern Canada. *EcoHealth*, *2*(2), 127–137. <https://doi.org/10.1007/s10393-005-3870-z>

Parveen, S., Hettiarachchi, K. A., Bowers, J., Jones, J. L., Tamplin, M. L., McKay, R.,... DePaola, A. (2008). Seasonal distribution of total and pathogenic *Vibrio parahaemolyticus* in Chesapeake Bay oysters and waters. *International Journal of Food Microbiology*, *128*, 354–361. <https://doi.org/10.1016/j.ijfoodmicro.2008.09.019>

Paterson, J. A., Ford, J., Berrang-Ford, L., Lesnikowski, A., Berry, P., Henderson, J., & Heymann, J. (2012). Adaptation to climate change in the Ontario public health sector. *BMC Public Health*, *12*(1). <https://doi.org/10.1186/1471-2458-12-452>

Patriarca, A., & Fernández Pinto, V. (2017). Prevalence of mycotoxins in foods and decontamination. *Current Opinion in Food Science*, *14*, 50–60. <https://doi.org/10.1016/J.COFS.2017.01.011>

Pinstrup-Andersen, P. (2013). Contemporary food policy challenges and opportunities. *Australian Journal of Agricultural and Resource Economics*, *58*(4), 504–518. <https://doi.org/10.1111/1467-8489.12019>

Planning and Development Department. (2013). *Agriculture protection and enhancement strategy in Surrey*. Surrey, BC.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, M. S., Iqbal, M. M., … Travasso, M. I. (2014). Food security and food production systems. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. *Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 485–533). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Pouillot, R., Hoelzer, K., Chen, Y., & Dennis, S. B. (2015). Listeria monocytogenes dose response revisited- incorporating adjustments for variability in strain virulence and host susceptibility. *Risk Analysis*, *35*(1), 90–108. <https://doi.org/10.1111/risa.12235>

PROOF. (2018). *Latest household food insecurity data now available*. Retrieved from <https://proof.utoronto.ca/new-data-available/>

Public Health Agency of Canada (PHAC). (2017). *FoodNet Canada Annual Report 2017*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/public-health/services/surveillance/foodnet-canada/publications/foodnet-canada-annual-report-2017.html>

Public Health Agency of Canada (PHAC). (2018). *Inequalities in food insecurity in Canada*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/public-health/services/publications/science-research-data/inequalities-food-insecurity-canada-infographic.html>

Rahel, F. J., & Olden, J. D. (2008). Assessing the effects of climate change on aquatic invasive species. *Conservation Biology*, *22*(3), 521–533. <https://doi.org/10.1111/j.1523-1739.2008.00950.x>

Rangel, J. M., Sparling, P. H., Crowe, C., Griffin, P. M., & Swerdlow, D. L. (2005). Epidemiology of *Escherichia coli* O157:H7 outbreaks, United States, 1982–2002. *Emerging Infectious Diseases*, *11*(4), 603. <https://doi.org/10.3201/eid1104.040739>

Rapinski, M., Cuerrier, A., Harris, C., Elders of Ivujivik, Elders of Kangiqsujuaq, & Lemire, M. (2018). Inuit perception of marine organisms: From folk classification to food harvest. *Journal of Ethnobiology*, *38*(3), 333–355. <https://doi.org/10.2993/0278-0771-38.3.333>

Ratelle, M., Skinner, K., Laird, M. J., Majowicz, S., Brandow, D., Packull-McCormick, S., … Laird, B. D. (2018). Implementation of human biomonitoring in the Dehcho region of the Northwest Territories, Canada (2016–2017). *Archives of Public Health*, *76*(1), 73. <https://doi.org/10.1186/s13690-018-0318-9>

Ravel, A., Smolina, E., Sargeant, J. M., Cook, A., Marshall, B., Fleury, M. D., & Pollari, F. (2010). Seasonality in human salmonellosis: assessment of human activities and chicken contamination as driving factors. *Foodborne Pathogens and Disease*, *7*(7), 785–794. <https://doi.org/10.1089/fpd.2009.0460>

Ready, E. (2016). Challenges in the Assessment of Inuit Food Security. *ARCTIC*, *69*(3), 266–280. <https://doi.org/10.14430/arctic4579>

Richmond, C. A. M., & Ross, N. A. (2009). The determinants of First Nation and Inuit health: a critical population health approach. *Health & Place*, *15*(2), 403–411. <https://doi.org/10.1016/j.healthplace.2008.07.004>

Rigét, F., Vorkamp, K., Bossi, R., Sonne, C., Letcher, R. J., & Dietz, R. (2016). Twenty years of monitoring of persistent organic pollutants in Greenland biota. A review. *Environmental Pollution (Barking, Essex: 1987)*, *217*, 114–123. <https://doi.org/10.1016/j.envpol.2015.11.006>

Roberts, M., & Cooke, R. (2020). Low on food, blizzard-weary St. John's shoppers head straight to supermarkets. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/newfoundland-labrador/grocery-stores-open-st-john-s-1.5433593>

Romero-Lankao, P., Smith, J., Davidson, D., Diffenbaugh, N., Kinney, P., Kirshen, P., … Villers Ruiz, L. (2014). North America. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1439–1498). Cambridge, UK and New York, USA: Cambridge University Press.

Rose, J., Epstein, P., Lipp, E., Sherman, B., Bernard, S., & Patz, J. (2001). Climate variability and change in the United States: potential impacts on water and foodborne diseases caused by microbiologic agents. *Environmental Health Perspectives*, *109*(S2), 211–221. <https://doi.org/10.1289/ehp.01109s2211>

Rose, N., Lunazzi, A., Dorenlor, V., Merbah, T., Eono, F., Eloit, M., … Pavio, N. (2011). High prevalence of Hepatitis E virus in French domestic pigs. *Comparative Immunology, Microbiology and Infectious Diseases*, *34*(5), 419–427. <https://doi.org/10.1016/j.cimid.2011.07.003>

Roser-Renouf, C., Maibach, E. W., & Li, J. (2016). Adapting to the changing climate: An assessment of local health department preparations for climate change-related health threats, 2008-2012. *PLoS ONE*, *11*(3). <https://doi.org/10.1371/journal.pone.0151558>

Rosol, R., Huet, C., Wood, M., Lennie, C., Osborne, G., & Egeland, G. M. (2011). Prevalence of affirmative responses to questions of food insecurity: International Polar Year Inuit Health Survey, 2007-2008. *International Journal of Circumpolar Health*, *70*(5), 488–497. <https://doi.org/10.3402/ijch.v70i5.17862>

Rosol, R., Powell-Hellyer, S., & Chan, H. M. (2016). Impacts of decline harvest of country food on nutrient intake among Inuit in Arctic Canada: impact of climate change and possible adaptation plan. *International Journal of Circumpolar Health*, *75*(1), 31127. <https://doi.org/10.3402/ijch.v75.31127>

Rudolph, K. R., & McLachlan, S. M. (2013). Seeking Indigenous food sovereignty: origins of and responses to the food crisis in northern Manitoba, Canada. *Local Environment*, *18*(9), 1079–1098. <https://doi.org/10.1080/13549839.2012.754741>

Sauchyn, D., Davidson, D., & Johnston, M. (2020). Prairie Provinces. In F.J. Warren, N. Lulham, & D.S. Lemmen (Eds.), *Canada in a Changing Climate: Regional Perspectives Report*. Ottawa, ON: Natural Resources Canada.

Sauchyn, D., Kulshreshtha, S., Barrow, E., Lemmen, D. S., Warren, F. J., Lacroix, J., & Bush, E. (2008). Prairies. In D. S. Lemmen, F. J. Warren, J. Lacroix, & E. Bush (Eds.), *From Impacts to Adaptation: Canada in a Changing Climate 2007* (pp. 275–328). Ottawa, ON: Natural Resources Canada.

Sawatzky, A., Cunsolo, A., Jones-Bitton, A., Middleton, J., & Harper, S. L. (2018). Responding to climate and environmental change impacts on human health via integrated surveillance in the Circumpolar North: A systematic realist review. *International Journal of Environmental Research and Public Health*, *15*(12), 2706. <https://doi.org/10.3390/ijerph15122706>

Schecter, A., & Gasiewicz, T. A. (Eds.). (2003). *Dioxins and health*. New York, NY: John Wiley & Sons, Inc. <https://doi.org/10.1002/0471722014>

Schmidhuber, J., & Tubiello, F. N. (2007). Global food security under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(50), 19703–19708. <https://doi.org/10.1073/pnas.0701976104>

Schnitter, R., & Berry, P. (2019). The climate change, food security and human health nexus in Canada: A framework to protect population health. *International Journal of Environmental Research and Public Health*, *16*(14), 1–2531. <https://doi.org/10.3390/ijerph16142531>

Séguin, J. (Ed.). (2008). *Human Health in a changing climate: A Canadian assessment of vulnerabilities and adaptive capacity*. Ottawa, ON: Health Canada.

Semenza, J. C., Herbst, S., Rechenburg, A., Suk, J. E., Höser, C., Schreiber, C., & Kistemann, T. (2012a). Climate change impact assessment of food-and waterborne diseases. *Critical Reviews in Environmental Science and Technology*, *42*(8), 857–890. <https://doi.org/10.1080/10643389.2010.534706>

Semenza, J. C., Hoeser, C., Herbst, S., Rechenburg, A., Suk, J. E., Frechen, T., & Kistemann, T. (2012b). Knowledge mapping for climate change and food-and waterborne diseases. *Critical Reviews in Environmental Science and Technology*, *42*(4), 378–411. <https://doi.org/10.1080/10643389.2010.518520>

Semenza, J. C., Suk, J. E., Estevez, V., Ebi, K. L., & Lindgren, E. (2012c). Mapping climate change vulnerabilities to infectious diseases in Europe. *Environmental Health Perspectives*, *120*(3), 385–392. <https://doi.org/10.1289/ehp.1103805>

Skinner, K., Hanning, R. M., Desjardins, E., & Tsuji, L. J. (2013). Giving voice to food insecurity in a remote indigenous community in subarctic Ontario, Canada: traditional ways, ways to cope, ways forward. *BMC Public Health*, *13*, 427. <https://doi.org/10.1186/1471-2458-13-427>

Smith, B. A., & Fazil, A. (2019). How will climate change impact microbial foodborne disease in Canada? *Canada Communicable Disease Report*, *45*(4), 108–113. <https://doi.org/10.14745/ccdr.v45i04a05>

Smith, B. A., Meadows, S., Meyers, R., Parmley, E. J., & Fazil, A. (2019). Seasonality and zoonotic foodborne pathogens in Canada: relationships between climate and *Campylobacter*, *E. coli* and *Salmonella* in meat products. *Epidemiology and Infection, 147*, e190. <https://doi.org/10.1017/S0950268819000797>

Smith, B. A., Ruthman, T., Sparling, E., Auld, H., Comer, N., Young, I., … Fazil, A. (2015). A risk modeling framework to evaluate the impacts of climate change and adaptation on food and water safety. *Food Research International*, *68*, 78–85. <https://doi.org/10.1016/J.FOODRES.2014.07.006>

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., … Sauerborn, R. (2014). Human health: impacts, adaptation, and co-benefits. In C. B. Field, V. Barros, D. Dokken, K. Mach, M. Mastrandrea, T. Bilir, … and L. L. W. B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 709–754). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Sonnino, R. (2016). The new geography of food security: Exploring the potential of urban food strategies. *Geographical Journal*, *182*(2), 190–200. <https://doi.org/10.1111/geoj.12129>

Springmann, M., Mason-D'croz, D., Robinson, S., Garnett, T., Godfray, C. J., Gollin, D., … Scarborough, P. (2016). Global and regional health effects of future food production under climate change: a modelling study. *The Lancet*, *387*(10031), 1937–1946. <https://doi.org/10.1016/S0140-6736(15)01156-3>

Statistics Canada. (2009). Food in Canada. In *Human Activity and the Environment: Annual Statistics* (p. 166). Retrieved from <https://www150.statcan.gc.ca/n1/pub/16-201-x/2009000/part-partie1-eng.htm>

Statistics Canada. (2012). *Household food insecurity, 2011-2012. Data from the 2011-2012 Canadian Community Health Survey*. Ottawa, ON. Retrieved from <https://www150.statcan.gc.ca/n1/pub/82-625-x/2013001/article/11889-eng.htm>

Statistics Canada. (2015). *Food Security in Canada*. Ottawa, ON.

Statistics Canada. (2018). *Canadian Community Health Survey 2017-18*. Ottawa, ON.

Statistics Canada. (2020). *Table 17-10-0057-01 Projected population, by projection scenario, age and sex, as of July 1 (x 1,000)*. <https://doi.org/10.25318/1710005701-eng>

Steiner, L., & Neathway, C. (2019). *Indigenous food safety and security: Community adaptations in the wake of climate pressures*. Vancouver, BC.

Sugimura, T., Wakabayashi, K., Nakagama, H., & Nagao, M. (2004). Heterocyclic amines: Mutagens/carcinogens produced during cooking of meat and fish. *Cancer Science*, *95*(4), 290–299. <https://doi.org/10.1111/j.1349-7006.2004.tb03205.x>

Tarasuk, V., Cheng, J., de Oliveira, C., Dachner, N., Gundersen, C., & Kurdyak, P. (2015). Association between household food insecurity and annual health care costs. *CMAJ*, *187*(14), E-429-E436. <https://doi.org/10.1503/cmaj.150234/-/DC1>

Tarasuk, V., & Mitchell, A. (2020). *Household Food Insecurity in Canada, 2017-18*. Toronto, ON. <https://doi.org/10.1097/00008486-200510000-00003>

Tarasuk, V., Mitchell, A., & Dachner, N. (2016). *Household Food Insecurity in Canada, 2014. Research to Identify Policy Options to Reduce Food Insecurity (PROOF)*. Toronto, ON. Retrieved from <https://proof.utoronto.ca/resources/proof-annual-reports/annual-report-2014/>

The Royal Society. (2009). *Reaping the benefits: Science and the sustainable intensification of global agriculture*. Retrieved from <https://royalsociety.org/topics-policy/publications/2009/reaping-benefits/>

Thomas, M. K., Murray, R., Flockhart, L., Pintar, K., Fazil, A., Nesbitt, A., … Pollari, F. (2015). Estimates of foodborne illness-related hospitalizations and deaths in Canada for 30 specified pathogens and unspecified agents. *Foodborne Pathogens and Disease*, *12*(10), 820–827. <https://doi.org/10.1089/fpd.2015.1966>

Thomas, M. K., Murray, R., Flockhart, L., Pintar, K., Pollari, F., Fazil, A., … Marshall, B. (2013). Estimates of the burden of foodborne illness in Canada for 30 specified pathogens and unspecified agents, circa 2006. *Foodborne Pathogens and Disease*, *10*(7), 639–648.

Thomson, B., & Rose, M. (2011). Environmental contaminants in foods and feeds in the light of climate change. *Quality Assurance and Safety of Crops & Foods*, *3*(1), 2–11. <https://doi.org/10.1111/j.1757-837X.2010.00086.x>

Tirado, M. C., Clarke, R., Jaykus, L. A., McQuatters-Gollop, A., & Frank, J. M. (2010). Climate change and food safety: A review. *Food Research International*, *43*(7), 1745–1765. <https://doi.org/10.1016/J.FOODRES.2010.07.003>

Toronto Public Health (TPH). (2015). *A climate of concern: climate change and health strategy for Toronto 2015*. Toronto, ON.

Umlauf, G., Bidoglioa, G., Christopha, E., Kampheusb, J., Krügerc, F., Landmannd, D., … Stehr, D. (2005). The situation of PCDD/Fs and Dioxin-like PCBs after the flooding of River Elbe and Mulde in 2002. *Acta Hydrochimica et Hydrobiologica*, *33*(5), 543–554. <https://doi.org/10.1002/aheh.200400597>

Umlauf, G., Christoph, E., Lanzini, L., Savolainen, R., Skejo, H., Bidoglio, G., … Scherer, H. (2011). PCDD/F and dioxin-like PCB profiles in soils amended with sewage sludge, compost, farmyard manure, and mineral fertilizer since 1962. *Environmental Science and Pollution Research International*, *18*(3), 461–470. <https://doi.org/10.1007/s11356-010-0389-9>

Undeman, E., Brown, T. N., Wania, F., & McLachlan, M. S. (2010). Susceptibility of human populations to environmental exposure to organic contaminants. *Environmental Science & Technology*, *44*(16), 6249–6255. <https://doi.org/10.1021/es1009339>

US Environmental Protection Agency (USEPA). (2021). *Health Effects of Exposures to Mercury*. Retrieved from <https://www.epa.gov/mercury/health-effects-exposures-mercury>

U.S. Global Change Research Program (USGCRP). (2016). *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (A. Crimmins, J. Balbus, J. Gamble, C. Beard, J. Bell, D. Dodgen, … L. Ziska, Eds.). Washington, DC. Retrieved from <https://health2016.globalchange.gov/low/ClimateHealth2016_FullReport_small.pdf >

Valcour, J. E., Charron, D. F., Berke, O., Wilson, J. B., Edge, T., & Waltner-Toews, D. (2016). A descriptive analysis of the spatio-temporal distribution of enteric diseases in New Brunswick, Canada. *BMC Public Health*, *16*, 204. <https://doi.org/10.1186/s12889-016-2779-5>

Venegas-Vargas, C., Henderson, S., Khare, A., Mosci, R. E., Lehnert, J. D., Singh, P., … Rust, S. (2016). Factors associated with Shiga toxin-producing *Escherichia coli* shedding by dairy and beef cattle. *Applied and Environmental Microbiology*, *82*(16), 5049–5056. <https://doi.org/10.1128/AEM.00829-16>

Verner, G., Schütte, S., Knop, J., Sankoh, O., & Sauerborn, R. (2016). Health in climate change research from 1990 to 2014: positive trend, but still underperforming. *Global Health Action*, *9*(1), 1–9. <https://doi.org/10.3402/gha.v9.30723>

Ville de Montréal. (2018). *Montréal's resilient city strategy*. Montréal, QC. Retrieved from <https://resilient.montreal.ca/assets/doc/strategie-montreal-ville-resiliente-en.pdf>

Wang, H., & Horton, R. (2015). Tackling climate change: The greatest opportunity for global health. *The Lancet*, *386*(10006), 1798–1799. <https://doi.org/10.1016/S0140-6736(15)60931-X>

Warren, F. J., & Lemmen, D. S. (Eds.). (2014). *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Ottawa, ON: Natural Resources Canada.

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., … Executive. (2015). Health and climate change: policy responses to protect public health. *The Lancet*, *386*(386), 1861–1914. <https://doi.org/10.1016/S0140-6736(15)60854-6>

Watts, N., Adger, W. N., Ayeb-Karlsson, S., Bai, Y., Byass, P., Campbell-Lendrum, D., … Costello, A. (2017). The Lancet Countdown: tracking progress on health and climate change. *The Lancet*, *389*(10074), 1151–1164. <https://doi.org/10.1016/S0140-6736(16)32124-9>

Weihe, P., Debes, F., Halling, J., Petersen, M. S., Muckle, G., Odland, J. Ø., Dudarev, A., Ayotte, P., Dewailly, É., Grandjean, P., & Bonefeld-Jørgensen, E. (2016). Health effects associated with measured levels of contaminants in the Arctic. *International Journal of Circumpolar Health*, *75*, 33805. <https://doi.org/10.3402/ijch.v75.33805>

Wesche, S. D., & Chan, H. M. (2010). Adapting to the impacts of climate change on food security among Inuit in the Western Canadian Arctic. *EcoHealth*, *7*(3), 361–373. <https://doi.org/10.1007/s10393-010-0344-8>

Wesche, S. D., O'Hare-Gordon, M. A. F., Robidoux, M. A., & Mason, C. W. (2016). Land-based programs in the Northwest Territories: Building Indigenous food security and well-being from the ground up. *Canadian Food Studies/La Revue Canadienne Des Études Sur l'alimentation*, *3*(2), 23–48. <https://doi.org/10.15353/cfs-rcea.v3i2.161>

Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508–513. <https://doi.org/10.1126/science.1239402>

Whyte, K. (2016). Indigenous food sovereignty, renewal and US settler colonialism. In M. Rawlinson, & C. Ward (Eds.), *The Routledge Handbook of Food Ethics*. Routledge.

Wong, J., & Schuchard, R. (2011). *Adapting to climate change: a guide for food, beverage, and agriculture companies*. San Francisco, California. Retrieved from <https://www.bsr.org/reports/BSR_Climate_Adaptation_Issue_Brief_Food_Bev_Ag2.pdf>

World Health Organization (WHO). (2008). *The world health report 2008: Primary health care (now more than ever)*. Geneva, Switzerland. Retrieved from <https://www.who.int/whr/2008/en/>

World Health Organization (WHO). (2014). *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s*. Geneva, Switzerland. Retrieved from <https://www.who.int/globalchange/publications/quantitative-risk-assessment/en/>

World Health Organization (WHO). (2017). *WHO guidelines on use of medically important antimicrobials in food-producing animals*. Retrieved from <https://www.who.int/foodsafety/areas_work/antimicrobial-resistance/cia_guidelines/en/>

Wu, X., Lu, Y., Zhou, S., Chen, L., & Xu, B. (2016). Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environment International*, *86*, 14–23. <https://doi.org/10.1016/j.envint.2015.09.007>

Yan, C., Liang, L. J., Zheng, K. Y., & Zhu, X. Q. (2016). Impact of environmental factors on the emergence, transmission and distribution of Toxoplasma gondii. *Parasites & vectors*, *9*, 137. <https://doi.org/10.1186/s13071-016-1432-6>

Young, I., Gropp, K., Fazil, A., & Smith, B. A. (2015). Knowledge synthesis to support risk assessment of climate change impacts on food and water safety: A case study of the effects of water temperature and salinity on *Vibrio parahaemolyticus* in raw oysters and harvest waters. *Food Research International*, *68*, 86–93. <https://doi.org/10.1016/j.foodres.2014.06.035>

Yusa, A., Berry, P., Cheng, J. J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015). Climate change, drought and human health in Canada. *International Journal of Environmental Research and Public Health*, *12*(7), 8359–8412. <https://doi.org/10.3390/ijerph120708359>

Zelinkova, Z., & Wenzl, T. (2015). The occurrence of 16 EPA PAHs in food - a review. *Polycyclic Aromatic Compounds*, *35*(2–4), 248–284. <https://doi.org/10.1080/10406638.2014.918550>

Zeuli, K., Nijhuis, A., & Gerson-Nieder, Z. (2018a). *Resilient food systems, resilient cities: a high-level vulnerability assessment of Toronto's food system*. Toronto, ON. Retrieved from <https://www.toronto.ca/legdocs/mmis/2018/hl/bgrd/backgroundfile-118076.pdf>

Zeuli, K., Nijhuis, A., Macfarlane, R., & Ridsdale, T. (2018b). The impact of climate change on the food system in Toronto. *International Journal of Environmental Research and Public Health*, *15*(11), 2344. <https://doi.org/10.3390/ijerph15112344>

Ziska, L., Crimmins, A., Auclair, A., Garofalo, J. F., Khan, A. S., Showler, A., & Thurston, J. (2016). Food safety, nutrition and distribution. In A. Crimmins, J. Balbus, J. Gamble, C. Beard, J. Bell, D. Dodgen, … L. Ziska (Eds.), *The impacts of climate change on human health in the United States: A scientific assessment* (pp. 189-216). Washington, DC: U.S. Global Change Research Program.

CHAPTER 9

Climate Change and Health Equity

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Author

Rebekka Schnitter, Health Canada

Contributing Authors

Ericha Moores, Natural Resources Canada

Peter Berry, Health Canada

Marielle Verret, Health Canada

Chris Buse, University of British Columbia and University of Northern British Columbia

Catherine Macdonald, Alliance for Healthier Communities

Melissa Perri, Alliance for Healthier Communities and University of Toronto

Daniel Jubas-Malz, University Health Network

Suggested Citation

Schnitter, R., Moores, E., Berry, P., Verret, M., Buse, C., Macdonald, C., Perri, M., & Jubas-Malz, D. (2022). Climate Change and Health Equity. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

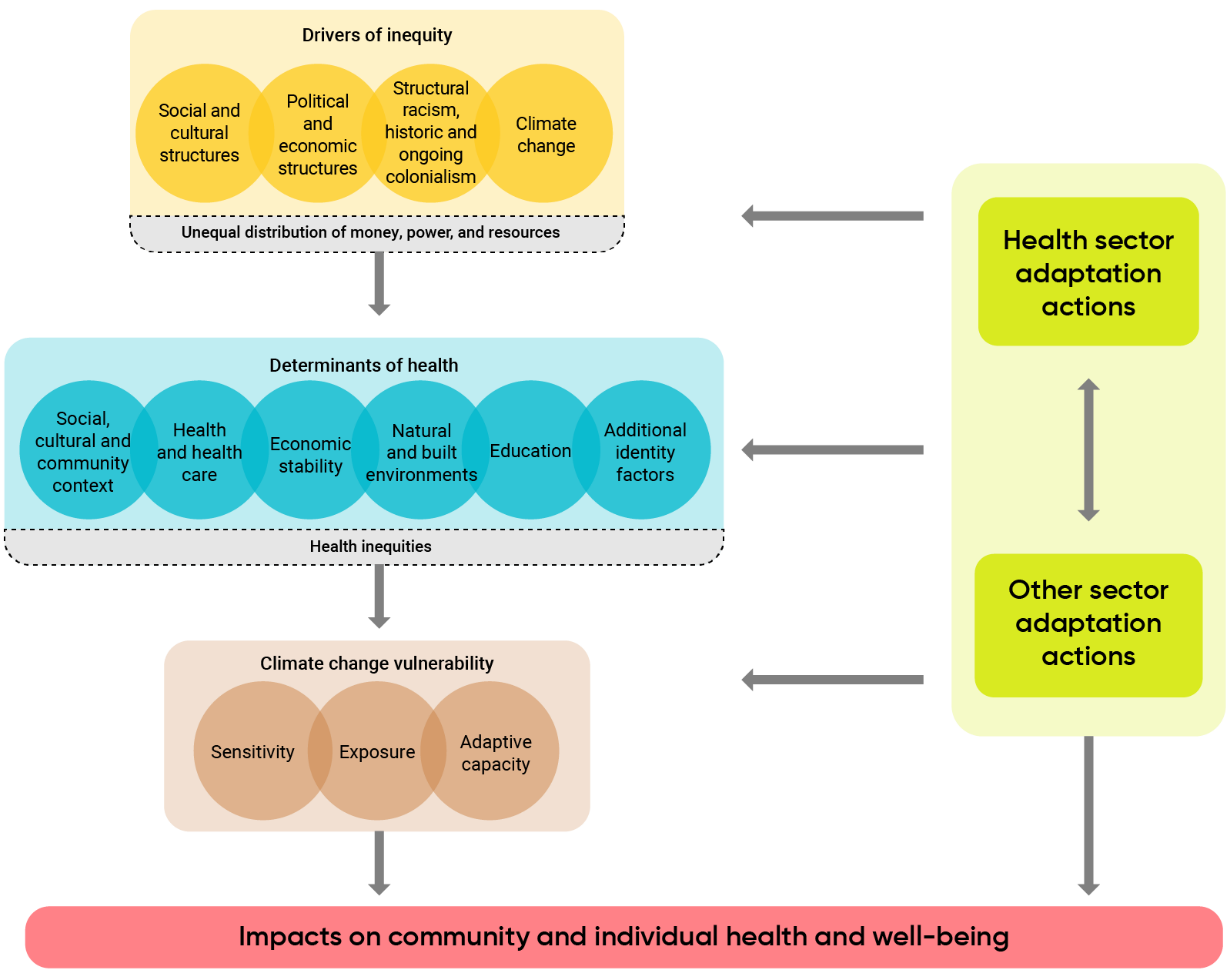
Summary

Changes in climate are exacerbating existing health inequities and creating conditions for new inequities to emerge. The health effects associated with climate change will not be experienced uniformly. Vulnerability to health impacts of climate change is determined by the exposure to climate change hazards, the sensitivity to possible impacts, and the capacity to respond to, or cope with them. At the individual level, these three factors are influenced by determinants of health, such as socio-economic status, housing quality, and education. Determinants of health interact and intersect with inequities in complex ways that render the experiences of diverse groups and individuals unique. Structural systems of oppression, such as racism and colonialism, also influence an individual's vulnerability to climate-related health risks. Therefore, effective adaptation measures must be intersectional and equity-based. If adaptation efforts are not carefully planned, adaptation efforts may benefit only part of the population, and inadvertently worsen existing inequities. Resilience and asset mapping, vulnerability mapping, equity impact assessments, and meaningful and inclusive community engagement and communications can all contribute to equity-centred adaptation measures.

Key Messages

- Climate change can exacerbate existing health inequities, defined as avoidable and unjust differences in health. These inequities — for example, disproportionate impacts on health from extreme heat — can increase the health risks from climate change for some individuals and populations. Knowledge gaps and data limitations make it difficult to assess and measure how climate change has already affected, and will continue to affect, health equity in Canada.
- The pathways through which climate change affects health inequities are complex and dynamic. These pathways often involve the conditions and factors that affect a person's health, known as determinants of health (such as, income, education, employment, and working and living conditions), which can increase or decrease an individual's exposure or sensitivity to climate-related health hazards and can create barriers that limit their ability to take protective measures.
- Structural systems of oppression (such as, racism, heteronormativity, and ableism) that result in health inequities are underlying drivers of vulnerability to climate change.
- Health equity should be an important focus of climate change and health vulnerability and adaptation assessments and related knowledge development activities. Mapping tools (asset mapping, vulnerability mapping), enhanced data collection, and inclusive community engagement will help identify populations and regions at increased risk, and better inform adaptation measures.
- Climate change adaptation measures meant to protect human health are not experienced in the same way across populations and communities. In the absence of careful planning, adaptation efforts may benefit only part of the population and inadvertently worsen existing health inequities.

- Health equity can be increased and determinants of good health strengthened through adaptation. Public health authorities should ensure that adaptation measures are planned and implemented so that people who are disproportionately affected by a warming climate benefit from them.
- Ensuring inclusive, equitable, and community-based participation in the adaptation process is critical for designing and implementing effective adaptation actions that protect the health of all Canadians. Participation of racialized and marginalized individuals and communities that already experience a disproportionate burden of illness and health inequities is required.
- Climate change mitigation and adaptation measures implemented outside of the health sector may affect determinants of health and health outcomes, in either positive or negative ways. Public health authorities can ensure that climate action supports health equity and related positive health outcomes in Canada through collaboration across jurisdictions, sectors, and disciplines.



Climate change and health equity framework.

9.1 Introduction

Climate change impacts and related health risks are experienced in all regions of the world, including Canada. These impacts, however, are not distributed uniformly (Friel, 2019; Ebi, 2020). Globally, the greatest health risks are currently, and projected to be, experienced by regions already facing disproportionate burdens of illness and health inequities, and among populations that have contributed the least to climate change (Islam & Winkel, 2017; Friel, 2019). In Canada, there are large disparities related to current and projected climate change impacts. For example, communities in Nunavut are experiencing warming at an average rate twice that of the rest of Canada and are observing some of the most severe impacts (Bush & Lemmen, 2019), despite having the lowest household greenhouse gas (GHG) emissions per capita (Statistics Canada, 2016).

A dynamic and complex relationship exists between climate change and health equity. Upstream drivers of inequities — such as social, cultural, economic, and political structures and systems; structural racism and historic and ongoing colonialism; and climate change itself — result in the uneven distribution of power and resources across society. This shapes the status of determinants of health (e.g., socio-economic status, exposure to environmental hazards, access to health care), which varies across individuals, communities, and regions. The resulting relative disadvantages create new or exacerbate existing health inequities, which are understood as avoidable and unjust disparities in health status.

The effects of climate change can undermine the status of determinants of health, for example, by hampering access to clean air, livelihood, secure shelter, and sufficient and safe food and drinking water (WHO, 2018). The status of determinants of health can, in turn, increase or decrease an individual's exposure or sensitivity to climate-related hazards and can create barriers that limit adaptive capacity (Health Canada, 2005). Existing health inequities can make it more difficult for some people to prepare for, cope with, and adapt to climate change impacts.

In addition, the outcomes of climate change adaptation actions meant to protect human health are not experienced in the same way across populations and communities. These actions can include those by decision makers outside of the health sector, for example, in water, energy, or transportation sectors. In the absence of proper planning, the outcomes of adaptation actions may benefit some individuals, while inadvertently increasing inequities for others. Adaptation planning processes, from conception to implementation and evaluation, should include diverse voices and perspectives, particularly from those disproportionately affected by climate change impacts on health. In many cases, there is an opportunity to enhance meaningful engagement and equitable participation in adaptation processes in Canada.

It is important to consider health equity in all climate change and health activities, such as conducting vulnerability and adaptation assessments (V&As) and building climate resilient health systems (see Chapter 10: Adaptation and Health System Resilience). The absence of such considerations may result in negative outcomes, such as inadvertently aggravating existing health inequities and overlooking underlying drivers of climate change vulnerability. Public health decision makers can leverage various tools, frameworks, and activities to enhance climate change and health activities by giving explicit consideration to health equity during planning, implementation, and evaluation of measures. Benefits of such an approach include equitable planning processes, interventions with more equitable outcomes, and increased capacity for communities to adapt (Deas et al., 2017; Rudolph et al., 2018; Cleveland et al., 2020). Adaptation actions offer the opportunity not only to protect health from risks posed by a changing climate, but also to strengthen determinants of health, support health equity, and build healthier, more climate resilient communities and health systems.

Strengthening determinants of health and redressing existing health inequities can help decrease vulnerability to health risks related to climate change and build adaptive capacity (WHO, 2015; Friel, 2019; Ebi & Hess, 2020). While downstream actions, such as those taken by public health actors, can contribute to redressing health inequities, dismantling the upstream drivers of inequities is necessary in order to achieve and sustain social and health equity (Rudolph et al., 2018). This will require actions beyond those of the public health sector. There is increasing recognition from policy leaders in and outside of Canada that responding to social and health inequities and related environmental issues requires collaborative, multisectoral policy action (Friel, 2019). However, it is out of the scope of this chapter to provide a detailed analysis of upstream policy interventions and options.

This chapter discusses the determinants of health and health equity, and their links to climate change, with specific attention to vulnerability and adaptation. A new framework for illustrating the dynamics that underlie relationships between climate change and health equity is presented to help understand how some populations and communities are experiencing disproportionate health impacts of climate change in Canada and may continue to do so without effective interventions. Then, tools and resources that support the integration of health equity considerations into climate change and health activities, such as V&As, are presented. This chapter also examines the relationship between health equity and climate change adaptation, focusing on the potentially positive or negative effects of adaptation action, and how measures can be designed to promote health equity. Examples of practical actions that can be taken to better integrate health equity considerations into climate change and health adaptation are then presented. The chapter closes with a discussion of knowledge gaps and research needs required to enable public health officials to take effective actions to protect all people in Canada from climate change.

9.2 Methods and Approach

A rigorous, flexible approach was used to identify literature and evidence relevant to climate change and health equity. Two databases, MEDLINE and Embase via Ovid, were searched for articles published between 2008 and 2020. English- and French-language literature was included in the search. The reference lists of relevant literature were also examined to identify articles not captured in the database search. Websites of key government, non-governmental, and international agencies (e.g., Public Health Agency of Canada, Health Canada, World Health Organization, provincial and territorial government websites, US Centers for Disease Control and Prevention, National Collaborating Centre for Determinants of Health) were examined to identify grey literature.

While Canadian research was prioritized, international research with results relevant to the Canadian context was also included. Not all population groups are represented equally in the climate change and health literature; experiences specific to people with disabilities, newcomers to Canada, and two-spirit, lesbian, gay, bisexual, transgender, queer, questioning, intersex and asexual (2SLGBTQQIA+) populations are less frequently addressed than are experiences of others. While there is significant literature exploring the impacts of climate change on Indigenous Peoples who live on reserves or in rural, remote, or Northern communities, there is very little empirical work addressing the vulnerabilities experienced by Indigenous Peoples who live in urban settings. Further, research on Inuit and First Nation communities is much more common than for Métis communities (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada).

9.3 Determinants of Health and Health Equity

Health inequity refers to health inequalities that are avoidable, unjust, and systematic (CSDH, 2008; NCCDH, 2013). In contrast, health equity is the absence of unfair systems and policies that cause health inequalities, resulting in fair conditions and opportunities conducive to good health for all (Government of Canada, 2019a). In Canada, health inequities, including the inequitable distribution of the burdens of disease and poor health, exist. For example, evidence indicates a social gradient in health, in which individuals low on the socio-economic spectrum generally experience worse health than individuals high on the socio-economic spectrum (CSDH, 2008).

Health inequities arise from upstream drivers, commonly structural in nature, that result in the unequal distribution of power and resources (National Academies of Science, Engineering, and Medicine, 2017). These drivers include social, cultural, economic, and political structures (Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019), such as powerful institutions and systems (e.g., governments, financial markets) as well as socially constructed systems of oppression (e.g., ableism, sexism, capitalism, cisnormativity, heteronormativity, classism, xenophobia), which play a significant role in shaping social norms and influencing how society is organized and functions (Rudolph & Gould, 2014; Rudolph et al., 2018; Cleveland et al., 2020).

Structural racism, including historic and ongoing colonialism, historic and cultural trauma, discrimination, and social exclusion, is also a significant driver of health inequities (Reading & Wien, 2009; Greenwood et al., 2018; CPHO, 2019; Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019). The cumulative history of disenfranchisement and marginalization has created an inequitable distribution of power and resources and has shaped social, economic, political, and cultural norms and systems, which benefit parts of the population, while excluding others (Shi et al., 2016), particularly Indigenous Peoples and racialized communities. Take, for example, the history of colonization and the impact that discriminatory programs, policies, and legislation had, and continues to have, on Indigenous Peoples (Halseth & Murdock, 2020). First Nations, Inuit, and Métis peoples experience disproportionate burdens of ill health, including "higher rates of infant mortality, tuberculosis, child and youth injuries and death, obesity and diabetes, youth suicide, and exposure to environmental contaminants" (Greenwood et al., 2018). Compared to non-Indigenous communities in Canada, the average life expectancy at birth is lower in Indigenous communities; the average life expectancy is 12 years lower for Inuit communities, 11.2 years lower for First Nations, and 6.9 years lower for Métis communities (PHAC, 2018).

Black people[1] also experience health inequities that are linked to processes of racism and discrimination, rooted in European colonization of Africa and the legacy of the transatlantic slave trade (PHAC, 2020). For example, between 2010 and 2013, 14.2% of Black people aged 18 years and older reported their health to be fair or poor, compared to 11.3% of White people in Canada (Pan-Canadian Health Inequalities Data Tool, 2017; PHAC, 2020). The history of colonization and its enduring effects demonstrates how inequities are systemic and intergenerational and can compound disadvantage and marginalization (Shi et al., 2016; Moser et al., 2017; Resurrección et al., 2019).

Upstream drivers that construct economic, political, environmental, and social factors and conditions are known as the determinants of health, which interact to shape an individual's ability to attain and maintain good health (PHAC, 2018; Government of Canada, 2019a). The relative disadvantages that result from unequal distribution of power and resources lead to variations in the status of determinants of health among individuals. Many determinants of health relate to individuals' positions in the societal hierarchy and the conditions in which they live, work, and age (e.g., income, education, employment) (Government of Canada, 2019a).

It is important to recognize that, while many common determinants of health frameworks have relevance for First Nations, Inuit, and Métis peoples, there are Indigenous-specific determinants of health that play a significant role in influencing health and well-being (Greenwood & de Leeuw, 2012; Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Self-determination, for example, has been noted as an important determinant of health that can influence all other determinants (Reading & Wien, 2009). In Chapter 2: Climate Change and Indigenous Peoples' Health in Canada, the authors highlight that perspectives of health and well-being vary within and between First Nations, Inuit, and Métis peoples and include a selection of frameworks for determinants of health that articulate these perspectives.

Climate change can also be understood as a driver of health inequities (Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019), given that the current and future impacts of climate change on health are not, and will not, be experienced uniformly. Those with more resources (e.g., financial, information, social networks) will be better placed to adapt to a changing climate and to take actions to protect their health. Climate change is understood as a "threat multiplier" that can exacerbate existing health inequities and create conditions for new ones to emerge.

Redressing health inequities is necessary to ensure all individuals in Canada have equal opportunity to reach their full health potential, despite their socio-economic or other socially determined circumstances (NCCDH, 2013). This is particularly important as the climate continues to warm and as impacts increase. Such action can also strengthen health systems, as health inequities result in significant health care costs. For example, between 2003 and 2006, the United States spent an estimated 230 billion USD in direct medical care costs and more than 1 trillion USD in indirect costs associated with health disparities experienced by minorities (Rudolph et al., 2015).

1 Black people generally include diverse individuals, populations, and communities in Canada that identify as having African or Caribbean ancestry (PHAC, 2020).

9.4 Climate Change Impacts on Health Equity

There is limited knowledge of how health impacts of current and future climate change will affect health equity in Canada. Evidence suggests that climate change exacerbates health inequities (Ebi et al., 2016; Rudolph et al., 2018; Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019; Friel, 2019); however, the magnitude of impacts on health equity, and extent to which climate change and health actions (e.g., adaptation measures) will strengthen or weaken health equity, are difficult to quantify. This section focuses on establishing linkages between climate change and health equity and provides examples relevant to the Canadian public health sector.

The pathways through which climate change impacts interact with upstream drivers of health inequities and determinants of health are complex. Many of these pathways and relationships are interrelated and dynamic, and they have implications for an individual's vulnerability to the health impacts from climate change. Compounding this complexity are climate change adaptation activities. Adaptation actions taken within the health system to protect human health from risks related to climate change, and those taken outside of the health system to address other climate change impacts on society, can have diverse effects on health equity. Figure 9.1 presents a framework that illustrates the relationships among climate change impacts, drivers of health inequities, determinants of health, and climate change adaptation activities.

The development of this framework was informed by a number of well-established frameworks for determinants of health (Dahlgren & Whitehead, 1991; Queensland Health, 2001; Solar & Irwin, 2010), as well as several conceptual frameworks that illustrate the relationship between climate change and health equity (Rudolph et al., 2015; Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019). The framework presented in this chapter simplifies these complex relationships and situates them in a context relevant to Canadian public health.

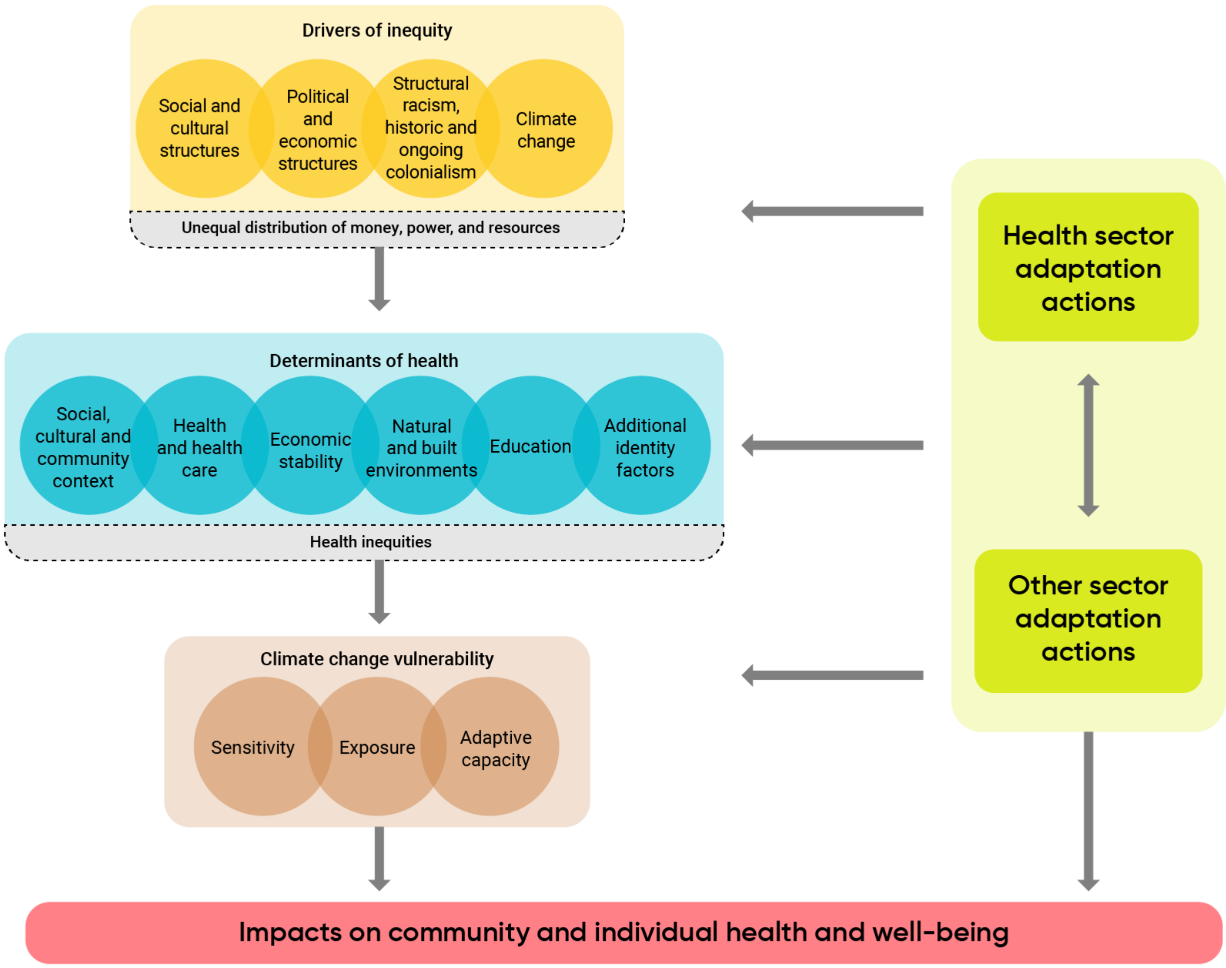


Figure 9.1 Climate change and health equity framework.

Upstream drivers of inequity result in the unequal distribution of power and resources, which shapes and influences the determinants of health. As previously noted, upstream drivers include social and cultural systems and structures (e.g., patriarchy, ableism, cisnormativity, and heteronormativity), political and economic systems, and structures (e.g., capitalism, political and educational institutions), structural racism, and historic and ongoing colonialism. Climate change is also a driver of inequity and can interact with other drivers to aggravate and enhance inequities, while also directly influencing the status of determinants of health. For example, impacts from climate change can cause "disturbances to livelihoods, reduced material resources, and a loss of a sense of control over one's life" (Friel, 2019, p.55). The differential status of determinants of health across a society (e.g., high-income versus low income, quality housing versus substandard housing), and the relative disadvantages this can result in, give rise to health inequities.

In many cases, determinants of health can drive vulnerability to climate-related health risks. For example, exposure to health risks, such as injury during an extreme weather event, is higher for individuals who live in substandard housing (Health Canada, 2005; Gamble et al., 2016; Munro et al., 2020; Raker et al., 2020). At the same time, climate change effects may also compound vulnerability to specific health risks, through their impact on determinants of health and existing health inequities. For example, low income households commonly spend a higher proportion of their income on energy costs and have difficulty investing in energy-efficiency measures for their homes (CER, 2020). The need to adopt protective measures (e.g., air conditioning, visiting cooling centres, purchasing light clothing) for increasing temperatures and extreme heat events can act as a financial burden for low income households, resulting in barriers to coping with heat.

Dimensions of health equity are also associated with climate change and health adaptation. In most cases, communities with more resources have higher adaptive capacity (UNEP, 2018; WHO, 2018). Because of this, they will likely be able to implement adaptation actions before, and more extensively than, disadvantaged communities, further increasing health disparities (Walpole et al., 2009). Many individuals and communities may face multiple risks and factors that compound vulnerability to climate change. For example, a number of First Nations communities lack access to safe drinking water in Canada. As of February 2020, there were 61 long-term drinking water advisories in effect for public water systems on reserves (Government of Canada, 2020). This inequity intersects with other challenges and inequities, such as a disproportionate burden of ill health (NCCAH, 2013) and high rates of food insecurity (FNFNES, 2019), which can compound vulnerability to climate change health risks in these communities. It is important to note that many marginalized communities have, and continue to demonstrate, significant adaptive capacity and resilience to climate change, despite challenges and barriers resulting from existing drivers of inequities (e.g., structural racism) and unequal distribution of power and resources.

The outcomes of adaptation actions are not always experienced in the same way across populations and communities, and, in the absence of careful planning, these outcomes can benefit some groups, while inadvertently causing adverse effects for others. However, adaptation measures present an opportunity to address underlying drivers of climate change vulnerability and promote health equity (see section 9.5.2 Adaptation Actions to Enhance Health Equity). Climate change adaptation measures implemented outside of the health sector may also affect determinants of health and health outcomes, highlighting the need for collaboration and partnerships across sectors to ensure that climate action supports positive health outcomes and health equity in Canada.

9.4.1 Dimensions of Equity in Climate Change and Health Vulnerability

In the context of climate change, vulnerability refers to the "degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2007). The vulnerability of individuals or groups to the health impacts of climate change is determined by the exposure to climate change hazards, the sensitivity to possible impacts, and the capacity to respond or cope with them (Berry et al., 2008; Gamble et al., 2016).

Understanding the concept of vulnerability, and its primary components, is important for public health actors and decision makers, and can aid in understanding health outcomes related to climate change, as well as in identifying where resources and adaptation measures are most needed. However, it is recognized that the term "vulnerability" can be highly stigmatizing when applied to individuals or population groups and has frequently perpetuated a narrative of victimization (see Box 9.1). The intent of the discussion in this section is not to label vulnerable populations, but, rather, to explore how health equity intersects with exposure, sensitivity, and adaptive capacity, to shape vulnerability to climate change. While this discussion focuses on determinants of health and health equity in the context of climate change vulnerability, it is important to recognize the systemic nature of health inequities that construct the conditions that ultimately shape vulnerability.

Box 9.1 Problematic narratives of "vulnerable populations"

Some research examining the heightened vulnerability of certain populations and communities has perpetuated a victimization narrative in which certain groups and communities are portrayed as passive and unable to take protective measures or respond to climate hazards. This narrative can be harmful to the populations and communities that it refers to, as there is increased risk of reinforcing damaging socially constructed ideas and existing stereotypes (Arora-Jonsson, 2011; Kaijser & Kronsell, 2014). Many communities and populations that are on the front lines of climate change have been, and continue to be, active drivers of change, demonstrating significant adaptive capacity and resilience despite unequal distribution of resources and capacity.

In addition, some literature has perpetuated another narrative that suggests that front-line communities, particularly Indigenous Peoples and women, have "special, almost divine, connection[s] to nature" (Kaijser & Kronsell, 2014). This narrative imposes and reinforces a problematic environmental caretaker role. This can result in additional labour and responsibilities for people and communities that are already strained for resources and capacity (Arora-Jonsson, 2011). Shifting the narrative from one that stereotypes people as victims and/or caretakers of the land to one that focuses on community assets and strengths could help to motivate and sustain climate action. Research activities must also become more inclusive. By framing climate change adaptation as a way to strengthen determinants of health and address drivers of health inequity, solutions can be co-developed and led by communities using local and traditional knowledge, culture, skills, and resources to plan, implement, and report on adaptation.

All individuals display some vulnerability factors to the health impacts of climate change; however, this vulnerability is not uniform. Disproportionate impacts and various experiences of adaptation and resilience have been observed across Canada (Wandel et al., 2010; Berry et al., 2014a; Sellers, 2018; Gouvernement du Québec, 2019). In many cases, the status of determinants of health plays an important role in influencing vulnerability (Kumar, 2018), can increase the risk of exposure or sensitivity to climate-related health risks, and can create barriers that limit adaptive capacity (see Figure 9.2). For example, while physiological processes (e.g., chronic diseases, decreased sense of thirst, reduced ability to sweat) can increase the vulnerability of seniors to heat-related health risks, the entire senior population does not experience the same degree of vulnerability. Some people may have greater access to air conditioning and cooling spaces, which have been found to mitigate health risks during extreme temperatures, whereas such adaptations may be less available to some seniors because of economic or mobility challenges (Health Canada, 2012).

Exposure refers to the degree to which individuals or populations may come into contact with climate-related health hazards (McMichael et al., 2003). Inequitable exposure to particular climate hazards can result in parts of the population experiencing heightened vulnerability and negative health outcomes. For example, urban heat islands experience warmer temperatures compared to surrounding regions and can magnify health impacts during heat waves (Health Canada, 2020). A study of the 175 largest urbanized areas in the continental United States found that in 97% of cities racialized populations are disproportionately exposed to high surface urban heat island intensity (SUHI), compared to White residents. Black residents, followed by Hispanic residents, have the highest average SUHI exposure. In terms of income, in 70% of cities, people living below the poverty line had significantly higher exposure compared to those living at twice the poverty line (Hsu et al., 2021). Another study in the United States found that of 108 urban areas analyzed, 94% displayed consistent city-scale patterns of elevated land surface temperatures in formerly redlined[2] neighbourhoods compared to non-redlined neighbourhoods by as much as 7°C (Hoffman et al., 2020).

In Canada, during a heat wave in Montréal, Quebec, in 2018, 66% of people who died were located in urban heat islands. Low-income and social isolation were also determined to be important risk factors (Gouvernement du Quebéc, 2019). In Toronto, Ontario, low income and racialized communities have less access to tree canopy cover and public green spaces, which can mitigate the urban heat island effect and provide other health co-benefits (Greene et al., 2018; Conway & Scott, 2020).

Sensitivity refers to the degree to which individuals are affected by a climate-related health risk (Adger et al., 2004). Sensitivity to climate change health impacts can be shaped by biological traits, such as age, genetics, and chronic health conditions (Gamble et al., 2016) and influenced by determinants of health, such as socio-economic status and availability of and access to health services (Berry et al., 2008). Climate change impacts may affect the status of such determinants and increase sensitivity to health risks related to climate change for some individuals. For example, food security is a key determinant of health and contributes to positive health outcomes. In Canada, a higher prevalence of household food insecurity has been reported among households with children under the age of 18, with households headed by single women being most negatively affected (Statistics Canada, 2012). There is also a higher prevalence of food insecurity in the Canadian North compared to the rest of the country. Climate change may challenge the availability, accessibility, and/or use of food for individuals (see Chapter 8: Food Safety and Security). Such effects can increase the prevalence of food insecurity and contribute to adverse health impacts. Compromised health status, due to food insecurity, could increase sensitivity to other health risks related to climate change, particularly among population groups that already disproportionately experience negative health outcomes from a warming climate.

2 "Redlining" is the historical practice in which neighborhoods were categorized ranging from "best" to "hazardous" for real estate investment. The categorization of neighborhoods was largely based on racial composition. The practice resulted in denial of loans and insurance, and subsequent disinvestment in racialized communities. Residents of redlined neighborhoods experienced increased segregation, lower home values and ownership, and lower personal credit scores. Despite the practice being banned in 1968, the majority of the neighborhoods previously categorized as "hazardous" in the US remain racialized communities and low-to-moderate income. The majority of neighborhoods categorized as favorable for investment remain predominantly White and above-average income (Hoffman et al., 2020).

Adaptive capacity refers to the ability of a system to adjust and manage climate change effectively, moderating or coping with adverse impacts (IPCC, 2007). Factors that contribute to adaptive capacity include access to economic resources, technology, information and skills, public health infrastructure, institutional arrangements, and the existing burden of disease (Grambsch & Menne, 2003; Berry et al., 2008). Existing social and health inequities contribute to the variation of adaptive capacity across individuals and communities in Canada. For example, it is well documented that those with limited access to and use of resources (e.g., financial, information, social networks) will experience the most difficulty adapting to climate change (UNEP, 2018; WHO, 2018; Friel, 2019). For example, low income households located in flood zones may not have the ability to relocate, which increases risk of exposure to flood hazards. In the absence of flood insurance, uninsured losses to property and belongings cannot be recovered, compounding economic disadvantage and further limiting individual adaptive capacity for future events (Islam & Winkel, 2017; Paavola, 2017).

Climate change impacts on determinants of health can further compound barriers to adaptive capacity of individuals and communities, which could result in increased vulnerability to poor health outcomes from a warming climate. The availability, accessibility, and acceptability[3] of public health and emergency management services and infrastructure is not only a determinant of health but can also support community resilience to climate change impacts on health (Séguin, 2008) and varies across communities in Canada. For example, experiences of inequitable availability, accessibility, and acceptability of health care services have been noted among First Nations, Inuit, and Métis peoples as a result of complex intersecting factors, including colonialism, geography, health systems, human resources, jurisdictional issues, cultural safety, communications, and the importance and use of traditional medicines (NCCIH, 2019). Thus, existing inequities related to health care services may limit adaptive capacity for some individuals, which could enhance vulnerability to climate change impacts on health.

3 The acceptability of health care services is the willingness of individuals to seek these services because of the perception that they are effective and service providers are responsive and "free of social and cultural biases" (NCCIH, 2019).

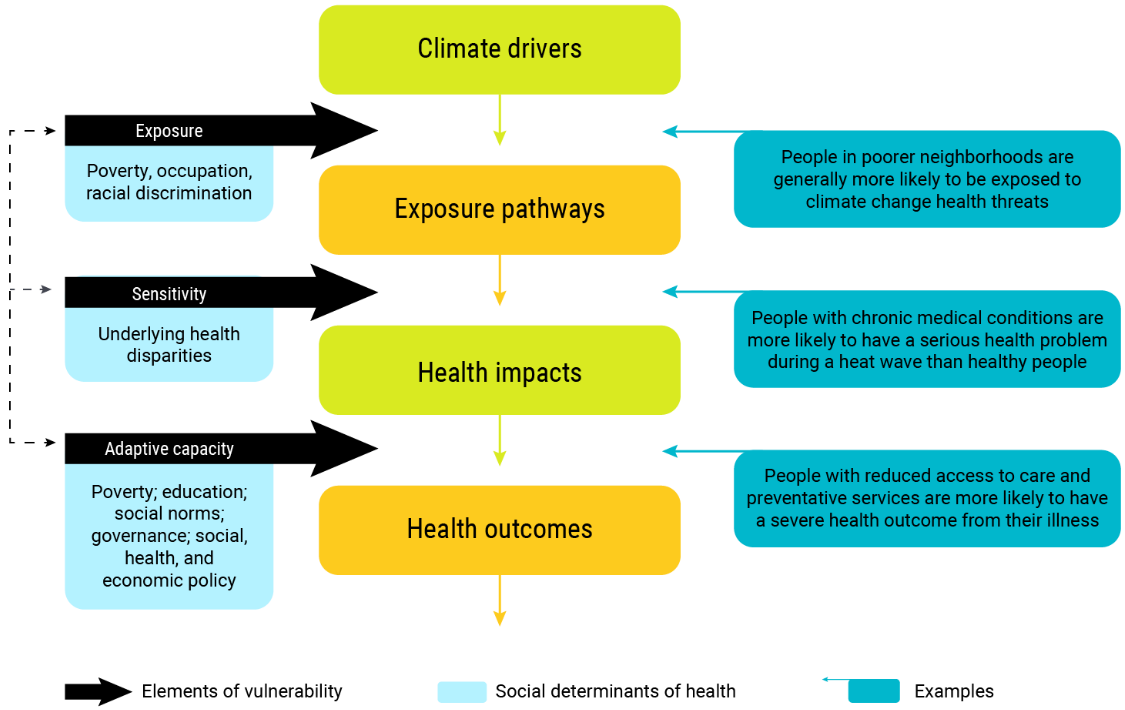


Figure 9.2 Social determinants of health interact with the three elements of vulnerability. Source: Gamble et al., 2016.

9.4.2 An Intersectional Approach to Understanding Climate Change and Health Vulnerability

In an effort to inform the development of adaptation measures to prepare for climate change, past Canadian climate change and health assessments have identified broad categorizations of "vulnerable populations" such as seniors and children, pregnant people, Indigenous Peoples, low income individuals, and immunocompromised or chronically ill people. Generalizations are often made regarding these populations' characteristics, conditions, and/or circumstances that increase vulnerability to particular health risks of climate change. However, such generalizations often fail to recognize the important heterogeneity of these population groups and may not adequately reflect how an individual or group understands themselves (Dhamoon & Hankivsky, 2011). They also often overlook how differences among and within populations may change over time in the face of climate change (Kaijser & Kronsell, 2014). This "universalizing" of various population groups disregards the multidimensional nature of vulnerability and may result in the unique needs of individuals being overlooked, creating barriers to effective adaptation. Further, it is common for climate change vulnerability research to focus on a single or limited number of discrete variables, such as economic status or sex (Kaijser & Kronsell, 2014; Bunce & Ford, 2015). As the understanding of climate change vulnerability evolves, there is increasing evidence that the characterization of vulnerability to the health impacts of climate change must include considerations of how multiple existing inequities can interact, shaping and compounding experiences and responses to climate change (Gamble et al., 2016). Employing an intersectional lens can contribute to this analysis and enhance understanding of climate change vulnerability.

Intersectionality is understood as the complex and interdependent interaction between various individual identity factors (e.g., sex, gender, age, language, ability) (Figure 9.3), social norms and cultural practices, institutional processes and systems of power and oppression (Dhamoon & Hankivsky, 2011; Kaijser & Kronsell, 2014; Hankivsky & Mussell, 2018). It can help to understand and identify existing power dynamics in society (Kaijser & Kronsell, 2014) and "encourages a contextual analysis that probes beneath single identities, experiences and social locations to consider a range of axes of difference to better understand any situation of disadvantage" (Dhamoon & Hankivsky, 2011, p. 38). The relevance of applying an intersectional approach to public health action to improve health equity has been established, although practical uptake appears low in Canada (NCCDH & NCCHPP, 2016).

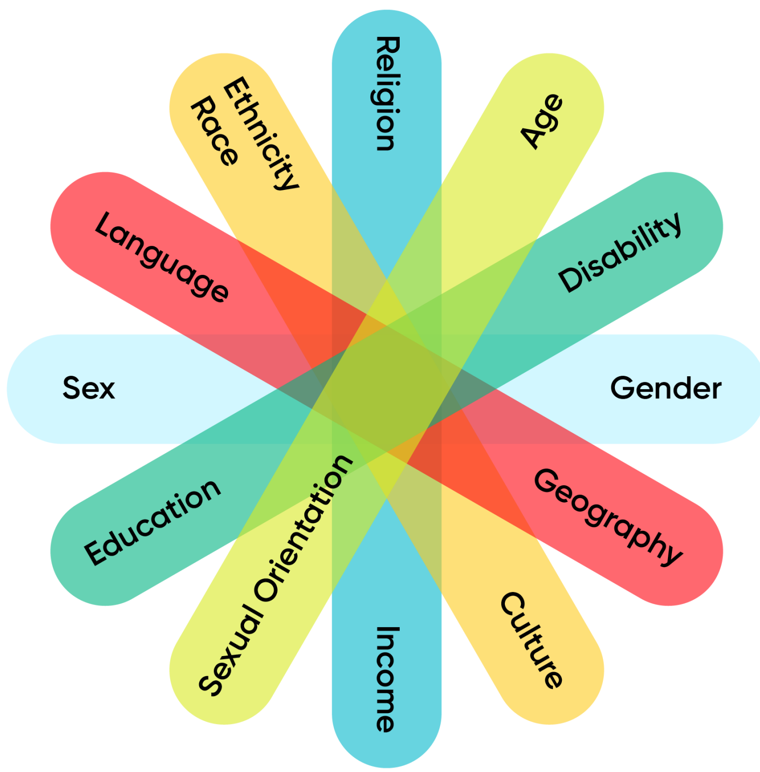


Figure 9.3 Examples of intersecting identity factors. Source: Adapted from Government of Canada, 2019b

Applying an intersectional approach to V&As, and to other climate change and health activities, can enhance understanding of the patterns of power, social conditions, and individual characteristics that contribute to health inequities and influence climate change vulnerability. Broadening this perspective of vulnerability also helps inform effective responses to climate change that can simultaneously address underlying drivers of inequity and broader social issues (Buse & Patrick, 2020). The application of intersectionality frameworks and the demonstrated effectiveness of practical application in the context of climate change has been limited. Nonetheless, tools informed by an intersectional approach, meant to be applied to policy, research, and programs across all sectors, are emerging in Canada (Box 9.2). An exploration of tools and resources that can enhance integration of health equity considerations into assessments of climate change and health vulnerability, and application of an intersectional approach, is provided in section 9.4.5 Integrating Health Equity into Climate Change and Health Actions.

Box 9.2 Gender Based Analysis Plus (GBA+) in the Government of Canada

The Government of Canada recognizes that an intersectional approach is essential to the development and implementation of inclusive policy, services, and initiatives for all sectors, including health. Gender Based Analysis Plus (GBA+) is an analytical process, informed by an intersectional approach, used to assess how diverse groups of men, women, and gender-diverse people may experience government programming, policies, research, and initiatives differently (Government of Canada, 2019b). GBA+ goes beyond sex and gender differences to consider how gender intersects with other identity factors such as race, ethnicity, socio-economic status, and other structural conditions. The Government of Canada is committed to applying GBA+ to current and future policies, programs, and initiatives, and it is required for key government and budget processes.

When data are available, applying the GBA+ tool to climate change mitigation and adaptation activities can result in the identification of positive and negative implications of the activities on various groups in the population. Measures to minimize negative impacts and enhance positive effects can then be implemented. This may be particularly effective when applied to V&As and to development and implementation of adaptation measures and strategies.

9.4.3 Drivers of Vulnerability: Determinants of Health and Health Inequities

As previously discussed, upstream drivers of health inequities, including social, cultural, economic, and political structures, as well as structural racism, ongoing colonialism, and climate change, result in the unequal distribution of power and resources. This influences the conditions in which individuals live and work, shaping determinants of health and giving rise to health inequities. Increasingly, determinants of health are recognized as major drivers of climate change vulnerability (Watts et al., 2015; Gamble et al., 2016; Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019). The determinants of health related to climate change can be grouped into six broad categories (Table 9.1). While not an exhaustive list, these determinants are commonly found in the climate change and public health literature. Although typically discussed as discrete factors, determinants of health interact with and influence each other. For example, income can determine the status of many other determinants of health, including stable and safe housing and economic access to nutritious food (Mikkonen & Raphael, 2010; CIHI, 2018).

Table 9.1 Examples of determinants of health related to climate change

Social and community context	• Social support and safety net • Social inclusion • Culture
Health and health care	• Access to primary care, including health care services • Healthy behaviours • Biology and genetic endowment
Economic stability	• Income • Housing stability • Food security • Employment and job security
Natural and physical environment	• Working conditions • Housing • Community and neighbourhood • Natural environment
Education	• Early childhood education and development • Language and literacy
Additional stratifiers/identity factors	• Gender and sex • Mobility • Race • Age • Ability/disability • Indigenous status

Source: Adapted from PHAC, 2008; Mikkonen & Raphael, 2010; Gamble et al., 2016; Ebi et al., 2017; Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019; Government of Canada, 2019a; USDHHS, 2020

At an individual level, vulnerability to health risks related to climate change likely increases as the number of determinants of poor health (e.g., low income, poor housing quality, food insecurity) increases. Importantly, individuals and populations that experience health inequities and determinants of poor health are not homogeneous, and much variation exists in terms of the experience of health impacts and degree of vulnerability, across and among population groups (see Box 9.3). These combinations vary for each individual and for each specific health risk. Improving determinants of health and redressing health inequities can, therefore, aid in reducing vulnerability to the health impacts of climate change. A selection of key determinants of health are analyzed below, establishing the linkages to climate change vulnerability.

Box 9.3 The heterogeneous nature of climate change and health vulnerability

In addition to differential experiences of vulnerability, perceptions of vulnerability and perceived efficacy of interventions can also differ among and within populations disproportionately affected by climate change. Benmarhnia et al. (2017) conducted a qualitative study seeking to understand perceptions of vulnerability in populations typically classified as "vulnerable" and their experiences with health intervention measures related to Montréal's heat action plan (HAP).

Two focus groups were conducted — one with individuals diagnosed with schizophrenia and one with individuals who have alcohol or drug addictions. Participants discussed their experiences during the last heat wave in Montréal; perception of vulnerability to heat-related health risks; and understanding, experience, and suitability of the HAP interventions.

The study found that there were significant differences in perceptions of vulnerability to heat-related risks between the two focus groups. There were also contrasting opinions between the two groups in terms of the appropriateness of the targeted interventions in the HAP. One group supported the idea that public health interventions should target specific populations, while the other suggested that addressing the root causes of vulnerability, such as social exclusion and material deprivation, should be a focus of public health policies. Differences among people within each group were related to perceptions of individual vulnerability to extreme heat, and these were particularly pronounced in participants of the group with addictions.

The heterogeneity of vulnerability between and within the focus groups suggests that "vulnerability is not conceived of nor experienced homogeneously by all populations defined as 'vulnerable' in public health policies" (Benmarhian et al., 2017, p. 6). The authors recommend that, after populations disproportionately affected have been identified, policy implementation should involve meaningful consideration of a range of experiences and different needs for public health assistance to maximize the effectiveness of interventions aimed at protecting health (Benmarhnia et al., 2017).

9.4.3.1 Natural and Built Environments

Human health depends on conditions constructed within social systems, but also the natural environment and ecosystems (Hancock, 2015). The state of ecosystems we live within, and their ability to provide the ecosystem services upon which we rely — known as the ecological determinants of health — are fundamental to human health. Changes in the environment that compromise the ability of ecosystems to function optimally and provide important life-sustaining resources and supplies (e.g., food, water, and oxygen) — for example, those associated with climate change — can negatively affect human health and well-being (CPHA, 2015). Recognizing the important interactions between ecological determinants of health and social determinants of health, the Canadian Public Health Association (CPHA) suggested that an eco-social approach in population health promotion is needed. Such an approach provides health and other co-benefits of a more just and sustainable society (CPHA, 2015).

The design and condition of the built environment is a significant determinant of health and encapsulates the external built environment where individuals live, work, play, and study. This includes roads, public transit systems, buildings, parks, and other infrastructure (MOHLTC, 2012; PHAC, 2017). Working conditions may be a source of physical risks and psychosocial stress, both of which have implications for health and well-being (Mikkonen & Raphael, 2010). Certain occupations can increase exposure to natural hazards that are worsened by climate change. For example, outdoor workers (e.g., agriculture, landscape, and construction workers) may be at increased risk to the health impacts of extreme heat, while emergency responders have increased exposure to extreme weather events such as wildfires, flooding, and hurricanes (Berry et al., 2014a; Gamble et al., 2016).

Safe, adequate housing, and well-planned neighbourhoods and cities can promote healthy behaviours and contribute to positive health outcomes (Mikkonen & Raphael, 2010), even as the climate warms. Communities with aging infrastructure may have more difficulty coping with climate impacts; for example, aging water and sewage infrastructure may contribute to increased risk of flooding and water contamination (Rudolph et al., 2018). In contrast, robust and durable housing may reduce exposure to extreme weather events.

9.4.3.2 Economic Stability

Economic stability and, specifically, income and income distribution have been identified as among the most influential determinants of health (Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas, 2019). Economic stability has close linkages with, and operates alongside, other determinants of health (CIHI, 2018). Income can determine the quality of other determinants of health, shaping an individual's overall living conditions (Mikkonen & Raphael, 2010; CIHI, 2018). For example, steady and adequate income can ensure stable and safe housing and access to food, which have important influences on human health.

In Canada, on average, low income individuals experience higher rates of chronic disease, heart attack, stroke, self-injury, and perceived poorer physical and mental health (CIHI, 2018). Low-income individuals and families may face increased challenges with accessing health care services, for example, prohibitive transportation costs, prohibitive costs of medication or medical treatments, and an inability to take time off work to go to appointments (CMA, n.d.). Inability to pay for out-of-pocket fees associated with health care can be a major barrier to accessing health care services (Whitehead & Dahlgren, 2007). The bottom 33% of Canadians, in terms of income earned, are 50% less likely to see a specialist when necessary, 50% more likely to have difficulty accessing health care services on weekends or evenings, and 40% more likely to wait five or more days to see a physician (Mikkonen & Raphael, 2010). Evidence suggests that quality of care is also lower for those with low socio-economic status, and discrimination by health care workers associated with low socio-economic status has been recorded (CIHI, 2018).

Low-income status is commonly associated with material and social deprivation (Mikkonen & Raphael, 2010). This is especially important in the context of climate change. Evidence suggests that those with fewer resources are less able to protect themselves and adapt to climate change (WHO, 2003; IPCC, 2014; Gamble et al., 2016; Friel, 2019). The impacts of climate-driven natural hazards can trigger household financial distress (Bank of Canada, 2021) and push people into poverty (Hallegatte et al., 2016). It was estimated that, in the absence of natural disasters for the year 2018, 26 million fewer people would have been in extreme poverty (World Bank, 2017). Globally, it is estimated that between 3 million and 16 million people could be forced into extreme poverty, primarily through climate change impacts on agriculture and food prices (Hallegatte, 2016; Hallegatte & Rozenberg, 2017).

9.4.3.3 Health Care Services and Accessibility

Accessibility, acceptability, and availability of health care are also important determinants of health. Access to health care varies across the population as a result of various socio-economic, geographic, and cultural factors (WHO, 2008). In Canada, geographic access to health care facilities and services differs across regions. For example, those living in rural and remote areas may have difficulty accessing health care due to geographic remoteness, long travel distances to facilities, long wait times, and limited access to specialty and emergency services (CIHI, 2018).

Individuals and populations that experience discrimination and stigmatization often face difficulties obtaining resources necessary for good health and encounter barriers accessing health services (PHAC, 2019). Discrimination based on race, religion, ethnic origin, gender, or sexual orientation is common, with over one in four people in Canada reportedly experiencing at least one form of discrimination in their lifetime (Godley, 2018; PHAC, 2019). 2SLGBTQQIA+, African, Caribbean, and Black people, as well as Indigenous Peoples, were more likely to report being unfairly treated while accessing health services than the general population in Canada (PHAC, 2019).

As noted above, cultural acceptability of health care can also present challenges to accessibility. Language barriers and cultural practices may create challenges for some, such as newcomers to Canada and Indigenous Peoples, in accessing and accepting health care (Whitehead & Dahlgren, 2007). First Nations, Inuit, and Métis peoples across Canada experience inequitable access to health care, which contributes to the reinforcement of existing health disparities. For many rural and remote Indigenous communities, accessing health care involves travelling long distances, and extended periods of separation from family and social networks, which can lead to emotional stress and discourage Indigenous Peoples from seeking care (NCCIH, 2019). Experiences of anti-Indigenous racism and discrimination also represent a significant barrier to health care, leading to unsafe care, mistrust, and ultimately poorer health outcomes (Goodman, 2017; NCCIH, 2019).

Access to health care can also be more challenging for those with disabilities. A study of Canadian women with disabilities found multiple barriers to accessing health care services, including negative attitudes and discriminatory practices from some health care providers (Gibson & Mykitiuk, 2012). Timely access to quality health care services can play an important role in reducing morbidity and mortality associated with climate-related health risks.

Climate change impacts on health systems in Canada are already being observed (see Chapter 10: Adaptation and Health System Resilience). For example, melting permafrost in the North can damage health and transportation infrastructure important for supply routes and access to health services (Séguin, 2008). Given that First Nations, Inuit, and Métis peoples face unique challenges in accessing health care services, climate change impacts on health systems are of particular concern (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada).

9.4.3.4 Social and Community Context

Social exclusion refers to individuals and groups that are excluded from fully participating in society. This commonly arises from the marginalization of populations, such as racialized groups, to effectively limit access to economic, social, and cultural resources (Mikkonen & Raphael, 2010; PHAC, 2019). People who experience social exclusion are more likely to be unemployed and low income, have difficulty accessing health care services, and have limited opportunities to advance their education (Mikkonen & Raphael, 2010).

At an individual level, social support networks, that is, strong relationships with and support from family, friends, and the community, have been associated with positive health outcomes (PHAC, 2008). The broader social environment context can also influence human health. A supportive society, which includes social stability, recognition of diversity, safety, good working relationships, and cohesive communities, can aid in reducing potential risks and adverse impacts on health (MOHLTC, 2012), including mental health (see Chapter 4: Mental Health and Well-Being). Such networks can be very important for coping with and adapting to climate change impacts. For example, while Indigenous communities in the North are disproportionately impacted by climate change, strong social capital has contributed to adaptive capacity and climate change resilience (Ratelle & Paquette, 2019). Actions such as cutting wood for Elders and sharing meat from hunting with community members strengthen social capital (Ratelle & Paquette, 2019) and contribute to positive health outcomes.

9.4.3.5 Education and Childhood Development

Education is an important determinant of health and can increase opportunities for employment and income security (PHAC, 2008; MOHLTC, 2012), thus influencing other important determinants of health (CIHI, 2008; WHO, 2008; Mikkonen & Raphael, 2010). Lower levels of education are associated with difficulty accessing health care services, decreased ability to interpret and understand health messaging and labels, greater use of emergency care, and unhealthy behaviours, such as smoking (CIHI, 2018).

Evidence suggests that early childhood development and experiences have significant biological, psychological, and social effects on health; the quality of early childhood development is strongly associated with social and economic gradients of advantage and disadvantage (PHAC, 2008; Mikkonen & Raphael, 2010; MOHLTC, 2012; Bennett & Friel, 2014). Existing inequities in child health outcomes can be exacerbated by climate change, which can limit adaptive capacity. For example, the ability of families to safely relocate when necessary, protect themselves from climate-related health risks, and recover from climate change impacts is enhanced as resources, power, and socio-economic status increase (Bennett & Friel, 2014).

Direct and indirect effects of climate change can affect the health of children (Helldén et al., 2021). For example, a study conducted in Southwestern Ontario found an association between extreme heat and increased emergency department visits among children (Wilk et al., 2020). Climate change impacts can also affect maternal, fetal, and infant health (Kuehn & McCormick, 2017; Bekkar et al., 2020). Canadian research has identified a positive association between heat exposure and gestational diabetes, sudden infant death syndrome, placental abruption, and early delivery (Auger et al., 2014; Auger et al., 2015; Booth et al., 2017; He et al., 2018). Existing inequities, variation in geographic region, and broader socio-economic conditions influence the impact of climate change on the health of children (Helldén et al., 2021).

Box 9.4 Human health, gender, and climate change in Canada

Gender is an important determinant of health and is also a factor influencing climate change vulnerability. Gender is understood as the socially constructed roles, norms, and values attributed to women and men (Preet et al., 2010). The relationship between climate change and gender has gained increasing attention in the climate change literature, complemented by global efforts to advance gender equality, human rights, and social equity (Sellers, 2018). However, existing studies often employ a narrow understanding of gender, examining the binary experiences of women and men (Bunce & Ford, 2015) and leaving out important consideration for other gender identities.

Individuals whose gender or gender expression do not fall within normative categories often experience marginalization, discrimination, and increased risk of violence, which may compound vulnerability to climate change. For example, international research finds that, following extreme weather events, 2SLGBTQQIA+ populations often face barriers to accessing disaster relief and recovery efforts. These barriers, often driven by social and religious stigma, can result in increased vulnerability to health impacts due to the lack of secure and safe shelter, medical care, food, and other unmet needs (Dominey-Howes et al., 2014; Gorman-Murrayet al., 2018; Resurrección et al., 2019). Importantly, 2SLGBTQQIA+ populations have demonstrated unique community-based coping strategies and adaptive actions during and after extreme events, such as hurricanes, despite their exclusion from response efforts (Dominey-Howes et al., 2014). The impact climate change currently has on 2SLGBTQQIA+ populations is a significant knowledge gap in international literature, as well as in Canadian research.

Understanding how gender roles may mediate health impacts across a population can aid in accurately assessing health vulnerabilities and developing effective adaptation measures. While there has been limited research on the gender-differentiated health impacts of climate change in Canada, some examples are provided below:

- Inuit women often take part in traditional livelihood activities, such as berry picking and sewing garments with sealskin. However, reduced opportunities and quality of traditionally harvested species have been observed, in part due to climate change effects, resulting in a reduction in earning potential and a shift in livelihood activities, which can have implications for health and well-being (Dowsley et al., 2010; Bunce et al., 2016).
- Inuit men are traditionally responsible for hunting activities. Given changing ice conditions and other hazards related to climate change (e.g., increased severe wind and flooding), the risk of injury for hunters is increasing (Ford et al., 2008).
- In Canada, men are more likely to hold jobs in resource sectors (e.g., agriculture and construction), where exposure to outdoor extreme heat can be high (Statistics Canada, 2018) (see Chapter 3: Natural Hazards).
- Gendered impacts associated with natural disasters, particularly on mental health and sexual violence, have been observed. For example, following the 2013 floods in High River, Alberta, a rise in anti-anxiety and sleep-aid prescriptions was reported among women. During this same period, a rise in sexual assault against women was also reported (Sahni et al., 2016).

9.4.4 Assessing Vulnerability to Climate Change Health Impacts

Health authorities across Canada and the world are increasingly using V&As as a tool to help individuals, communities, and health systems prepare for climate change (Berry et al., 2018). In Canada, 35% of public health authorities already have, or are in the process of conducting, a V&A (University of Waterloo Research Centre, 2019). They can be conducted at the local, regional, or national levels.

The primary objectives of a V&A are to understand the association between climate and health outcomes, identify current and future impacts on health, understand current conditions of vulnerability to climate-related health impacts, explore adaptation options that effectively reduce the current and future adverse health implications of climate change, and contribute to capacity-building within health organizations to respond to climate change (WHO, 2013; Ebi et al., 2016; Berry et al., 2018).

Results of V&As, supported by findings from academic literature, help public health authorities identify individuals and communities that experience disproportionate impacts on health associated with specific, discrete, individual and contextual characteristics (e.g., sex, gender, age, geographic isolation, low income) (Benmarhnia et al., 2017; Buse, 2018). When a health equity lens is applied in V&As, they can elucidate conditions that contribute to vulnerability specific to the geographic region assessed and determine how existing health inequities may be exacerbated with climate change. In the public health field, understanding which individuals and groups may face disproportionate impacts from climate change can be useful for prioritizing health adaptation measures and resources (Benmarhnia et al., 2017; Berry et al., 2018). Additionally, identifying existing health inequities and other local conditions that drive vulnerability in a V&A can promote the allocation of resources to address upstream drivers of negative health outcomes to strengthen health equity in a community (Buse, 2018).

According to a survey of Ontario health units in 2016, only 42% of respondents applied a health equity lens when identifying, prioritizing, and addressing climate change and health risks in their region (Doyle, 2017). Results of a 2019 survey of Canadian health units indicate that 85.1% of respondents consider implications for populations deemed to be at higher risk of climate change impacts in their climate change and health adaptation actions; however, only 37.3% consider implications for Indigenous Peoples, and 17.9% consider sex- and gender-based implications (University of Waterloo Survey Research Centre, 2019).

An intersectional approach can provide information on interacting variables, at an individual and structural level, that shape individual lives and health status (Dhamoon & Hankivsky, 2011) and that influence health inequities. When applied to a V&A process, this can be helpful in identifying which populations may be at higher risk of health impacts related to climate change. New V&A guidance from WHO (WHO, 2021) and from Health Canada (Health Canada, 2022) includes explicit consideration of health equity. Existing tools may complement V&A activities and adaptation actions. For example, the Ontario Ministry of Health and Long-Term Care's *Health Equity Impact Assessment* (HEIA) tool can be used to identify unintended — negative or positive — health impacts of a planned policy, program, or initiative on marginalized populations (MOHLTC, 2012). The HEIA workbook and templates allow users to identify unintended health impacts and develop recommendations for adjustments to mitigate adverse effects and maximize positive impacts among marginalized populations. They can also be used to increase the capacity of organizations to integrate health equity into decision making models and service design and delivery (MOHLTC, 2012). While the HEIA tool does not explicitly include climate change, the tool could be useful in assessing the outcomes of climate change and health adaptation measures and policies, as part of a V&A process.

9.4.5 Integrating Health Equity into Climate Change and Health Actions

Climate change and health is an area of increasing interest and work for local and regional public health units (see Chapter 10: Adaptation and Health System Resilience). While the concept and promotion of health equity is not new for public health actors, challenges remain about how to most effectively integrate this into climate change and health activities. Building on the four primary roles identified in the *Public Health Roles for Health Equity Action Framework* (Region of Waterloo Public Health, 2009; NCCDH, 2013), Table 9.2 identifies a range of public health actions to address climate change and improve health equity. These actions should be accompanied by a recognition and understanding of how historic and ongoing colonialism and racism are central to the creation of inequities.

Table 9.2 Actions to address climate change through established public health roles to improve health equity

ROLE 1: ASSESS AND REPORT ON CLIMATE CHANGE IMPACTS AND RELATED HEALTH INEQUITIES
• Conduct a climate change and health V&A » Devote time and resources to thoughtfully frame health equity in assessments, identify root causes of existing health inequities, and record data and knowledge gaps » Conduct deep, respectful, and meaningful engagement with Indigenous and other racialized and marginalized communities, integrating local and traditional knowledge, expertise, and community solutions throughout the assessment process » Internally, ask staff with a focus on health equity to inform the assessment » Communicate findings to partners, stakeholders, and the community using products tailored to meet the needs of diverse populations (e.g., incorporating language and accessibility considerations) • Contribute to the knowledge base on public health actions to address climate change and health equity » Document case examples of adaptation activities, promising practices, and lessons learned after V&As are conducted » Conduct community asset mapping to better understand existing assets in the community that contribute to climate change resilience (Rudolph et al., 2018; UCLA, n.d.)

ROLE 1: ASSESS AND REPORT ON CLIMATE CHANGE IMPACTS AND RELATED HEALTH INEQUITIES (CONTINUED)

- Collect data on the health impacts of climate change with an equity lens
  - For example, track deaths caused by extreme heat among racialized individuals living in low income communities or mental health impacts of climate change among socially disadvantaged populations
  - Whenever possible, enhance data collection efforts to capture sex-, race-, and gender-disaggregated data, as well as other demographic data (e.g., socio-economic status)
- Incorporate equity considerations into regular monitoring, surveillance, and reporting

ROLE 2: MODIFY AND ORIENT GHG MITIGATION AND ADAPTATION ACTIVITIES TO REDUCE HEALTH INEQUITIES

- Assess climate change actions for their implications for health equity before implementing them, to minimize negative outcomes and maximize benefits
  - For example, use the *Health Equity Impact Assessment Tool* (MOHLTC, 2012), conduct key stakeholder interviews with community organizations that work with populations at increased risk, and carry out meaningful engagement with populations that are disproportionately affected
- Identify opportunities to enhance co-benefits of GHG mitigation and adaptation actions, with particular attention to strengthening determinants of good health and addressing root causes of vulnerability

ROLE 3: PARTNER AND COLLABORATE WITH OTHERS TO BUILD CLIMATE-RESILIENT COMMUNITIES

- Engage in equitable, community-driven adaptation planning (Adaptation Clearinghouse, 2011; ITK, 2019)
- Contribute to municipal and regional plans for climate-resilient communities (PlanH, n.d.)
  - Support further understanding of the concept of unequal vulnerability (Salas et al., 2019)
  - Identify opportunities to address root causes of health inequities (Buse, 2018) and promote determinants of good health
- Identify and build collaborative partnerships within and outside of the health sector, and across all levels of government, to support multisectoral networks focused on climate change activities
- Engage with Indigenous and other racialized communities as partners and sources of expertise

ROLE 4: PARTICIPATE IN POLICY DEVELOPMENT RELATED TO CLIMATE CHANGE

- Embed health equity into all policy measures
  - For example, explicitly include health equity in mission, vision, and value statements (The Greenlining Institute, 2019)
  - Recognize the interconnected systems that drive health inequities and contribute to climate change vulnerability (e.g., racism, colonialism, economic structures, etc.)
- Raise awareness of needed policies that reduce carbon emissions, contribute to climate-resilient communities, and reduce health inequities
- Identify opportunities to mainstream climate change considerations into all proposed health policies and regularly evaluate impacts on populations who experience health inequities (PlanH, n.d.; The Greenlining Institute, 2019)

Source: Adapted from Muzumdar, 2020; NCCDH, 2021

For many local and regional health units, conducting a V&A is often the first step to protecting their communities from health impacts and adapting to future climate change. Such units can conduct practical activities and exercises to better understand the social context of their respective jurisdiction and identify drivers of climate change and health vulnerability. They can make the V&A more robust and support the development of tailored adaptation options for populations at higher risk of impacts. Examples of activities, described below, include resilience and asset mapping, vulnerability mapping, climate change and health projections, inclusive public engagement, and communications.

9.4.5.1 Resilience and Asset Mapping

Communities have many existing resources that play an important role in building climate resilience (e.g., social networks and cohesion). However, such assets and resources can be difficult to identify in common sources of data. Community surveys and community-based participatory asset mapping are exercises and tools that can identify people, organizations, spaces, and other “intangible factors” that contribute to community resilience (Rudolph et al., 2018; UCLA, n.d.). Such information is valuable for informing V&As and developing adaptive responses (Buse & Patrick, 2020).

Local initiatives that build an assets-based approach to mapping resilience to climate change and other hazards at the community level are increasing in Canada; many of these follow guidance outlined by Colussi (2000). For example, the Building Resilient Neighbourhoods (BRN) project (BRN, n.d.) has run applied projects across the Capital Regional District of British Columbia, in which local community members participate in assessing the resilience of their own neighbourhood to various shocks. The BRN project supplies a suite of online resources to support communities in undertaking such an assessment, including checklists for resilient neighbourhoods, workshop planning materials, and associated tools (e.g., scenario planning, asset mapping, resilience assessment). The BRN initiatives guide communities through exercises that consider a range of issues often overlooked in traditional planning, such as consideration for determinants of health and well-being (Wipond et al., 2017).

The City of Vancouver's Resilient Neighbourhood Toolkit is employed in a similar initiative and includes a series of modules for neighbourhood climate resilience assessment activities, including asset mapping and development of resilience action plans (City of Vancouver, n.d.). These activities provide opportunities to strengthen relationships among people in different neighbourhoods and increase understanding of where risks may exist that would affect certain households or streets. They also examine the community's capacity to plan and respond to climate change impacts. Another innovative example includes a role-playing game called Resilientville Canada (CREW, n.d.), in which players take on the role of a community stakeholder facing a scenario of either a flood, windstorm, or earthquake. The game gets players to think about their social relationships within a neighbourhood and what assets will assist them in strengthening their ability to respond to climate-related shocks or stresses.

These examples of resilience and asset mapping focus more broadly on understanding the assets available in communities that contribute to, and enhance resilience to, a broad range of shocks and stressors, including extreme weather events and climate change impacts. Assets that contribute to resilience in the health sector and mitigate human health impacts are generally included in these exercises. While these activities can be modified to focus specifically on health system resilience, there is also benefit in focusing on resilience-building activities and asset mapping from a broader perspective. This facilitates multisectoral collaboration on climate change activities that include appropriate linkages to human health and the health system.

9.4.5.2 Vulnerability Mapping

Vulnerability mapping provides information on patterns of social conditions and climate change vulnerability in a particular region (Gamble et al., 2016; Foster et al., 2019), and can inform V&As. Mapping can be accomplished, for example, by developing a social vulnerability index, which uses social vulnerability indicators (e.g., socio-economic status, housing tenure, education, age, race, access to medical services, etc.) to elucidate the social conditions that drive vulnerability to health impacts or hazards related to climate change (Rudolph et al., 2018; Foster et al., 2019). Commonly, social vulnerability maps are combined with maps that display exposure to biophysical hazards related to climate change (e.g., wildfires, flooding, sea level rise, urban heat islands). The resulting maps aid in understanding the intersection of social and biophysical vulnerabilities and in identifying neighbourhoods and regions that experience disproportionate risk. Vulnerability maps can inform the V&A process by identifying populations and neighbourhoods that may be disproportionately affected by climate change hazards, such as extreme heat events or flooding, and help inform public health interventions (Rinner et al., 2010; Gamble et al., 2016; Foster et al., 2019).

Developing vulnerability indexes and frameworks are typically the first step in developing vulnerability maps. There are a variety of approaches to developing vulnerability indicators and indexes related to climate change impacts, and various Canadian examples exist (Rinner et al., 2010; Chakraborty et al., 2020; Yu et al., 2021). Raval et al. (2019) conducted a review of more than 40 existing climate change vulnerability frameworks that analyze community vulnerability to climate impacts in California. The review found a lack of frameworks that adequately reflect the intersectional nature of climate vulnerability. Four frameworks were highlighted in the report, recognized for excelling in their ability to comprehensively integrate multiple exposures, population sensitivity, and adaptive capacity, as well as their breadth in terms of the number of indicators incorporated across exposures and other vulnerability factors and in terms of taking data accessibility into account (Raval et al., 2019). These frameworks included:

- Public Health Alliance of Southern California's *California Healthy Places Index* (PHASC, 2018)
- California Department of Public Health's *California Building Resilience Against Climate Effects: Climate Change and Health Vulnerability Indicators* (CalBRACE, 2018)
- California Energy Commission's *Social Vulnerability to Climate Change* (Mazur et al., 2010)
- *Climate Change Vulnerability Screening Index* (English et al., 2013)

These frameworks and indexes may be adapted by public health authorities to increase understanding of characteristics and conditions in their regions that may increase or decrease vulnerability to various climate change health risks. Such knowledge can be used to inform and enhance V&As.

Tools based on geographic information systems (GIS) and vulnerability mapping exercises can also be helpful in developing and implementing adaptation measures. For example, urban forests provide a number of environmental, social, and economic benefits that support health equity, including mitigating air pollution; mitigating urban heat island effects; contributing to the management of surface water quantity and quality; maintaining and enhancing natural heritage; enhancing economic value; providing direct cost savings; supporting improved physical health and emotional well-being; and strengthening communities and enhancing social equity (Morrison, 2017). Recognizing these benefits, the Region of Peel, Ontario, developed the *Peel Tree Planting Prioritization Tool*, which aids decision makers in determining where tree planting is most beneficial to the community (Richardson, n.d.). Accounting for 12 target benefits, which include supporting improved physical health and emotional well-being, strengthening communities, and enhancing social equity, the GIS-based tool generates maps at various geographic scales that identify areas in Peel Region for tree planting where benefits will be maximized (Richardson, n.d.).

Box 9.5 The surveillance and prevention of the impacts of extreme meteorological events on the public health system, Quebec

In 2010, the Surveillance and Prevention of the Impacts of Extreme Meteorological Events on the Public Health System (SUPREME) programme was developed by the Institut national de santé publique du Québec (INSPQ) in collaboration with the Ministry of Public Security (Québec), and the Meteorological Service of Environment Canada (now Environment and Climate Change Canada). Combining elements of early warning systems, vulnerability mapping, and monitoring and surveillance into a single, real-time, integrated system, SUPREME provides public health officials and emergency responders with provincial-level information during extreme weather events, informing the implementation of preventive measures and response plans (Toutant et al., 2011; Gosselin et al., 2018; INSPQ, 2020).

The SUPREME system has three primary components. First, when weather forecasts report a possible extreme weather event, warnings are sent via email to alert health authorities in real time. Second, SUPREME's online portal provides surveillance and monitoring of six weather hazards: extreme heat, flooding, extreme cold, heavy snowfall events, wildfires, and ice storms. Estimated impacts of these hazards to human health are also provided, including mortality rates, hospitalizations, emergency department visits, ambulance transport, and calls to Info-Santé (INSPQ, 2020). Finally, the online portal includes a GIS-based application that displays geographic data on health risks (e.g., urban heat islands), protection factors (e.g., medical services, infrastructure, green spaces, and buildings with air conditioning), and the location of vulnerable regions. For example, socio-demographic data and other indicators, including a regional deprivation index, housing conditions, and language, are used to provide maps that identify communities and regions that may experience increased vulnerability to extreme heat events (Toutant et al., 2011; INSPQ, 2021).

Since its creation, SUPREME has been evaluated twice for level of use, effectiveness, and overall user satisfaction. Assessment results indicate user satisfaction is high, and the system is very useful for public health authorities (Bustinza et al., 2016; Gosselin et al., 2018). Further, when evaluating SUPREME following an extreme heat event in 2010, it was found that the system mitigated the effects of the event on population health compared to previous heat events (Toutant et al., 2011).

9.4.5.3 Climate Change and Health Projections

Climate change projections can provide useful information on how mortality, morbidity, and/or other health outcomes related to climate warming may change in the future. This information can help inform adaptation and response plans and aid policy makers in understanding long-term impacts of climate change and needed resources (Sellers & Ebi, 2017; Rudolph et al., 2018).

Changes in demographic and socio-economic conditions, urbanization, land use, investments in new technologies, governance, the extent to which equity issues are addressed, and other factors can influence vulnerability to future health impacts of climate change (Ebi et al., 2016). For example, knowledge of how populations exposed to various climate hazards may change (e.g., aging, health status, migration) can assist decision makers to plan adaptation measures to protect populations from health risks (Rudolph et al., 2018). Further, considering how health care service and delivery is expected to evolve over the coming decades and how they may need to be altered to adapt to climate change is important for health sector decision makers to include in iterative planning processes to plan for climate change (Sellers & Ebi, 2017).

9.4.5.4 Inclusive Community Engagement

Health equity cannot be realized without transparent and accountable inclusion and meaningful engagement that provides individuals and groups with agency to represent their interests and experiences (USDN, 2017; Rudolph et al., 2018; Friel, 2019). An effective way of including diverse groups and perspectives is through broad community engagement when undertaking a V&A. Residents and community-based organizations (CBOs) can provide valuable information related to the history and social context of a neighbourhood, past experiences with climate events, existing assets and resources that contribute to adaptive capacity, and the success and/or challenges of previous public health adaptations (Rudolph et al., 2018). Community residents, particularly through CBOs, can provide assistance with data collection and support communication and outreach activities with individuals and populations in their respective networks (USDN, 2017). There are a number of public engagement strategies and frameworks, and each have their own strengths and benefits (NCCDH, 2013; Oickle, 2020). Public health authorities may establish various engagement strategies throughout a V&A process, choosing specific activities that align with the objectives of each step in the process.

9.5 Adaptation

Adaptation is the response that an individual, community, or system takes to better cope with, manage, or adjust to changing conditions (Smit & Wandel, 2006) (see Chapter 10: Adaptation and Health System Resilience). Over the past decade, the field of climate change and health adaptation has grown significantly in Canada, with an increasing number of diverse actors, available resources, and adaptation strategies (Berry et al., 2014a). There are multiple dimensions of health equity associated with climate change adaptation. Individuals have varying capacity to adapt to climate-related health risks, given differences in determinants of health and related contextual factors, such as distribution of resources (Lynn et al., 2011; Ebi et al., 2016). The outcomes of adaptation measures are not always uniform or experienced in the same way, and the planning and design process of adaptation activities have sometimes left out important voices and partners, such as low income communities, racialized populations, and Indigenous Peoples (USDN, 2017; Foster et al., 2019).

Increasingly, public health actors are recognizing the dimensions of health equity associated with adaptation actions and strategies. However, efforts to account for and address health equity in adaptation interventions have been limited in Canada and globally. Existing climate change and health equity literature commonly analyzes dimensions of equity from the perspective of unequal distribution of climate change impacts and vulnerability (Bennette & King, 2018), with significantly less information on how to ensure that the adaptation design and implementation process is equitable, that outcomes are fair, and that equity is protected and promoted effectively (Deas et al., 2017; Schlosberg et al., 2017). Despite this knowledge gap, opportunities to better account for and integrate health equity in climate change adaptation exist. Additionally, adaptation policies and measures offer the opportunity to address multiple issues simultaneously, such as protecting health from a changing climate, while strengthening determinants of health and redressing drivers of health inequity.

9.5.1 Adaptation Measures and Equitable Outcomes

Adaptation actions should provide benefits to those most in need; however, outcomes from these measures are not experienced in the same way across populations and communities. In the absence of careful planning and implementation, adaptation measures may have unintended outcomes that adversely impact some population groups or exacerbate existing inequities (Levy & Patz, 2015; Boeckmann & Zeeb, 2016). For example, while air conditioning units can be effective adaptation measures for extreme heat, prohibitive energy bills may keep some households from using air conditioning, which may increase their risk of health impacts related to heat (EPA, 2008). In addition, air conditioning can generate a significant amount of waste energy, further increasing outdoor air temperatures (Salamanca et al., 2014), exacerbating the urban heat island effect, and increasing cooling demands, which can increase heat-related health risks for those who do not have access to air conditioners.

Increasing green spaces in an urban centre can reduce health risks associated with urban heat islands and has a number of associated health co-benefits (Friel, 2019; Health Canada, 2020). However, an increase in green spaces could also result in unintended consequences. For example, new green spaces could perpetuate gentrification and increase property values in the neighbourhood, which may lead to the displacement of low income residents and small local businesses (USDN, 2017; Kreslake, 2019; Cleveland et al., 2020). A literature review on the creation of green spaces in urban centres concluded that these spaces generally benefited communities that are predominantly high-income and White (Wolch et al., 2014). To address these concerns, adaptation plans may involve instituting rent-control policies and other strategies to maintain housing affordability when creating green spaces (USDN, 2017).

When adaptation programs are put in place, individuals and population groups may face barriers to accessing and using the measures effectively. In efforts to reduce risks from extreme heat, cooling centres are often established for residents to get relief. However, an individual who has challenges with mobility (e.g., due to low income, disability, and/or social isolation) may have difficulty gaining access to a centre unless appropriate supportive measures are put in place (Health Canada, 2012). The City of Greater Sudbury partnered with Greater Sudbury Transit to make all transit trips free of charge during extreme heat events to ensure equitable access to cooling centres (Evergreen, 2020). Such considerations are needed to ensure that adaptation measures can be accessed and used by all, particularly those who face disproportionate risk of health impacts related to climate change. Considerations of equity should guide intervention strategies, and strategies will be most effective when they are developed in partnership with the community and decision makers from across a variety of sectors.

9.5.2 Adaptation Actions to Enhance Health Equity

Public health officials can leverage adaptation actions and climate change resilience-building efforts to improve health equity and strengthen determinants of health (Boeckmann & Zeeb, 2014; Gould & Rudolph, 2015; Deas et al., 2017; Rudolph et al., 2018). This is important given that, in Canada, some health disparities continue to increase (PHAC, 2018), as does income inequality, particularly in urban centres (Hankivsky, 2014; CPA, 2017).

An example of a collaborative project for climate change adaptation that simultaneously strengthened determinants of health is the InosiKatigeKagiamik Illumi: Healthy Homes in Nunatsiavut initiative in Nain, Nunatsiavut, Newfoundland and Labrador. It is estimated that 38% of children in Nunatsiavut live in a home that is in need of major repairs, and 86% of homes show signs of damage from permafrost melt and ground subsidence (ISC, 2019). Homelessness, overcrowding, and difficulties with keeping homes warm due to poor quality of structures and/or a lack of economic resources for heating needs were identified as undermining health and well-being in the community (Bennett, 2015). Additionally, a lack of land suitable for building, the high cost of development, and a frequent need to repair or replace existing homes created a number of difficulties meeting housing needs in rapidly expanding communities. The aim of the project was to develop climate-resilient housing infrastructure that was also culturally relevant, affordable, energy efficient, and reduced the health impacts from overcrowded dwellings and mould. Upon a thorough assessment of existing homes in Nain and the surrounding region, residents were engaged in a community-driven process for housing design in which they shared existing housing challenges and design preferences, which allowed for important cultural values to inform the design of a prototype multi-unit, climate-adapted housing development (ISC, 2019). Space to store hunting equipment, a large steel sink for cleaning fish and preparing sealskins, and large open-concept living spaces to allow for gathering were all features proposed by residents that were incorporated into the final design (Bennett, 2015).

Another example is the Nunamin Illihakvia Learning from the Land (phase 1) and TUMIVUT: Tracks of Our Ancestors Towards a Healthy Future (phase 2) project implemented in Ulukhaktok, Inuvialuit Settlement Region, Northwest Territories. This two-phase project focused on strengthening community health and food security through increased transmission of Inuit traditional knowledge and promotion of the Inuinnaqtun language (ISC, 2019). The program brought together Inuit youth, experienced hunters and sewers, and Elders; through a series of activities, knowledge was shared and skills were built around caribou hunting, traditional sewing skills, and language. These skill sets and values are important to Inuit in Ulukhaktok, contributing to a healthy lifestyle, physically, mentally, and culturally (ISC, 2019). Many benefits were observed as a result of the program. Inuit youth gained practical skills that have economic and social value, which was particularly beneficial for those who did not have family members who could teach them these traditional skills, or who lacked equipment or economic resources to participate in such activities. Participants also noted an increased sense of well-being, reduced stress, and strengthened cultural identity (ISC, 2019). The project supported values and skills that are important for individual and community health, while also strengthening determinants of health (e.g., food security) and building capacity to adapt to increasing climate and societal change.

BlueLA Carshare program is an example of an initiative that combines climate change action with health-equity objectives. To reduce air pollution and mitigate GHG emissions associated with personal vehicles, the City of Los Angeles, California, collaborated with partners to develop an electric vehicle (EV) carsharing pilot project — BlueLA — which was funded through a grant from the California Air Resources Board. Launched in 2018, BlueLA prioritized service to disadvantaged communities, accounting for low income residents in areas with high exposure to air pollution to redress existing health and social inequities. Carshare memberships were provided to low income residents at a discounted cost. The EV fleet simultaneously reduced local air pollution from gas-fuelled vehicles and mitigated GHG emissions (SUMC, 2019a).

In the first year of the project, 80 EVs were introduced to the community, 130 charging points and 26 charging stations were installed, nearly 2000 residents registered as BlueLA members, and more than 12,000 trips were made. Approximately 260 t of CO_2 were avoided as a result (SUMC, 2019b). Given the success of the program, BlueLA was awarded a grant of $3 million dollars from California Air Resources Board to initiate phase 2, which will involve scaling up the project to expand into three additional regions: South Los Angeles, East Los Angeles, and East Hollywood (SUMC, 2019b).

9.5.3 Planning Adaptation Measures with Equity in Mind

Adaptation measures that result in equitable outcomes emerge from equitable adaptation processes. Ensuring equitable participation and the inclusion of diverse voices at all stages of the adaptation process results in better planning and policy making (Race Forward, 2018). While common engagement practices and strategies involve many community members, important voices may be missed. Deliberate efforts must be made to ensure participation by those who are most at risk of health impacts related to climate change. Meaningful engagement can provide valuable information concerning the unique context and social conditions of the target community, including current power dynamics and existing inequities. This information is required to develop transformative, effective, and equitable adaptation measures that reflect the expertise and perspectives of those most affected (Drolet & Sampson, 2017; Schlosberg et al., 2017; Race Forward, 2018).

There are significant challenges with meaningful public engagement in the adaptation process. For example, engagement opportunities may be reactive and conducted only after a planning process has been initiated and/or after major decisions have already been made. Budget and timeline constraints can also limit the effectiveness of engagement processes (USDN, 2017; Foster et al., 2019; Evergreen, 2020). Decision makers can ensure more comprehensive participation by ensuring that an appropriate timeline and budget for engagement is included in the plan from the outset, engaging community members from the beginning of the development and design process, and incorporating input from community members into the adaptation strategy to more effectively reflect the needs and unique vulnerabilities of the community (Foster et al., 2019). This would ensure that interventions address the specific conditions, health risks, and challenges in the community (Ebi, 2009). Other benefits of broad community engagement include increased “buy-in” of the final adaptation actions, enhanced reach of information dissemination activities, and greater capacity to participate in future decision making and planning activities in neighbourhoods (USDN, 2017).

In Canada, there are examples of effective, broad community and stakeholder engagement during adaptation design processes. For example, as part of Middlesex-London Health Unit’s V&A process, a workshop was conducted with more than 100 people from various community groups, government agencies, and the health sector. In addition to validating preliminary findings from the vulnerability assessment, participants were also provided the opportunity to discuss concerns about climate change impacts on health already observed in the community, and identify collaborative efforts needed for effective adaptation. Additionally, workshop participants provided their views on (Berry et al., 2014b):

- options for reducing current and future risks to health through adaptation;
- challenges for current and future adaptation efforts to protect health;
- willingness of organizations to participate in strategies for climate change and health adaptation; and
- effective avenues for communicating the results of the V&A.

Perceptions of needed or appropriate climate interventions may differ between the public and decision makers. For example, Schlosberg et al. (2017) reviewed local council climate adaptation plans in Australia and compared them to concerns related to climate change and proposed adaptation efforts posted on local environmental groups' websites and social media accounts. The analysis found that there was often little correlation between the climate adaptation plans and the concerns expressed by public and environmental groups regarding impacts and their suggested adaptation measures. Local government plans largely followed a risk- or resilience-based approach, while public interest groups were much more focused on climate change impacts on "basic needs and capabilities of everyday life" (e.g., health, food security, housing, etc.), which are required to achieve social justice (Nussbaum, 2011; Schlosberg et al., 2017) and support health equity. Participatory and community engagement approaches are an opportunity to reduce this disconnect between decision makers and public needs and perceptions, and thereby develop effective adaptations that support health equity.

A 2018 U.S. study highlighted the importance of engaging with and understanding the views and perceptions of community members to support the development of climate change measures (Kreslake, 2019). To gain insight into the perceived importance of adaptation and GHG mitigation measures, residents from three regions in the United States (Southern California, Florida, and Arizona) recently affected by extreme weather events were surveyed. Participants were categorized using individual-level indicators of vulnerability to the health impacts of climate change. The study revealed that perceptions varied across population groups, with differences in the types of adaptation and GHG mitigation interventions considered most important. For example, there was greater perceived importance of enhanced emergency alert systems among individuals with chronic illness (Kreslake, 2019). In addition, racialized groups prioritized communication activities from local government regarding climate change impacts and GHG mitigation efforts. Low-income residents were among those who indicated the greatest support for actions that would strengthen social services during extreme weather events (Kreslake, 2019).

The differences in perceptions across these groups illustrate the important role public engagement can play in developing climate change and health actions. Working with community members and stakeholders ensures that adaptation interventions reach those who are disproportionately affected, provide information in an accessible way, and motivate and empower individuals to make appropriate choices (Ebi & Semenza, 2008). Participatory approaches to developing adaptation measures can create the space and opportunity for front-line and disadvantaged communities to actively participate in decision making processes that result in policies and programs that will directly affect their lives (Ebi & Semenza, 2008; MSC, 2015; USDN, 2017, The Greenlining Institute, 2019).

Box 9.6 Inuit-led community-based adaptation approach

Community-based adaptation processes enable the local community to determine the methods and objectives of measures for climate change adaptation. These often involve a partnership between communities and institutions and build on existing local and traditional knowledge, skills, networks, technologies, practices, and social and cultural norms to produce adaptation measures that address the unique needs of local residents (Kirkby et al., n.d.).

For example, Siku, the Inukitut word for sea ice, is a newly developed mobile application and web platform designed by and for Inuit. The app seeks to increase the safety of Inuit hunters from weather and climate-related hazards, while revitalizing traditional knowledge by sharing practices in their own language (Arctic Elder Society, 2019).

With the loss of permafrost and melting sea ice, the safety of hunters has been a prominent concern for Northern communities. The app attempts to address these concerns by integrating modern weather forecasting, sea ice data, and satellite imagery with first-hand accounts of conditions and wildlife sightings using traditional place names in multiple dialects (Arctic Elder Society, 2019). This technology allows hunters to share changing and dangerous conditions with their communities using their own language and knowledge systems. For example, in one instance, a hunter marked an ice field with a warning sign on the map in the app, using the Inuit language to describe the condition (Tutton, 2019). Hours later, the map had been updated by other hunters to show that a crack had widened to the point that, if hunters had crossed it, they would have been unable to return (Tutton, 2019).

The Arctic Elder Society, a charity-based organization in Sanikiluaq, Nunavut, supported the app as a way to increase the safety of community hunters, as well as to revitalize traditional practices and mobilize Inuit knowledge and dialects (Arctic Elder Society, 2019). The community-based approach empowers the hunters and citizens as active determinants of community well-being, while increasing social cohesion and knowledge of language and cultural practices. This app is a unique project that highlights the right to self-determination of Indigenous communities and draws on the strengths of a community to address climate change challenges in an innovative and culturally relevant manner.

Engaging with community members who are at higher risk of climate change impacts on health can also enhance existing strategies for climate change adaptation. In a project to better address equity in its climate change adaptation work, the City of Vancouver partnered with a non-profit organization, Evergreen, to conduct engagement activities among populations whose "voices are not often heard in public decision making on climate change" (FCM, 2021). In total, more than 500 community members participated in the engagement process, and 21 key stakeholders from community service organizations were interviewed. Engagement activities were tailored to meet specific socio-cultural needs and interests of particular population groups (e.g., activities were offered in five different languages), designed to reflect the populations' interests and activities (e.g., a senior walking group was engaged in an urban forest walk, where their observations of climate change and coping behaviours during extreme heat were collected) and held at familiar, safe locations (Evergreen, 2020; FCM, 2021). By sharing their lived experiences, community members provided significant information on the current climate change and health challenges they face, specifically in relation to extreme heat and air quality. Feedback on the effectiveness of existing adaptation measures and strategies was collected, along with particular needs related to cooling centres, climate change education and awareness, transportation, and access to water. As a result, recommendations for enhanced and additional adaptation measures were developed, and will be incorporated into the city's adaptation strategy (Evergreen, 2020).

A number of frameworks provide guidance and promising practices for inclusive and equitable community engagement for planning for climate change resilience and adaptation, including:

- *Community-Based Adaptation to Climate-Related Health Impacts Framework* (Ebi & Semenza, 2008)
- *Making Equity Real in Climate Adaptation and Community Resilience Policies and Programs: A Guidebook* (The Greenlining Institute, 2019)
- *Equitable, Community-Driven Climate Preparedness Planning Framework* (USDN, 2017)
- *Community-Driven Climate Resilience Planning Framework* (Movement Strategy Centre, 2015)
- *Working Better Together: Collaborating with Inuit on Climate Actions in Inuit Nunangat: A Framework for Governmental and Non-Governmental Bodies* (ITK, 2019)

To appropriately increase the representation and participation of groups that have often been excluded from developing and shaping climate change and health adaptation measures, it is important for decision making organizations and actors to recognize, acknowledge, and remove barriers to participation (such as financial burdens, travel requirements, language, child care, etc.), as well as to demonstrate sensitivity to the context in which engagement is taking place (Dhamoon & Hankivsky, 2011). Prioritizing time and resources to invest in relationship-building and cultivating trust is key to this process, as is creating spaces and engagement processes that are culturally relevant, inclusive, and safe for marginalized populations.

Key considerations and actions that can guide decision makers as they seek to address climate change and health risks through community engagement and community-based approaches include the following:

- Engage communities and residents at the beginning of and throughout the process of climate change assessment and adaptation (Moser et al., 2017).
- Recognize the power dynamics between decision-making actors and community members, specifically with groups that experience discrimination (Dhamoon & Hankivsky, 2011; Hankivsky, 2014).
- Address and replace patterns of behaviours that perpetuate inequities, for example, dominance of Western science versus Indigenous knowledge(s) and uneven patterns of participation in decision-making processes.
- Work with the community to identify current priorities, concerns, challenges, and existing inequities (Dhamoon & Hankivsky, 2011).
- Identify the level of literacy about climate change and health in the community, and tailor engagement activities appropriately.
- Acknowledge communities and marginalized members as active agents of change and determine community strengths and assets — avoiding victimization narratives.

- Listen to community members and incorporate their local knowledge and assets.
- Meet partners where they are and where they are coming from (Shi et al., 2016; Moser et al., 2017); for example, conduct engagement activities and speak with residents where they are most comfortable, such as traditional community gathering places.

Recognizing the importance of community input into the development of climate change action plans and adaptation strategies, local and regional decision makers are developing innovative, community-based approaches to collect input. In 2012, the City of Portland, Oregon, began the process of updating its climate action plan. Aware that considerations for social equity were absent in prior climate change strategies, the City administration took intentional action to integrate equity in every stage of the process and ensured that the plan featured an equity lens (Williams-Rajee & Evans, 2016). An Equity Working Group was created, made up of six CBOs that represented low income populations and racialized communities. Funding was provided to these CBOs to support participation in the working group. The Equity Working Group collaborated with the Climate Action Plan Steering Committee to finalize an equity considerations framework, which staff used to assess every action proposed in the draft climate action plan. The Equity Working Group then reviewed the updated plan to ensure its input had been incorporated effectively. An *Equity Implementation Guide* was also developed by the Equity Working Group as a companion piece to the final *2015 Climate Action Plan*, and the guide included an implementation approach and further recommendations for incorporating equity into climate change actions (Williams-Rajee & Evans, 2016).

The outcomes of adaptation measures are borne by individuals and organizations at the local level, which may foster the perception that adaptation actions are the sole responsibility of local decision makers (Pelling & Garschagen, 2019). However, it is important that health equity aspects of adaptation are considered at all scales of decision making, given that national, provincial, and territorial policies, standards, and regulations, such as land-use planning, building codes, taxation, financial incentives, environmental regulation, and related measures influence local conditions and livelihoods and affect many important determinants of health (Pelling & Garschagen, 2019).

In addition to working with a broad range of community members and organizations, stakeholders in and outside of the health sector should be engaged in planning for climate change and health adaptation. Climate change impacts and conditions that affect determinants of health cross multiple sectors and do not fall neatly into defined jurisdictions and mandates, making it difficult to allocate responsibility to one particular sector (Friel, 2019). To maximize the opportunity adaptation measures offer to strengthen determinants of health and address drivers of health inequity, collaboration, across a range of disciplines (science, social sciences, humanities, etc.) and sectors is key (CSDH, 2008; Friel, 2019).

9.5.4 Evaluating Adaptation Measures for Health Equity

The complex interactions among determinants of health, current and projected health inequities, and climate change adaptation measures makes it challenging to assess the immediate and long-term effects of climate change interventions on human health and health equity (Boeckmann & Zeeb, 2016). Given the urgency of climate change, particularly in relation to effects on the severity and frequency of extreme weather events, decision makers must often design and implement adaptation actions in the absence of this information. Evaluating adaptation measures for their effectiveness in protecting health, including the promotion of health equity, can provide important information about their benefits and identify where modifications may be necessary.

Frameworks that specifically evaluate the impact of climate change adaptation actions on health equity are limited, and few have been evaluated or implemented in practice. Nevertheless, they may be useful in guiding public health authorities in their efforts to prepare for climate change impacts. For example, Boeckmann and Zeeb's (2016) framework assesses the effectiveness of an adaptation measure by evaluating its effect on seven domains of health determinants (e.g., infrastructure, social, economic, community, environmental) (Figure 9.4). Indicators and guiding questions related to access to information, cultural values, health services, and civic engagement, are provided to assist users in conceptualizing the positive and negative implications of their adaptation measures.

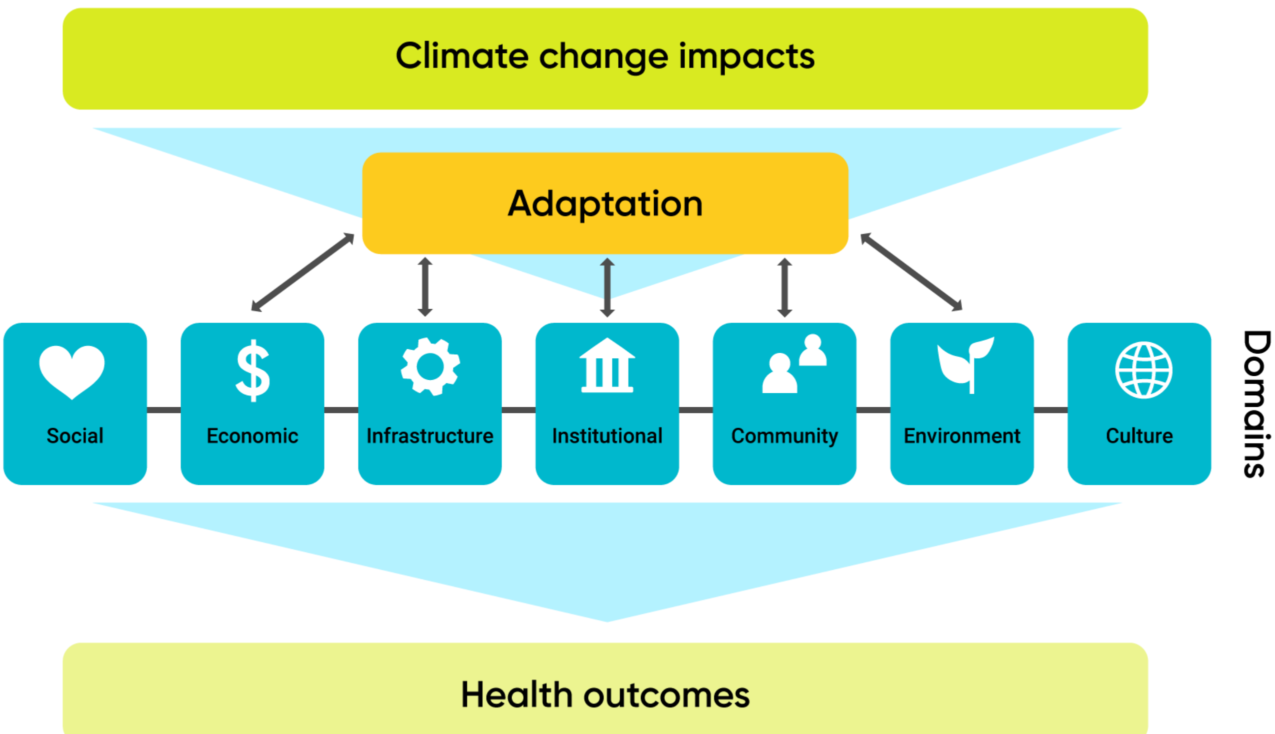


Figure 9.4 Domain-driven theoretical framework to evaluate adaptation based on justice concerns. Source: Boeckmann & Zeeb, 2016.

Recognizing the difficulties associated with attributing health outcomes with specific adaptation measures in many cases, this framework highlights the linkages between adaptation and the broader social domains associated with determinants of health (Boeckmann & Zeeb, 2016). This provides a much broader conceptualization of how adaptation measures fit into various social contexts and can advance understanding of possible short- and long-term impacts of adaptation measures on health equity as well as related concepts of environmental justice. The framework indicators and guiding questions could be applied in V&As conducted by health authorities to evaluate health adaptation strategies as well as measures implemented in other sectors that may have direct and/or indirect impacts on human health. Given that a variety of actors are involved in each of the seven domains, the framework also promotes a multisectoral approach to adaptation development and evaluation. The practical use of the framework depends on the data available (Boeckmann & Zeeb, 2016); however, collaboration among practitioners, academia, and other stakeholders can facilitate acquisition of needed research and data.

As noted previously, the HEIA tool (MOHLTC, 2012), and GBA+ tool (Government of Canada, 2019b), although not designed specifically in the context of climate change, could be useful for considering health equity in climate change actions when applied to V&A processes and adaptation actions. The *Equity Assessment Tool* (Race Forward, 2018) can also be applied to climate change and health activities; it proved to be effective in identifying opportunities to enhance racial equity in planning and community-engagement activities in a pilot project in Seattle, Washington, based on an extreme heat scenario (Equity Matters, 2015).

9.6 Knowledge Gaps

In Canada, many knowledge gaps exist about the current impact of climate change on health equity, and how this might be exacerbated with future warming. There is increasing recognition that health equity must guide adaptation plans; however, there are limited Canadian examples and resources to assist public health actors in these activities, and specific examples of health adaptation measures that promote health equity are sparse. In many cases, advancing the research and knowledge in this field will require collaboration across different levels of government (from local to national scale), sectors, and disciplines. Important knowledge needs include:

- Enhanced understanding of how the status of determinants of health and multiple existing health inequities can influence current and future climate change and health vulnerability in Canada. This includes:
    - Increased analysis of upstream drivers of inequities, including social, cultural, economic, and political structures and systems, and how these interact with climate change to create and exacerbate differential health risks and impacts.
    - Enhanced understanding of how determinants of health and other identity factors individually influence vulnerability to climate change impacts on health, and the compounding effect they may have when taken together. For example, sex-based differences are often identified when examining climate change impacts on particular populations, but analysis of vulnerability as a result of gender is rare (Bunce & Ford, 2015).
    - Enhanced data collection, including sex-, race-, and gender-disaggregated data, as well as other demographic data (e.g., socio-economic status) is required to better analyze how various identity factors and existing inequities intersect to shape climate change vulnerability.

- As the understanding of the multidimensional nature of vulnerability evolves, new frameworks and tools for assessing individual and community health impacts of climate change that account for multiple, simultaneous drivers of vulnerability are required. They should include methods to capture information on the broader social, cultural, political, and economic conditions and systems that construct inequities, and allow for analysis of how these may further compound vulnerability.
- In Canada, there is very little understanding of the relationship between the geographic distribution of populations disproportionately affected by climate change, and health system capacity. For example, studies that analyze health system capacity relative to where disproportionately affected populations live is needed to better inform V&As and develop effective adaptation strategies.
- The gap between theoretical approaches (e.g., intersectionality) and practice should be bridged to enhance knowledge of how to better account for and integrate health equity considerations into climate change and health activities, such as V&As and adaptation plans.
- Enhanced understanding of how various GHG mitigation and adaptation strategies led by the health sector as well as other sectors, can affect determinants of health and existing health inequities, in a positive or negative way, is needed (Paavola, 2017). Rigorous adaptation evaluation and monitoring frameworks and tools are required to better understand this relationship.
- Enhanced guidance and examples of cross-jurisdictional, cross-discipline, and multisectoral adaptation measures to protect health and promote health equity are needed.

9.7 Conclusion

This chapter explores the linkages among climate change, determinants of health, and health equity, with a particular focus on the dimensions of health equity in climate change vulnerability and adaptation. The drivers of climate change and of health inequities are very similar. Large systems, such as transportation, energy, and food systems, are significant sources of GHG emissions, but also shape living and working conditions and influence other determinants of health (Rudolph et al., 2018). The status of determinants of health can mediate the impacts of climate change on health and has a significant effect on vulnerability to such impacts and on the ability to adapt. Evidence suggests that climate change impacts can result in new health inequities in Canada, and increase existing ones. This is being observed now and is expected to continue in the future in the absence of future adaptations that address inequities.

As understanding of vulnerability continues to evolve, an intersectional approach to conducting V&As and adaptation development can capture the complexities of the intersecting drivers of vulnerability and the heterogeneous nature of disproportionately affected populations. Greater application of intersectional approaches and practices in climate change and health research will provide learnings that public health officials can use in their efforts to plan for climate change.

Given the variation in the status of determinants of health, and thus climate change vulnerability, the efficacy of adaptation and response measures to health risks related to climate will vary across individuals, communities, and regions. The outcomes of adaptation actions are not always equitable and can inadvertently increase health inequities, further reducing adaptive capacity.

Disadvantaged and marginalized populations commonly experience disproportionate climate change impacts on health and often have limited ability to cope or adapt. Thus, it is important that public health actors consider health equity in their climate change and health actions. To date, the degree to which health equity has been integrated and promoted in climate change and health activities, both globally, and in Canada, has been limited. While key knowledge gaps remain, opportunities exist to better account for and integrate considerations of health equity into V&As, and adaptation actions to ensure equitable outcomes. Asset mapping, vulnerability mapping, and health equity frameworks can complement V&A processes. Enhanced community engagement, multisectoral collaboration, and evaluating adaptation measures for impacts on health equity can ensure needs are met and outcomes are equitable.

Climate change adaptation and mitigation measures can be leveraged to address systemic drivers of health inequities and other social injustices, which can increase positive health outcomes, social cohesion, and resilience to climate change (Rudolph et al., 2018; Kreslake, 2019). Broad multisectoral collaboration and cooperation on policy development are needed to advance this work. Public health actors and decision makers from all sectors and disciplinary fields have an important opportunity to protect Canadians from climate change impacts while concurrently redressing existing inequities and strengthening determinants of health.

9.8 References

Adaptation Clearinghouse. (2011). *Guide to equitable, community-driven climate preparedness planning*. Retrieved from <https://www.adaptationclearinghouse.org/resources/guide-to-equitable-community-driven-climate-preparedness-planning.html>

Adger, W.N., Brooks, N., Kelly, M., Bentham, G., Agnew, M., & Eriksen, S. (2004). *New indicators of vulnerability and adaptive capacity.* Tyndall Centre Working Paper. Norwich, United Kingdom: Tyndall Centre for Climate Change Research. Retrieved from <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.112.2300&rep=rep1&type=pdf>

Arctic Elder Society. (2019). *The Indigenous Knowledge Social Network*. SIKU. Retrieved from <https://siku.org/>

Arora-Jonsson, S. (2011). Virtue and vulnerability: Discourses on women, gender and climate change. *Global Environmental Change, 21*(2), 744-751.

Auger, N., Fraser, W.D., Smargiassi, A., & Kosatsky, T. (2015). Ambient Heat and Sudden Infant Death: A Case-Crossover Study Spanning 30 Years in Montreal, Canada. *Environmental Health Perspectives*, *123*(7), 712–716. <https://doi.org/10.1289/ehp.1307960>

Auger, N., Naimi, A., Smargiassi, A., Lo, E., & Kosatsky, T. (2014). Extreme heat and risk of early delivery among preterm and term pregnancies. *Epidemiology, 25*(3), 344-350. doi: 10.1097/EDE.0000000000000074.

Bank of Canada. (2021). *Financial System Review – 2021*. Retrieved from <https://www.bankofcanada.ca/2021/05/financial-system-review-2021/#v6>

Bekkar, B., Pacheco, S., Basu, R., & DeNicola, N. (2020). Association of Air Pollution and Heat Exposure With Preterm Birth, Low Birth Weight, and Stillbirth in the US: A Systematic Review. *JAMA Network Open, 3*(6), e208243. doi:10.1001/jamanetworkopen.2020.8243

Benmarhnia, T., Alexander, S., Price, K., Smargiassi, N.K., & Kaufman, J.S. (2017). The heterogeneity of vulnerability in public health: a heat wave action plan as a case study. *Critical Public Health, 28*(5), 619-625. doi:10.1080/09581596.2017.1322176.

Bennett, J. (2015). *Housing innovations in Nunatsiavut.* Canadian Geographic. Retrieved from <https://www.canadiangeographic.ca/article/housing-innovations-nunatsiavut>

Bennett, C.M., & Friel, S. (2014). Impacts of climate change on inequities in child health. *Children*, *1*(3), 461-473. doi: 10.3390/children1030461

Bennett, H., & King, P. (2018). Pro-equity climate change and environmental sustainability action by district health boards in Aotearoa/New Zealand. *New Zealand Medical Journal, 131*(1481), 56-63.

Berry, P., Clarke, K.L., Fleury, M.D., & Parker, S. (2014a). Human health. In F.J. Warren, & D.S. Lemmen (Eds), *Canada in a changing climate: sector perspectives on impacts and adaptation* (pp. 191-232). Ottawa, ON: Government of Canada.

Berry, P., Enright, P.M., Shumake-Guillemot, J., Prats, E.V., & Campbell-Lendrum, D. (2018). Assessing health vulnerabilities and adaptation to climate change: A review of international progress. *International Journal of Environmental Research and Public Health*, *15*(12), 2626. <https://doi.org/10.3390/ijerph15122626>

Berry, P., McBean, G., & Seguin, J. (2008). Vulnerabilities to natural hazards and extreme weather. In J. Seguin (Ed), *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity* (pp. 43-112). Ottawa, ON: Health Canada.

Berry, P., Paterson, J., & Buse, C. (2014b). *Assessment of Vulnerability to the Health Impacts of Climate Change in Middlesex-London.* Middlesex-London Health Unit.

Boeckmann, M., & Zeeb, H. (2014). Using a social justice and health framework to assess European climate change adaptation strategies. *International Journal of Environmental Research and Public Health, 11*(12), 12389-12411. <https://doi.org/10.3390/ijerph111212389>

Boeckmann, M., & Zeeb, H. (2016). Justice and equity implications of climate change adaptation: A theoretical evaluation framework. *Healthcare, 4*(65). doi:10.3390/healthcare4030065

Booth, G.L., Luo, J., Park, A.L., Feig, D.S., Moineddin, R., & Ray, J.G. (2017). Influence of environmental temperature on risk of gestational diabetes. *CMAJ : Canadian Medical Association Journal = Journal de l'Association Medicale Canadienne*, *189*(19), E682–E689. <https://doi.org/10.1503/cmaj.160839>

Building Resilient Neighbourhoods (BRN). (n.d.). Retrieved from <https://resilientneighbourhoods.ca/>

Bunce, A., & Ford, J. (2015). How is adaptation, resilience, and vulnerability research engaging with gender? *Environmental Research Letters, 10*(12), 123003. doi:10.1088/1748-9326/10/12/123003

Bunce, A., Ford, J., Harper, S., & Edge, V. (2016). Vulnerability and adaptive capacity of Inuit women to climate change: A case study from Iqaluit, Nunavut. *Natural Hazards, 83*(3), 1419–1441. Retrieved from: <https://doi.org/10.1007/s11069-016-2398-6>

Buse C. G. (2018). Why should public health agencies across Canada conduct climate change and health vulnerability assessments? *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *109*(5-6), 782–785. <https://doi.org/10.17269/s41997-018-0118-6>

Buse, C.G., & Patrick, R. (2020). Climate change glossary for public health practice: from vulnerability to climate justice. *Journal of Epidemiology & Community Health, 74*(10), 1-5.

Bush, E., & Lemmen, D.S. (Eds.). (2019). *Canada's Changing Climate Report.* Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019/>

Bustinza, R., Lebel, G., & Dubé, M. (2016). *Evaluation of the performance of extreme heat warnings issued by the SUPREME system in Quebec from 2010 to 2016.* Institut National de Santé Publique du Québec. Retrieved from <https://www.inspq.qc.ca/sites/default/files/publications/2291_evaluation_performance_avertissement_chaleur_supreme.pdf>

California Building Resilience Against Climate Effects (CalBRACE). (2018). *Climate Change and Health Vulnerability Indicators for California.* Sacramento, CA: California Department of Public Health.

Canadian Energy Regulator (CER). (2020). *Market snapshot: Fuel poverty across Canada – lower energy efficiency in lower income households*. Retrieved from <https://www.cer-rec.gc.ca/nrg/ntgrtd/mrkt/snpsht/2017/08-05flpvrt-eng.html?=undefined&wbdisable=false>

Canadian Institute for Health Information (CIHI). (2008). *Reducing Gaps in Health: A Focus on Socio- Economic Status in Urban Canada, Canadian Population Health Initiative*. Retrived from <https://secure.cihi.ca/free_products/Reducing_Gaps_in_Health_Report_EN_081009.pdf>

Canadian Institute for Health Information (CIHI). (2018). *In Pursuit of Health Equity: Defining Stratifiers for Measuring Health Inequality. A Focus on Age, Sex, Gender, Income, Education and Geographic Location.* Retrieved from <https://www.cihi.ca/sites/default/files/document/defining-stratifiers-measuring-health-inequalities-2018-en-web.pdf>

Canadian Medical Association (CMA). (n.d.). *CMA Position Statement: Ensuring Equitable Access to Care*. Retrieved from <https://www.cma.ca/sites/default/files/2018-11/PD14-04-e.pdf>

Canadian Public Health Association (CPHA). (2015). *Global Change and Public Health: Addressing the Ecological Determinants of Health*. Retrieved from <https://www.cpha.ca/sites/default/files/assets/policy/edh-discussion_e.pdf>

Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., & Scott, D. (2020). A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. *International Journal of Disaster Risk Reduction, 43*, 101394. <https://doi.org/10.1016/j.ijdrr.2019.101394>

Chartered Professional Accountants Canada (CPA). (2017). *Income inequality in Canada: The urban gap*. Retrieved from <https://www.cpacanada.ca/en/the-cpa-profession/about-cpa-canada/key-activities/public-policy-government-relations/economic-policy-research/income-inequality-canada>

Chief Public Health Officer (CPHO). (2019). *Addressing Stigma: Towards a More Inclusive Health System.* Government of Canada. Retrieved from: <https://www.canada.ca/content/dam/phac-aspc/documents/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/addressing-stigma-what-we-heard/stigma-eng.pdf>

City of Vancouver. (n.d.). *Resilient Neighbourhoods Program*. Retrieved from: <https://vancouver.ca/people-programs/resilient-neighbourhoods-program.aspx>

Cleveland, C.J., Ashmore, J., Barnhart, A., Dudley, T., Lillie, M., Zhang, A., Lusk, K., Plastrik, P., & Cleveland, J. (2020). *Climate of Crisis: How Cities Can Use Climate Action to Close the Equity Gap, Drive Economic Recovery, and Improve Public Health.* Boston, MA: Boston University Institute for Sustainable Energy, Boston University Initiative on Cities, Innovation Network for Communities. Retrieved from <https://www.bu.edu/ise/files/2020/09/climate-of-crisis-september-2020.pdf>

Colussi, M.M. (2000). *The Community Resilience Manual – A Resource for Rural Recovery & Renewal.* Canadian Centre for Community Renewal. Retrieved from <https://communityrenewal.ca/sites/all/files/resource/P200_0.pdf>

Commission on Social Determinants of Health (CSDH). (2008). *Closing the gap in a generation. Health equity through action on the social determinants of health.* Retrieved from <https://www.who.int/social_determinants/final_report/csdh_finalreport_2008.pdf>

Commission of the Pan American Health Organization on Equity and Health Inequities in the Americas. (2019). *Health Equity and Dignified Lives-Report of the Commission of the Pan American Health Organization on Equity and Health Inequalities in the Americas.* Washington, DC: Pan American Health Organization. Retrieved from <https://iris.paho.org/handle/10665.2/51571>

Conway, T., & Scott, J.L. (2020). *Urban Forests in a Changing Climate.* The Greenbelt Foundation. Retrieved from <https://d3n8a8pro7vhmx.cloudfront.net/greenbelt/pages/14604/attachments/original/1600457503/UrbanForestsChangingClimate_REPORT_E-ver_REV.pdf?1600457503>

CREW. (n.d.). *Resilient Ville Canada*. Retrieved from <http://www.crewtoronto.ca/resilientville/>

Dahlgren, G., & Whitehead, M. (1991). *Policies and Strategies to Promote Social Equity in Health*. Stockholm, Sweden: Institute for Future Studies. Retrieved from <http://eurohealthnet.eu/sites/eurohealthnet.eu/files/publications/DETERMINE-Final-Publication-Story.pdf>

Deas, M., Grannis, J., Hoverter, S., & DeWeese, J. (2017). *Opportunities for Equitable Adaptation in Cities: A Workshop Summary Report.* Georgetown Climate Center. Retrieved from <http://www.georgetownclimate.org/files/report/GCC-Opportunities_for_Equitable_Adaptation-Feb_2017.pdf>

Dhamoon, R.K., & Hankivsky, O. (2011). Why the Theory and Practice of Intersectionality Matter to Health Research and Policy. In O. Hankivsky (Ed), *Health Inequities in Canada: Intersectional Frameworks and Practices* (pp. 16-50). Vancouver, BC: UBC Press. Retrieved from <https://www.ubcpress.ca/asset/9407/1/9780774819756.pdf>

Dominey-Howes, D., Gorman-Murray, A., & McKinnon, S. (2014). Queering disasters: on the need to account for LGBTI experiences in natural disaster contexts. *Gender, Place & Culture, 21*(7), 905-918. <https://doi.org/10.1080/0966369X.2013.802673>

Dowsley, M., Gearheard, S., Johnson, N., & Inksetter, J. (2010). Should we turn the tent? Inuit women and climate change. Études Inuit Studies, 34(1), 151–165. <https://doi.org/10.7202/045409ar>

Dolyle, H. (2017). Public health unit survey 2016: Climate change and health. Presentation to TOPHC.

Drolet, J. L., & Sampson, T. (2017). Addressing climate change from a social development approach: Small cities and rural communities' adaptation and response to climate change in British Columbia, Canada. *International Social Work, 60*(1), 61-73. doi: 10.1177/0020872814539984

Ebi, K. L. (2009). Facilitating climate justice through community-based adaptation in the health sector. *Environmental Justice*, *2*(4), 191-195. <https://doi.org/10.1089/env.2009.0031>

Ebi, K. L. (2020). Mechanisms, policies, and tools to promote health equity and effective governance of the health risks of climate change; *Journal of Public Health Policy, 41*,11-13. doi:10.1057/s41271-019-00212-2.

Ebi, K. L., Anderson, V., Berry, P., Paterson, J., & Yusa, A. (2016). *Ontario Climate Change and Health Vulnerability and Adaptation Assessment Guidelines*. Retrieved from <http://www.health.gov.on.ca/en/common/ministry/publications/reports/climate_change_toolkit/climate_change_toolkit.pdf>

Ebi, K. L., Fawcett, S. B., Spiegel, J., & Tovalin, H. (2016). Carbon pollution increases health inequities: lessons in resilience from the most vulnerable. *Revista Panamericana de Salud Publica = Pan American journal of public health*, *40*(3), 181–185.

Ebi, K. L., & Hess, J. J. (2020). Health Risks Due To Climate Change: Inequity In Causes And Consequences. *Health Affairs (Project Hope)*, *39*(12), 2056–2062.

Ebi, K.L., Hess, J.J., & Watkiss, P. (2017). Health Risks and Costs of Climate Variability and Change. In C.N. Mock, R. Nugent, O. Kobusingye, & K.R. Smith (Eds.), *Injury Prevention and Environmental Health, 3rd edition.* Washington, DC: The International Bank for Reconstruction and Development & The World Bank. doi: 10.1596/978-1-4648-0522-6_ch8

Ebi, K. L., & Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine*, *35*(5), 501-507. doi: 10.1016/j.amepre.2008.08.018.

English, P. M., Richardson, R., Morello-Frosch, M., Pastor, J., Said, G., King, W., … & Jerrett., M. (2013). Racial and Income Disparities in Relation to a Proposed Climate Change Vulnerability Screening Method for California. *The International Journal of Climate Change: Impacts and Responses, 4*(2), 1–18.

Environmental Protection Agency (EPA). (2008). Urban Heat Island Basics. In *Reducing Urban Heat Islands: Compendium of Strategies*. Retrieved from <https://www.epa.gov/sites/production/files/2017-05/documents/reducing_urban_heat_islands_ch_1.pdf>

Equity Matters. (2015). *Extreme heat scenario-based pilot project in frontline communities- Community-driven planning process- Racial equity mini evaluation.* City of Seattle. Retrieved from <https://www.usdn.org/uploads/cms/documents/heat_sceanrio_racial_equity_evaluation_mini-report_-_final.pdf>

Evergreen. (2020). *Climate Risks- Engaging Vulnerable Populations.* Retrieved from <https://www.evergreen.ca/downloads/pdfs/Evergreen_Climate_Risks_Report_2020_FINAL.pdf>

Federation of Canadian Municipalities (FCM). (2021). *Climate Change Adaptation through an Equity Lens*. Retrieved from <https://fcm.ca/en/resources/mcip/climate-change-adaptation-through-equity-lens>

First Nations Food, Nutrition and Environment Study (FNFNES). (2019). *Summary of key findings for eight Assembly of First Nations regions 2008-2018*. Retrieved from <http://www.fnfnes.ca/docs/FNFNES_Report_Summary_2020-05-27_FINAL.pdf>

Ford, J. D., Pearce, T., Gilligan, J., Smit, B., & Oakes, J. (2008). Climate change and hazards associated with ice use in northern Canada. *Arctic, Antarctic, and Alpine Research, 40*(4), 647–659. Retrieved from <https://doi.org/10.1657/1523-0430(07-040)[FORD]2.0.CO;2>

Foster, S., Leichenko, R., Nguyen, K. H., Blake, R., Kunreuther, H., Madajewicz, M., Petkova, E. P., Zimmerman, R., Corbin-Mark, C., Yeampierre, E., Tovar, A., Herrera, C., & Ravenborg, D. (2019). New York City Panel on Climate Change 2019 Report Chapter 6: Community-Based Assessments of Adaptation and Equity. *Annals of the New York Academy of Sciences*, *1439*(1), 126–173. <https://doi.org/10.1111/nyas.14009>

Friel, S. (2019). *Climate Change and the People's Health* (N. Krieger, Ed). Oxford University Press.

Gamble, J.L., Balbus, J., Berger, M., Bouye, K., Campbell, V., Chief, K., … & Wolkin, A.F. (2016). Populations of Concern. In A.J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, & L. Ziska (Eds), *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program. Retrieved from <https://s3.amazonaws.com/climatehealth2016/low/ClimateHealth2016_09_Populations_small.pdf>

Georgetown Climate Center. (2020). *Equitable Adaptation Legal and Policy Toolkit.* Retrieved from <https://www.georgetownclimate.org/adaptation/toolkits/equitable-adaptation-toolkit/introduction.html>

Gibson, B.E., & Mykitiuk, R. (2012). Health Care Access and Support for Disabled Women in Canada: Falling Short of the UN Convention on the Rights of Persons with Disabilities: A Qualitative Study. *Women's Health Issues, 22*(1), e111-e118.

Godley, J. (2018). Everyday discrimination in Canada: Prevalence and patterns. *Canadian Journal of Sociology 43*(2), 111-142. <https://doi.org/10.29173/cjs29346>

Goodman, A., Fleming, K., Markwick, N., Morrison, T., Lagimodiere, L., Kerr, T., & Western Aboriginal Harm Reduction Society. (2017). "They treated me like crap and I know it was because I was Native": The healthcare experiences of Aboriginal peoples living in Vancouver's inner city. *Social Science & Medicine, 178*, 87-94.

Gorman-Murray, A., McKinnon, S., Dominey-Howes, D., Nash, C.J., & Bolton, R. (2018). Listening and Learning: Giving Voice to Trans Experiences of Disasters. *Gender, Place & Culture, 25*(2), 166–87. <https://doi.org/10.1080/0966369X.2017.1334632>

Gosselin, P., Bustinza, R., Jeffers, S., Gachon, P., Bussières, L., Gosselin, D., Martin, P., & Labrecque, S. (2018). Supreme: An Integrated Heat Health Warning System for Quebec. In J. Shumake-Guillemot, & L. Fernandez-Montoya (Eds.), *Climate Services for Health: Improving Public Health Decision-making in a New Climate.* Geneva, Switzerland: World Health Organization & World Meteorological Organization. Retrieved from <http://www.ghhin.org/assets/case_study_pdf/WHO-WMO_Case_Phase_3_Ch5k.pdf>

Gould, S., & Rudolph, L. (2015). Challenges and opportunities for advancing work on climate change and public health. *International Journal of Environmental Research and Public Health, 12*(12), 15649-15672. doi:10.3390/ijerph121215010

Gouvernement du Québec. (2019). *Vague de chaleur été 2018 à Montréal: enquête épidémiologique.* Montréal, QC. Retrieved from <https://santemontreal.qc.ca/professionnels/drsp/publications/publication-description/publication/2162/>

Government of Canada. (2019a). *Social determinants of health and health inequalities.* Retrieved from <https://www.canada.ca/en/public-health/services/health-promotion/population-health/what-determines-health.html>

Government of Canada. (2019b). *What is GBA+?* Retrieved from <https://cfc-swc.gc.ca/gba-acs/index-en.html>

Government of Canada. (2020). *Ending long-term drinking water advisories.* Retrieved from <https://www.sac-isc.gc.ca/eng/1506514143353/1533317130660>

Grambsch, A., & Menne, B. (2003). Adaptation and adaptive capacity in the public health context. In A.J. McMichael, D.H. Campbell-Lendrum, C.F. Corvalan, K.L. Ebi, A. Githeko, J.D. Scherage, & A. Woodward (Eds.), *Climate change and human health: Risks and responses* (pp. 1–17). Geneva, Switzerland: World Health Organization. Retrieved from <https://www.who.int/globalchange/publications/climatechangechap11.pdf?ua=1>

Greene, C.S., Robinson, P.J., & Millward, A.A. (2018). Canopy of advantage: Who benefits most from city trees? *Journal of Environmental Management, 208*(15), 24-35. <https://doi.org/10.1016/j.jenvman.2017.12.015>

Greenwood, M.L., & de Leeuw, S. N. (2012). Social determinants of health and the future well-being of Aboriginal children in Canada. *Paediatrics & Child Health*, *17*(7), 381–384.

Greenwood, M.L, de Leeuw, S., & Lindsay, N. (2018). Challenges in health equity for Indigenous peoples in Canada. *The Lancet, 391*(10131), 1645-1648. <https://doi.org/10.1016/S0140-6736(18)30177-6>

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). *Shock Waves: Managing the Impacts of Climate Change on Poverty.* Climate Change and Development. Washington, DC: World Bank. Retrieved from <https://openknowledge.worldbank.org/handle/10986/22787>

Hallegatte, S., & Rozenberg, J. (2017). Climate change through a poverty lens. *Nature Climate Change, 7*(4), 250–256. <https://doi.org/10.1038/nclimate3253>

Halseth, R., & Murdock, L. (2020). *Supporting Indigenous self-determination in health: Lessons learned from a review of best practices in health governance in Canada and internationally.* Prince George, BC: National Collaborating Centre for Indigenous Health. Retrieved from <https://www.nccih.ca/Publications/Lists/Publications/Attachments/317/Ind-Self-Determine-Halseth-Murdoch-EN-web-2020-12-02.pdf>

Hancock, T. (2015). Population health promotion 2.0: An eco-social approach to public health in the Anthropocene. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *106*(4), e252–e255. <https://doi.org/10.17269/cjph.106.5161>

Hankivsky, O. (2014). *Intersectionality 101. Institute for Intersectionality and Research and Policy, SFU.* Retrieved from <http://vawforum-cwr.ca/sites/default/files/attachments/intersectionallity_101.pdf>

Hankivsky, O., & Mussell, L. (2018). Gender-Based Analysis Plus in Canada: Problems and Possibilities of Integrating Intersectionality. *Canadian Public Policy, 44*(4), 303-316.

He, S., Kosatsky, T., Smargiassi, A., Bilodeau-Bertrand, M., & Auger, N. (2018). Heat and pregnancy-related emergencies: Risk of placental abruption during hot weather. *Environment International*, *111*, 295–300. <https://doi.org/10.1016/j.envint.2017.11.004>

Health Canada. (2005). *Climate change: Preparing for the health impacts*. Retrieved from <https://www.hc-sc.gc.ca/sr-sr/alt_formats/hpb-dgps/pdf/pubs/hpr-rps/bull/2005-climat/2005-climat-eng.pdf>

Health Canada. (2012). *Heat Alert and Response Systems to Protect Health: Best Practices Guidebook*. Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/pdf/pubs/climat/response-intervention/response-intervention-eng.pdf>

Health Canada. (2020). *Reducing Urban Heat Islands to Protect Health in Canada: An Introduction for Public Health Professionals*. Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/hc-sc/documents/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada/Reducing-Urban-Heat-EN.pdf>

Helldén, D., Andersson, C., Nilsson, M., Ebi, K. L., Friberg, P., & Alfvén, T. (2021). Climate change and child health: a scoping review and an expanded conceptual framework. *The Lancet. Planetary Health*, *5*(3), e164–e175. <https://doi.org/10.1016/S2542-5196(20)30274-6>

Hsu, A., Sheriff, G., Chakraborty, T. et al. Disproportionate exposure to urban heat island intensity across major US cities. Nat Commun 12, 2721 (2021). <https://doi.org/10.1038/s41467-021-22799-5>

Indigenous Services Canada (ISC). (2019). *Community Voices on Climate Change and Health Adaptation in Northern Canada*. Government of Canada. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/19-012-climate-change-c2-ang.pdf>

Institut National de Santé Publique du Québec (INSPQ). (2020). *Surveillance and Prevention of the Impacts of Extreme Meteorological Events on Public Health System (SUPREME)*. Retrieved from <https://www.inspq.qc.ca/en/post-disaster-mental-health-impacts-surveillance-toolkit/surveillance-systems/surveillance-and-prevention-impacts-extreme-meteorological-events-public-health-system-supreme>

Institut National de Santé Publique du Québec (INSPQ). (2021). *Géo portail de santé publique*. Retrieved from <https://www.inspq.qc.ca/en/post-disaster-mental-health-impacts-surveillance-toolkit/statistical-dissemination-portals/geo-portail-sante-publique>

Inuit Tapiriit Kanatami (ITK). (2019). *National Inuit Climate Change Strategy*. Ottawa, ON. Retrieved from <https://www.itk.ca/wp-content/uploads/2019/06/ITK_Climate-Change-Strategy_English.pdf>

Intergovernmental Panel on Climate Change (IPCC). (2007). *AR4 Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, C.E. Hanson, Eds). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2014). Summary for policymakers. In Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, & L.L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Islam, S.N., & Winkel, J. (2017). *Climate change and social inequality*. New York, NY: United Nations, Department of Economic and Social Affairs. Retrieved from <https://www.un.org/esa/desa/papers/2017/wp152_2017.pdf>

Kaijser, A., & Kronsell, A. (2014). Climate change through the lens of intersectionality. *Environmental Politics, 23*(3), 417-433. doi:10.1080/09644016.2013.835203

Kirkby, P., Williams, C., & Huq, S. (n.d.). *A brief overview of Community-Based Adaptation*. International Centre for Climate Change and Development (ICCCAD). Retrieved from <http://icccad.net/wp-content/uploads/2015/12/A-brief-overview-of-Community-Based-Adaptation.pdf>

Kreslake, J.M. (2019). Perceived importance of climate change adaptation and mitigation according to social and medical factors among residents of impacted communities in the United States. *Health Equity, 3*(1), 124-133. doi:10.1089/heq.2019.0002

Kuehn, L., & McCormick, S. (2017). Heat Exposure and Maternal Health in the Face of Climate Change. *International Journal of Environmental Research and Public Health*, *14*(8), 853. <https://doi.org/10.3390/ijerph14080853>

Kumar, N. (2018). *Cities, Climate Change & Health Equity*. Wellesley Institute. Retrieved from <https://www.wellesleyinstitute.com/wp-content/uploads/2018/06/Cities-Climate-Change-Health-Equity-WIJune-2018-fv.pdf>

Levy, B.S., & Patz, J.A. (2015). Climate change, human rights, and social justice. *Annals of Global Health, 81*(3), 310-321.

Lynn, K., MacKendrick, K., & Donoghue, E.M. (2011). *Social vulnerability and climate change: Synthesis of literature.* Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. Retrieved from <https://www.fs.fed.us/pnw/pubs/pnw_gtr838.pdf>

Mazur, L., Milanes, C., Randles, K., Siegel, D., & the Integrated Risk Assessment Branch, Office of Environmental Health Hazard Assessment (OEHHA). (2010). *Indicators of Climate Change in California: Environmental Justice Impacts.* Sacramento, CA: California Environmental Protection Agency. Retrieved from <https://oehha.ca.gov/media/downloads/climate-change/document/climatechangeej123110.pdf>

McMichael, A.J., Campbell-Lendrum, D.H., Corvalan, C.F., Ebi, K.L., Githeko, A.K., Scheraga, J.D., & Woodward, A. (2003). *Climate change and human health: Risks and responses.* Geneva, Switzerland: World Health Organization. Retrieved from <https://www.who.int/globalchange/publications/climchange.pdf>

Mikkonen, J., & Raphael, D. (2010). *Social Determinants of Health: The Canadian Facts.* York University School of Health Policy and Management. Retrieved from <https://thecanadianfacts.org/The_Canadian_Facts.pdf>

Morrison, K. (2017). *Leveraging the Benefits of Green Space for Environmental and Public Health Benefits.* Retrieved from <https://practisingecohealth.ca/wp-content/uploads/2018/10/Casebook-Final.pdf>

Moser, S.C., Coffee, J., & Seville, A. (2017). *Rising to the Challenge, Together: A Review and Critical Assessment of the State of the US Climate Adaptation Field.* Retrieved from <https://kresge.org/sites/default/files/library/rising_to_the_challenge_together_linked_0.pdf>

Movement Strategy Centre (MSC). (2015). *Community-driven climate resilience planning: a framework.* Retrieved from<https://movementstrategy.org/b/wp-content/uploads/2016/07/MSC-Community_Driven_Climate_Resilience_Planning.pdf>

Munro, A., Boyce, T., & Marmot, M. (2020). *Sustainable Health Equity: Achieving A Net-Zero UK.* London, United Kingdom: Institute of Health Equity. Retrieved from <http://www.instituteofhealthequity.org/resources-reports/sustainable-health-equity-achieving-a-net-zero-uk/main-report.pdf>

Muzumdar, P. (2020). *Centring equity in emerging public heath responses to climate change.* National Collaborating Centre for Determinants of Health. Retrieved from <https://nccdh.ca/blog/entry/centring-equity-in-emerging-public-health-responses-to-climate-change#Reference%2037>

National Academies of Sciences, Engineering, and Medicine. (2017). *Communities in Action: Pathways to Health Equity* (J.N. Weinstein, A. Geller, Y. Nagussie, & A. Baciu, Eds.). Washington, DC: The National Academies Press. Retrieved from <https://www.nap.edu/read/24624/chapter/1>

National Collaborating Centre for Aboriginal Health (NCCAH). (2013). *An Overview of Aboriginal Health in Canada.* Retrieved from <https://www.ccnsa-nccah.ca/docs/context/FS-OverviewAbororiginalHealth-EN.pdf>

National Collaborating Centre for Determinants of Health (NCCDH). (2013). *A guide to community engagement frameworks for action on the social determinants of health and health equity.* Retrieved from <https://nccdh.ca/resources/entry/a-guide-to-community-engagement-frameworks>

National Collaborating Centre for Determinants of Health (NCCDH) & National Collaborating Centre for Healthy Public Policy (NCCPP). (2016). *Public Health Speaks: Intersectionality and Health Equity.* Antigonish, NS and Montreal, QC. Retrieved from <https://nccdh.ca/images/uploads/comments/Intersectionality_And_Health_Equity_EN_Mar24.pdf>

National Collaborating Centre for Indigenous Health (NCCIH). (2019). *Access to Health Services as a Social Determinant of First Nations, Inuit and Metis Health.* Retrieved from <https://www.nccih.ca/docs/determinants/FS-AccessHealthServicesSDOH-2019-EN.pdf>

National Collaborating Centre for Determinants of Health. (2021). Climate change resilience part 2: Public health roles and actions. Antigonish (NS): NCCDH, St. Francis Xavier University.

Nussbaum, M.C. (2011). *Creating capabilities: the human development approach*. Cambridge, MA: Harvard University Press.

Oickle, D. (2020). *Community engagement: A public health strategy to inform action on health inequities*. National Collaborating Centre for Determinants of Health. Retrieved from <https://nccdh.ca/blog/entry/community-engagement-a-public-health-strategy-to-inform-action-on-health-in>

Ontario Ministry of Health and Long-Term Care (MOHLTC). (2012). *Health Equity Impact Assessment (HEIA) Workbook.* Retrieved from <http://www.health.gov.on.ca/en/pro/programs/heia/docs/workbook.pdf>

Paavola, J. (2017). Health impacts of climate change and health and social inequalities in the UK. *Environmental Health, 16*(1), 113. doi:10.1186/s12940-017-0328-z

Pan - Canadian Health Inequalities Data Tool, 2017 Edition. A joint initiative of the Public Health Agency of Canada, the Pan - Canadian Public Health Network, Statistics Canada, and the Canadian Institute of Health Information.

Pelling, M., & Garschagen, M. (2019). Put equity first in climate adaptation. *Nature, 569*(7756), 327-329.

PlanH. (n.d.). *Climate action and public health*. Victoria, BC: BC Healthy Communities Society. Retrieved from <https://planh.ca/take-action/healthy-environments/natural-environments/page/climate-action-public-health>

Preet, R., Nilsson, M., Schumann, B., & Evengård, B. (2010). The gender perspective in climate change and global health. *Global Health Action*, *3*(1). <https://doi.org/10.3402/gha.v3i0.5720>

Public Health Agency of Canada (PHAC). (2008). *The Chief Public Health Officer's Report on the State of Public Health in Canada, 2008.* Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/phac-aspc/migration/phac-aspc/cphorsphc-respcacsp/2008/fr-rc/pdf/CPHO-Report-e.pdf>

Public Health Agency of Canada (PHAC). (2017). *Designing Healthy Living: The Chief Public Health Officer's Report on the State of Public Health in Canada 2017.* Retrieved from <https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living/PHAC_CPHO-2017_Report_E.pdf>

Public Health Agency of Canada (PHAC). (2018). *Key Health Inequalities in Canada: A National Portrait, Pan-Canadian Public Health Network.* Retreived from <https://www.canada.ca/content/dam/phac-aspc/documents/services/publications/science-research/key-health-inequalities-canada-national-portrait-executive-summary/key_health_inequalities_full_report-eng.pdf<

Public Health Agency of Canada (PHAC). (2019). *Addressing Stigma: Towards a More Inclusive Health System.* Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/phac-aspc/documents/corporate/publications/chief-public-health-officer-reports-state-public-health-canada/addressing-stigma-what-we-heard/stigma-eng.pdf>

Public Health Agency of Canada (PHAC). (2020). *Social Determinants and Inequities in Health for Black Canadians: A Snapshot, Pan-Canadian Public Health Network*. Retrieved from <https://www.canada.ca/content/dam/phac-aspc/documents/services/health-promotion/population-health/what-determines-health/social-determinants-inequities-black-canadians-snapshot/health-inequities-black-canadians.pdf>

Public Health Alliance of Southern California (PHASC). (2018). *The California Healthy Places.* California Healthy Places Index. Retrieved from <https://healthyplacesindex.org/>

Queensland Health. (2001). *Social Determinants of Health: The Role of Population Health Queensland, Summary Document.* Queensland, Australia: Queensland Government. Retrieved from <http://web.archive.org/web/20120506050300/http://www.health.qld.gov.au/ph/documents/hpu/24310.pdf>

Race Forward. (2018). *Equity Assessment Tool Zero Cities Project*. Retrieved from <https://www.usdn.org/uploads/cms/documents/equity_assessment_tool_-zero_cities_project_-_race_forward_2019.pdf>

Raker, E.J., Arcaya, M.C., Lowe, S.R., Zacher, M., Rhodes, J., & Waters, M.C. (2020). Mitigating health disparities after natural disasters: Lessons from the RISK project. *Health Affairs, 39*(12), 2128-2135. <https://doi.org/10.1377/hlthaff.2020.01161>

Ratelle, M., & Paquette, F. (2019). *Indigenous peoples in Canada show how social cohesion is key to resilience.* Global Center on Adaptation. Retrieved from <https://gca.org/solutions/indigenous-peoples-in-canada-show-how-social-cohesion-is-key-to-resilience?utm_sq=g9jvsmn5a4>

Raval, A., Chen, T., & Shah, P. (2019). *Mapping Resilience: A Blueprint for Thriving in the Face of Climate Disasters.* Asian Pacific Environmental Network. Retrieved from <https://apen4ej.org/wp-content/uploads/2019/07/APEN-Mapping_Resilience-Executive_Summary.pdf>

Reading, C.L., & Wien, F. (2009). *Health inequalities and social determinants of Aboriginal peoples' health*. Prince George, BC: National Collaborating Centre for Aboriginal Health. Retrieved from <https://www.nccih.ca/docs/determinants/RPT-HealthInequalities-Reading-Wien-EN.pdf>

Resurrección, B.P., Bee, B.A., Dankelman, I., Park, C.M.Y., Halder, M., & McMullen, C.P. (2019). *Gender-transformative climate change adaptation: advancing social equity*. Stockholm Environment Institute. Retrieved from <https://www.sei.org/wp-content/uploads/2019/11/gender-transformative-climate-change-adaptation.pdf>

Richardson, G.R.A (n.d.). *Peel Region Tree Priority Planting Tool.* Retrieved from <https://www.iclr.org/wp-content/uploads/PDFS/17_Peel_Region.pdf>

Rinner, C., Patychuk, D., Bassil, K., Nasr, S., Gower, S., & Campbell, M. (2010). The role of maps in neighborhood-level heat vulnerability assessment for the city of Toronto. *Cartography and Geographic Information Science, 37*(1), 31-44. doi:10.1559/152304010790588089

Rudolph, L., & Gould, S. (2014). Why we need climate, health, and equity in all policies. *NAM Perspectives*. <https://doi.org/10.31478/201412e>

Rudolph, L., Gould, S., & Berko, J. (2015). *Climate Change, Health, and Equity: Opportunities for Action*. Oakland, CA: Public Health Institute. Retrieved from <http://www.phi.org/wp-content/uploads/migration/uploads/application/files/h7fjouo1i38v3tu427p9s9kcmhs3oxsi7tsg1fovh3yesd5hxu.pdf>

Rudolph, L., Harrison, C., Buckley, L., & North, S. (2018). *Climate Change, Health, and Equity: A Guide for Local Health Departments.* Oakland, CA and Washington, D.C: Public Health Institute and American Public Health Association. Retrieved from <https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx?la=en&hash=14D2F64530F1505EAE7AB16A9F9827250EAD6C79

Sahni, V., Scott, A. N., Beliveau, M., Varughese, M., Dover, D. C., & Talbot, J. (2016). Public health surveillance response following the southern Alberta floods, 2013. *Canadian Journal of Public Health*, *107*(2), e142-e148.

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., & Wang, M. (2014). Anthropogenic Heating of the Urban Environment due to Air Conditioning. *Journal of Geophysical Research: Atmospheres, 119*(10), 5949-5965. doi:10.1002/2013JD021225

Salas, R. N., Knappenberger, P., & Hess, J.J. (2019). *The Lancet Countdown on Health and Climate Change: Policy Brief for the United States of America.* Lancet Countdown and American Public Health Association. Retrieved from <http://www.lancetcountdownus.org/wp-content/uploads/2020/12/FINAL-2020_12_02_Lancet-Countdown-Policy-Document-USA-ENG.pdf?hsCtaTracking=3d902c23-c855-441f-ab5d-61f4f76a2ea1%7C6d90df30-4bf7-42f3-a282-f61d5292a03e>

Schlosberg, D., Collins, L.B., & Niemeyer, S. (2017). Adaptation policy and community discourse: risk, vulnerability and just transformation. *Environmental Politics, 26*(3), 413-437. doi:10.1080/09644016.2017.1287628

Séguin, J. (Ed). (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity*. Ottawa, ON: Health Canada. Retrieved from <https://cdn.dal.ca/content/dam/dalhousie/pdf/faculty/science/emaychair/Reports%20Section/Emay_HumanHealthChangClim.pdf>

Sellers, S. (2018). *Climate Change and Gender in Canada: A Review, Women's Environment & Development Organization*. New York, NY: Women's Environment and Development Organization (WEDO). Retrieved from <https://wedo.org/wp-content/uploads/2018/04/GGCA-CA-RP-07.pdf>

Sellers, S., & Ebi, K.L. (2017). Climate Change and Health under the Shared Socioeconomic Pathway Framework. *International Journal of Environmental Research and Public Health*, *15*(1), 3. <https://doi.org/10.3390/ijerph15010003>

Shared-Use Mobility Center (SUMC). (2019a). *Electric and Equitable: Learning from the BlueLA Carsharing Pilot*. Retrieved from <https://learn.sharedusemobilitycenter.org/wp-content/uploads/NewFile_SUMC_04.15.19.pdf>

Shared-Use Mobility Centre (SUMC). (2019b). *BlueLA Electric Vehicle Carshare Pilot a success after one year – awarded $3 million to expand to three additional disadvantaged communities in Los Angeles.* Retrieved from <https://sharedusemobilitycenter.org/bluela-electric-vehicle-carshare-pilot-a-success-after-one-year-awarded-3-million-to-expand-to-three-additional-disadvantaged-communities-in-los-angeles/>

Shi, L., Chu, E., Anguelovski, I., Aylett, A., Debats, J., Goh, K., Schenk, T., Seto, K.C., Dodman, D., Roberts, D., Roberts, J.T., & VanDeveer, S.D. (2016). Roadmap towards justice in urban climate adaptation research. *Nature Climate Change, 6*, 131-137. doi:10.1038/nclimate2841

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282-292.

Solar, O. & Irwin, A. (2010). A conceptual framework for action on the social determinants of health. Social Determinants of Health Discussion Paper 2 (Policy and Practice). <https://www.who.int/sdhconference/resources/ConceptualframeworkforactiononSDH_eng.pdf>

Statistics Canada. (2012). Household food insecurity, 2011-2012. In *Data from the 2011-2012 Canadian Community Health Survey*. Retrieved from <http://www.canada.ca/en/health-canada/services/nutrition-science-research/food-security/household-food-security-statistics-2011-2012.html>

Statistics Canada. (2016). *Household greenhouse gas emissions per capita, by province and territory, 2016*. Retrieved from <https://www150.statcan.gc.ca/n1/daily-quotidien/190123/mc-d001-eng.htm>

Statistics Canada. (2018). *Table 282-0007 Labour Force Survey estimates (LFS), by North American Industry Classification System (NAICS), sex and age group, unadjusted for seasonality*. Retrieved from <http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=2820007>

The Greenlining Institute. (2019). *Making equity real in climate adaptation and community resilience policies and programs: a guidebook*. Retrieved from <https://greenlining.org/publications/2019/making-equity-real-in-climate-adaption-and-community-resilience-policies-and-programs-a-guidebook/>

Toutant, S., Gosselin, P., Bélanger, D., Bustinza, R., & Rivest, S. (2011). An open source web application for the surveillance and prevention of the impacts on public health of extreme meteorological events: the SUPREME system. *International Journal of Health Geographics*, *10*, 39. <https://doi.org/10.1186/1476-072X-10-39>

University of California, Los Angeles (UCLA). (n.d.). *Section 1: Asset Mapping.* UCLA Center for Health Policy Research. Retrieved from <http://healthpolicy.ucla.edu/programs/health-data/trainings/Documents/tw_cba20.pdf>

University of Waterloo Survey Research Centre. (2019). *Survey of health sector officials: A contribution to Health Canada's climate change and health adaptation capacity building program and the national assessment technical and data analysis report*. Report prepared for Health Canada.

U.S. Department of Health and Human Services (USDHHS). (2020). *Social determinants of health, Office of Disease Prevention and Health Promotion.* Retrieved from <https://www.healthypeople.gov/2020/topics-objectives/topic/social-determinants-of-health>

Urban Sustainability Directors Network (USDN). (2017). *Guide to equitable, community-driven climate preparedness planning.* Retrieved from <https://www.usdn.org/uploads/cms/documents/usdn_guide_to_equitable_community-driven_climate_preparedness-_high_res.pdf>

United Nations Environment Programme (UNEP). (2018). *The Adaptation Gap Report 2018.* Nairobi, Kenya: United Nations Environment Programme (UNEP). Retrieved from <https://www.unenvironment.org/resources/adaptation-gap-report>

Vancouver Coastal Health. (2021). *Community Health and Climate Change*. Retrieved from <https://storymaps.arcgis.com/stories/4352804ebb4b4765b7b9b25745bfce19>

Walpole, S.C., Rasanathan, K., & Campbell-Lendrum, D. (2009). Natural and unnatural synergies: climate change policy and health equity. *Bulletin of the World Health Organization, 87*, 799-801. doi:10.2471/BLT.09.067116

Wandel, J., Riemer, M., de Gómez, W., Klein, K., de Schutter, J., Randall, L., Morrison, M., Poirier, S., & Singleton, C. (2010). *Homelessness and Global Climate Change: Are we ready? A report from the study on the vulnerability to global climate change of people experiencing homelessness in Waterloo Region.* Waterloo, ON. doi. 10.13140/2.1.1317.7927

Watts, N., Campbell-Lendrum, D., Maiero, M., Montoya, L.F., & Lao, K. (2015). *Strengthening Health Resilience to Climate Change: Technical Briefing for the World Health Organization.* Geneva, Switzerland: World Health Organization. Retrieved from <https://www.who.int/docs/default-source/climate-change/technical-briefing---health-resilience-to-climate-change.pdf?sfvrsn=b0772759_1&download=true>

Whitehead, M., & Dahlgren, G. (2007). *Concepts and principles for tackling social inequities in health: Levelling up Part 1.* World Health Organization Europe. Retrieved from <http://www.euro.who.int/__data/assets/pdf_file/0010/74737/E89383.pdf>

Wilk, P., Gunz, A., Maltby, A., Ravichakaravarthy, T., Clemens, K.K., Lavigne, E., Lim, R., Vicedo-Cabrera, A.M. (2020). Extreme heat and paediatric emergency department visits in Southwestern Ontario. *Paediatrics & Child Health*, 1-5. <https://doi.org/10.1093/pch/pxaa096>

Williams-Rajee, D., & Evans, T. (2016). *Climate Action through Equity: The Integration of Equity in the Portland and Multnomah County 2015 Climate Action Plan.* City of Portland. Retrieved from <https://www.portland.gov/sites/default/files/2019-07/cap-equity-case-study-web29jul.pdf>

Wipond, R., Barter, S., & Colussi, M. (2017). *The Building Resilient Neighbourhoods Project: Four Years of Learnings 2012-2016.* Retrieved from <http://resilientneighbourhoods.ca/wp-content/uploads/2017/03/BRN_Four_Years_WEB.pdf>

Wolch, J.R., Byrne, J., & Newell, J.P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning, 125*, 234-244. <https://doi.org/10.1016/j.landurbplan.2014.01.017>

World Health Organization (WHO). (2003). *Climate Change and Human Health: Risks and Responses* (A.J. McMichael, D.H. Campbell-Lendrum, C.F. Corvalán, K.L. Ebi, A.K. Githeko, J.D. Scheraga, & A. Woodward, Eds.). Geneva, Switzerland. Retrieved from <https://www.who.int/globalchange/publications/climchange.pdf>

World Health Organization (WHO). (2008). *Closing the Gap in a Generation: Health Equity through Action on the Social Determinants of Health - Final Report of the Commission on Social Determinants of Health*. Retrieved from <https://www.who.int/social_determinants/thecommission/finalreport/en/>

World Health Organization (WHO). (2013). *Protecting Health from Climate Change: Vulnerability and Adaptation Assessment.* Geneva, Switzerland. Retrieved from <https://apps.who.int/iris/bitstream/handle/10665/104200/9789241564687_eng.pdf?sequence=1&isAllowed=y>

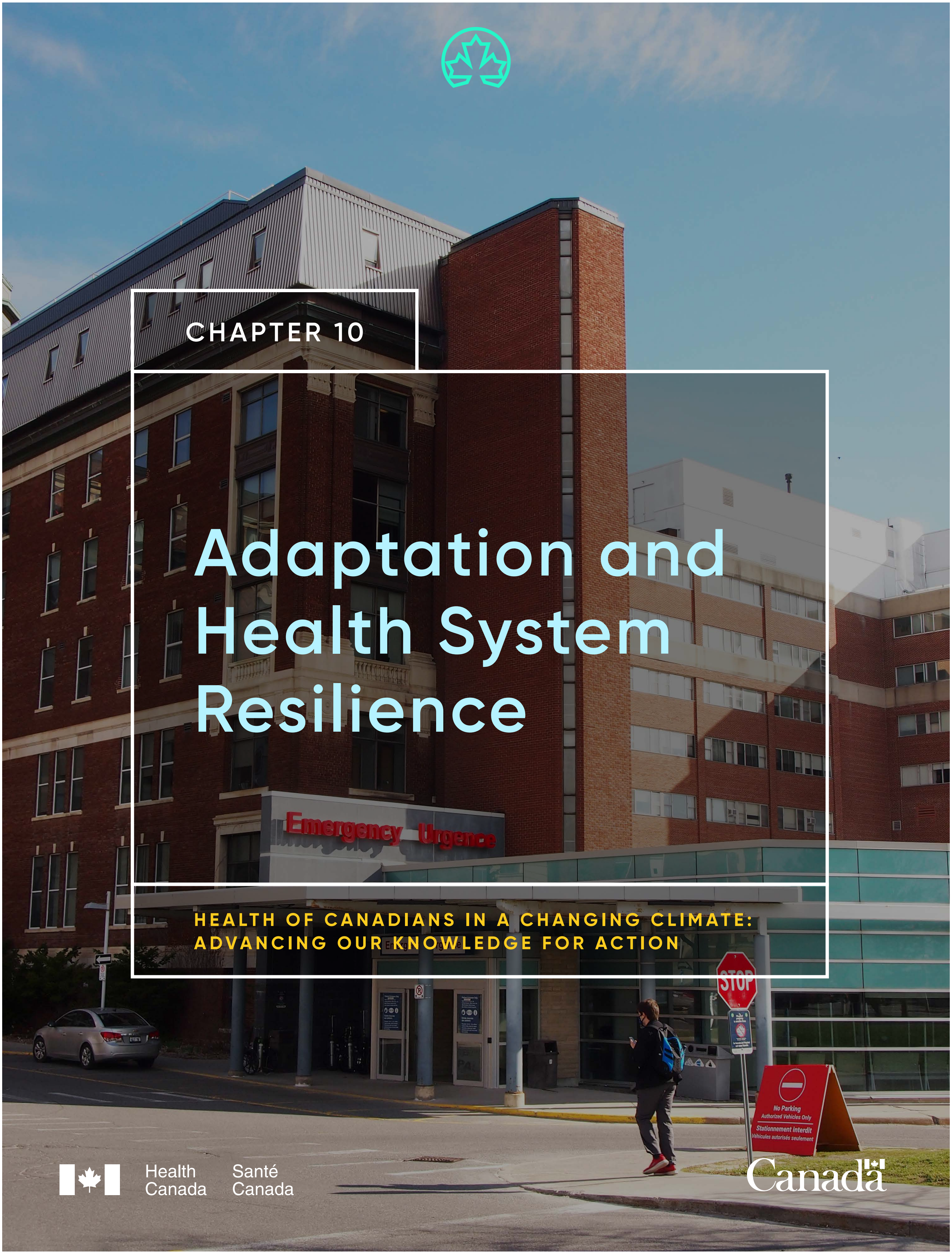
World Health Organization (WHO). (2015). *Strengthening Health Resilience to Climate Change*. Geneva, Switzerland. Retrieved from <https://unfccc.int/files/parties_observers/submissions_from_observers/application/pdf/684.pdf>

World Health Organization (WHO). (2018). *COP24: Special Report Health and Climate Change. Geneva, Switzerland.* Retrieved from <https://apps.who.int/iris/bitstream/handle/10665/276405/9789241514972-eng.pdf?ua=1>

World Health Organization (WHO). (2021). Climate Change and Health Vulnerability and Adaptation Assessment. Geneva: World Health Organization.

Yu, J., Castellani, K., Forysinski, K., Gustafson, P., Lu, J., Peterson, E., Tran, M., Yao, A., Zhao, J., & Brauer, M. (2021). Geospatial indicators of exposure, sensitivity, and adaptive capacity to assess neighbourhood variation in vulnerability to climate change-related health hazards. *Environmental Health : A Global Access Science Source*, *20*(1), 31. <https://doi.org/10.1186/s12940-021-00708-z>

Yu, J., Castellani, K., Yao, A., Cawley, K., Zhao, X., Brauer, M. (2020). *Mapping spatial patterns in vulnerability to climate change-related health hazards: 2020 Report.* Vancouver, BC: University of British Columbia. Retrieved from <https://open.library.ubc.ca/cIRcle/collections/facultyresearchandpublications/52383/items/1.0380851>



CHAPTER 10

Adaptation and Health System Resilience

HEALTH OF CANADIANS IN A CHANGING CLIMATE: ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Lead Author

Peter Berry, Health Canada

Contributing Authors

Paddy Enright, Health Canada and University of Waterloo

Linda Varangu, Canadian Coalition for Green Health Care

Shanaya Singh, Health Canada

Céline Campagna, Institut national de santé publique du Québec and Centre Terre, Eau, Environnement of the Institut national de la recherche scientifique

Pierre Gosselin, Institut national de santé publique du Québec andCentre Terre, Eau, Environnement of the Institut national de la recherche scientifique

David Demers-Bouffard, Institut national de santé publique du Québec

Denise Thomson, University of Alberta

Jérôme Ribesse, Synergie Santé Environnement

Susan Elliott, University of Waterloo

Suggested Citation

Berry, P., Enright, P., Varangu, L., Singh, S., Campagna, C., Gosselin, P., Demers-Bouffard, D., Thomson, D., Ribesse, J., & Elliott, S. (2022). Adaptation and Health System Resilience. In P. Berry & R. Schnitter (Eds.), *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action*. Ottawa, ON: Government of Canada.

Table of Contents

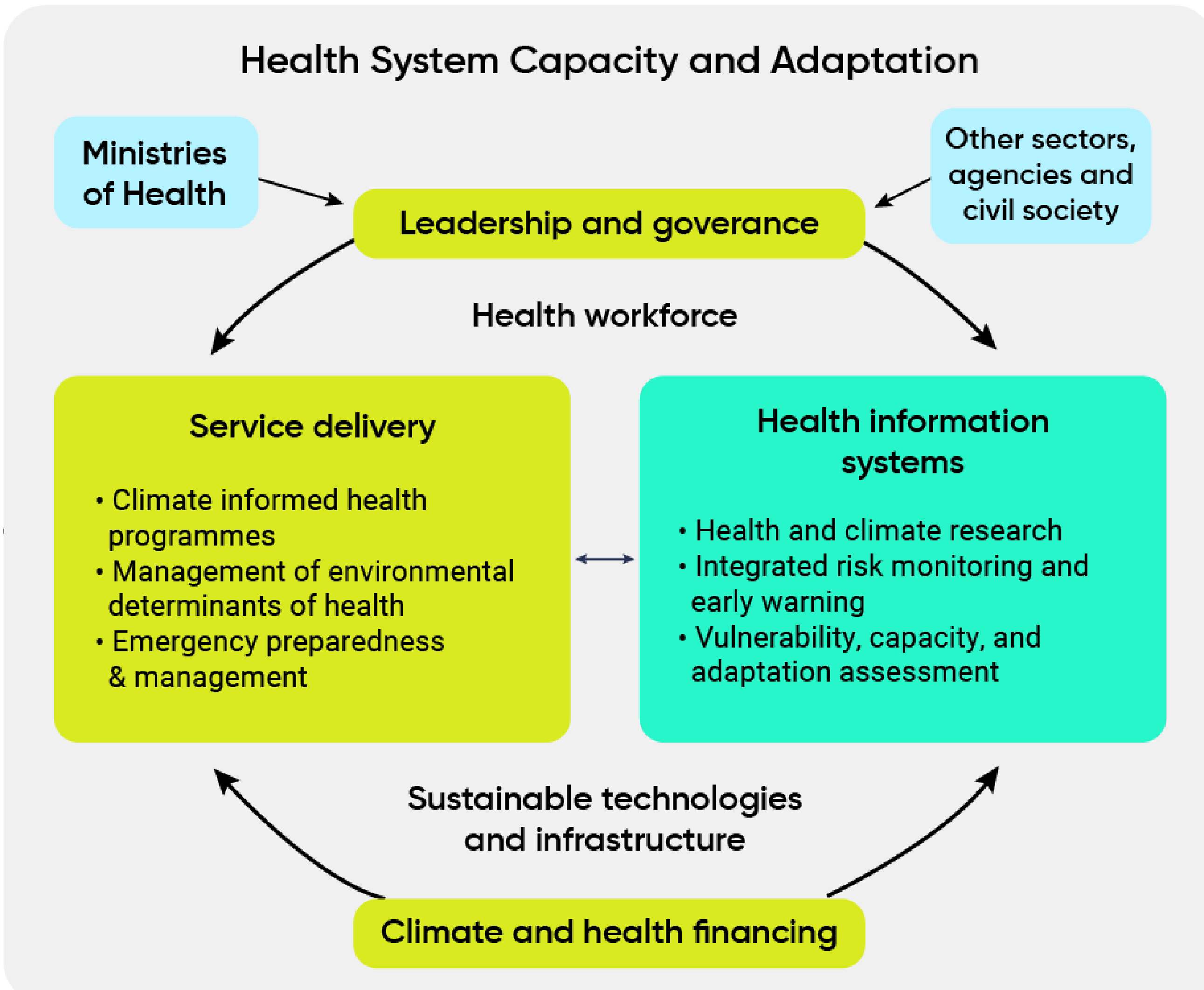
Summary

Changes in climate are affecting the health of Canadians and their health systems. Recent floods, wildfires, extreme heat events, and severe storms have had impacts on health facilities and disrupted care to those in need. Adaptation measures such as assessments of risks and vulnerabilities, integrated surveillance and warning systems, health professional training, and public education can help prepare Canadians and build the climate resilience of health systems. Well-designed efforts to adapt to climate change impacts and reduce greenhouse gas (GHG) emissions within and outside of the health sector can result in very large and near-term co-benefits to health. Many health authorities in Canada are increasing adaptation efforts. However, disparities in efforts exist across the country and adaptation needs to be rapidly scaled up to protect health as Canada continues to warm.

Key Messages

- The effects of climate change on health and on health systems in Canada are already evident and will worsen if existing vulnerabilities are not addressed and if gaps in health adaptation are not closed.
- Efforts to adapt to climate change — focusing on its health impacts — can significantly reduce current and future impacts on individual Canadians, communities, and health systems.
- Climate change impacts on health pose significant economic costs to Canadians, and these costs will increase in the future unless Canada adapts effectively.
- Canadian health authorities are undertaking a range of measures to adapt to climate change but are still lagging in many climate change and health actions to respond to the growing risks to Canadians.
- Many health authorities are not considering key drivers of vulnerability for specific population groups and therefore may not be addressing important aspects of adaptation for people disproportionately affected, such as First Nations, Inuit, and Métis peoples, racialized populations, seniors, women, and those of lower socio-economic status.
- Individual Canadians need to increase preparedness for climate change impacts. Many still need to take necessary measures to protect themselves and their loved ones from growing risks to health.
- Health authorities must take measures to increase the climate resilience of health systems. This means ensuring they remain operational when threatened by hazards and sustainable over the longer term, which is one of the most effective ways to protect human health and well-being from the impacts of climate change. Adaptation measures must be scaled up rapidly and substantially if current and future health impacts are to be reduced.
- Protecting Canadians from climate change requires a commitment to Indigenous leadership and partnership in research and adaptation efforts, including engaging with Indigenous Peoples in a meaningful way and recognizing and using Indigenous knowledge in a respectful way.

- Major co-benefits to human health can be achieved when decision makers in other sectors (such as water, transportation, energy, housing, urban design, agriculture, conservation) promote health and health equity through the design and implementation of actions to adapt to climate change and mitigate GHGs.
- Strong measures to reduce GHGs are needed to protect Canadians, their communities, and their health systems from climate change. The health sector can show leadership in reducing its carbon footprint and improving environmental sustainability, while building resilience to future climate change impacts.



Climate resilience of health systems functions. Source: WHO, 2022, Working paper on measuring climate resilience of health systems.

10.1 Introduction

Recent scientific research has identified potentially more severe impacts of climate change on societies, including on human health and health systems, at more modest increases in global mean temperatures (Hoegh-Guldberg et al., 2018; Ebi et al., 2019). These findings, along with the goal of "enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change" in the Paris Agreement (UNFCCC, 2015, p. 9), have increased recognition among health sector officials of the importance of adaptation measures to prepare for the health impacts of climate change.

Haines and Ebi (2019, p. 271) suggest that, "Climate change is causing injuries, illnesses, and deaths, with the risks projected to increase substantially with additional climate change, threatening the health of many millions of people if there are not rapid increases in investments in adaptation and mitigation." Growing threats to the health of Canadians from current climate variability and future climate change, as documented in other chapters of this assessment, require health authorities and individual Canadians to proactively prepare for the impacts.

Adaptation measures that get ahead of the curve of increasing climate impacts on ecosystems, infrastructure, communities, and health systems will need to move beyond incremental approaches to adopt transformative changes. Transformational adaptation directly addresses drivers of risks, including underlying vulnerability factors, and contributes to adaptive capacity, and resilience while enhancing social equity and gender empowerment (Crump et al., 2019). The term resilience is used in this chapter to refer to "the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation" (IPCC, 2014, p. 5). Effective action to protect health also requires health authorities and their partners to rapidly bring proven interventions to scale (Ebi, 2016; Patz & Thomson, 2018).

Previous science assessments increased knowledge of how weather, climate, and the health of Canadians are inter-related; how risks might be expected to increase as the climate continues to rapidly warm and become more variable; and what actions are needed to protect populations. They also highlighted that the resilience of health systems and the willingness of decision makers to take needed adaptive actions will largely determine whether and how much future climate change disrupts communities and affects health and quality of life (Berry, 2008).

Specific findings related to the adaptation process and measures being implemented by individual Canadians and health systems included the following (Berry, 2008; Berry et al., 2014a):

- Roles and responsibilities for health adaptation in Canada have been identified in some areas.
- Many adaptation actions are being taken by health authorities at all levels of government and by voluntary organizations, including some examples of mainstreaming climate change information into current programs and policies.
- There are significant gaps in knowledge of the effectiveness of adaptations.

- Gaps in existing adaptation efforts and abilities to cope with risks, combined with widespread exposure to climate-related hazards, indicate significant vulnerability to the health impacts of climate change.
- Health systems in Indigenous communities are vulnerable to the impacts of climate change and there are significant challenges in the capacity to adapt and protect health.[1]
- Projected health, demographic, and climate trends suggest vulnerability will continue to increase.
- Without ramped-up efforts to adapt, health and social services will come under increasing pressure from climate change impacts, such as extreme weather events and disasters.
- There are significant opportunities to adapt, stemming from from health officials' growing interest and awareness of threats from climate change, new tools to develop needed measures, and individual Canadians' ability to shift their behaviour and architectural practices to adjust to changing climate conditions.
- If land-use planning, infrastructure development, emergency preparedness, environmental management, transportation planning and climate adaptation activities fail to incorporate human health considerations, Canadians will become more vulnerable to climate change impacts on health.
- Climate change impacts may exceed the thresholds of current health and related systems (e.g., surge capacity, infrastructure design), which were designed based on assumptions of a stable climate that are now decades old.
- The increasing probability of cumulative and/or irreversible impacts means there may be limits to adaptation and the ability to protect individuals and communities from some impacts on health.
- Health authorities at all levels of government need to make tailored adaptation efforts due to differences in demographic and health trends, resources and expertise, health care and social service delivery, infrastructure, and community design.
- Many health and emergency management authorities must mobilize around and proactively plan for climate change impacts. Leadership and multi-sectoral actions on the issue are needed to make strides in preparing Canadians.

This chapter reviews the development of knowledge since 2012 to build on these findings. It examines current impacts of climate variability and change on health systems in Canada and the state of health adaptation by health authorities and individual Canadians. Opportunities to increase the resilience of individuals, communities, and health systems, as well as challenges to such efforts, are examined to support health officials' efforts to prepare for future impacts. Analysis draws upon findings and recommendations from previous national assessments and other sources, to explore whether progress is being made in preparing for the impacts of climate change on health in Canada.

1 The term Indigenous is used in this chapter to refer collectively to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples, as defined under Section 35 of the *Constitution Act, 1982*. Wherever possible, clear distinctions are made between these three distinct, constitutionally recognized groups. However, some generalizations are made, depending on the number and nature of citations used (e.g., Indigenous Peoples reflects more than one Indigenous group being referenced) and in instances where there may be shared experiences.

10.2 Methods and Approach

A number of research projects were commissioned for development of this chapter, including studies on:

- current levels of adaptation by Canadian health authorities;
- opportunities and barriers to health adaptation in Quebec; and
- health co-benefits of greenhouse gas (GHG) mitigation measures.

10.2.1 Current Levels of Adaptation by Canadian Health Authorities

An online survey of the status of Canadian health authorities' actions to prevent, respond to, and adapt to the impacts of climate change and the adaptive capacity and vulnerability of health systems in Canada was conducted in both official languages. The survey examined which climate risks health authorities addressed most frequently, populations considered to be at highest risk, and current adaptation activities. In total, 219 participants representing local to national health authorities across Canada were invited to complete the online survey. Online survey data collection took place from January 17 to March 13, 2019 (eight weeks). A total of 80 surveys were completed with the following breakdown: Atlantic provinces 7; Quebec 11; Ontario 34; Prairie provinces 13; British Columbia and the territories 15.

10.2.2 Opportunities and Barriers to Health Adaptation in Quebec

Given that the province of Quebec has developed the earliest and most extensive climate change and health program in Canada, this study examined the level of adaptation to climate change in the Quebec health sector to understand factors that can influence the integration of the climate change dimension, mainly adaptation, in these organizations. To determine the factors that may have influenced climate change adaptation in Quebec's health sector, a literature review and interviews with representatives of the health community were conducted. The literature review, conducted in May 2019, identified the factors that facilitate or hinder the implementation of climate change adaptation actions by public institutions, and the results were used as the basis for the interview questions. This was an exploratory review of the literature, since the quality assessment and methodological rigour of the selected studies were not in sufficient depth to qualify as systematic. The EBSCOhost by Web of Science and Google Scholar search engines were used for the research.

Interviews were conducted between July 2019 and November 2019. Participants in the study represented regions across the province and a variety of health-sector functions related to climate change. In total, 49 people were interviewed, including 25 officials from 16 of Quebec's 18 health regions. The majority of individuals work in environmental health, but others working in occupational health, infectious diseases, health promotion, monitoring, construction, and civil safety were also interviewed. Seven officials from the Institut national de santé publique du Québec (INSPQ) and seven from the Ministère de la Santé et des Services sociaux (MSSS) were also interviewed, as were two people from Ministère de l'Environnement et de la Lutte aux changements climatiques. A total of eight officials from Centres intégrés de santé et des services sociaux (CISSS) and Centres intégrés universitaires de santé et des services sociaux (CIUSSS) also participated in the study.

10.2.3 Health Co-Benefits of Greenhouse Gas Mitigation Measures

This study examined evidence of health co-benefits or risks from GHG mitigation technologies, with a focus on Canada. Background information on the current knowledge of health co-benefits or risks was obtained through a literature review. Articles identified were then reviewed by title and abstract, based on established inclusion criteria. Papers had to discuss known climate change mitigation technologies or policies; how they reduce or mitigate GHGs, short-lived climate pollutants, or air pollution; and at least one corresponding human health co-benefit and/or associated co-risk. Peer-reviewed journal articles, reports, and books were included. Review articles were excluded from the analysis but were used for background information for the literature review. The structured review of literature was done from July to October 2018 and was conducted using the electronic databases EMBASE, MEDLINE, and Global Health.

10.3 Health Adaptation to Protect Canadians

10.3.1 Health Adaptation Actors

Measures to help people prepare for the impacts of climate change can significantly reduce health risks as the climate continues to change (Smith et al., 2014; Campbell-Lendrum et al., 2015; Ebi et al., 2018a; WHO, 2018c; Haines & Ebi, 2019). By and large, the risks to health presented by climate change are not new; public health authorities have years of experience and evidence-based learnings about measures to address the health effects of air and water pollution, contaminated food, vector-borne diseases, ozone depletion, and extreme weather events (e.g., extreme heat events, floods, droughts, wildfires, ice storms, hurricanes) (Frumkin et al., 2008; Séguin, 2008; WHO, 2013; Ebi & del Barrio, 2017).

Preparing for the health impacts of climate change requires a wide range of actors in society to adapt at multiple temporal and geographic scales that take into account complex drivers and feedback mechanisms of the human–environment system (Crump et al., 2019). Adaptation actors include individual Canadians (all Canadians, but particularly people at highest risk of impacts) (see Chapter 9: Climate Change and Health Equity and Chapter 2: Climate Change and Indigenous Peoples' Health in Canada), health sector decision makers in and outside of government, health care and social services professionals (e.g., doctors, nurses, home care providers, social workers, pharmacists), officials in other health-related sectors (e.g., water systems), and researchers. Health sector adaptation includes health officials, in collaboration with those in other fields, taking action to understand, assess, prepare for, and help prevent the health impacts of climate change, particularly on the highest-risk populations. It includes designing, implementing, monitoring, and evaluating specific measures to reduce health risks (Ebi & Semenza, 2008) and includes broader efforts to increase the climate resilience of health systems. Programs, policies, and measures are most effective in the shorter and longer term if they concomitantly address inequities and boost general population health, which is the foundation of climate-resilient individuals and communities.

10.3.2 Health Adaptation Process

Adaptation planning by health authorities will often focus on efforts to reduce priority risks from specific climate hazards already affecting population health (e.g., development of heat alert and response systems [HARS]), surveillance of emerging or new vector-borne diseases, interventions to reduce health risks of wildfire smoke), or hazards that threaten health in the future. Health adaptation and resilience-building should move society beyond simple coping, which is reactive and concerned primarily with minimizing the immediate damage from a particular climate-related impact. Reactive coping responses often lead to greater vulnerability in the face of increasingly severe climate change threats. By contrast, health adaptation and resilience-building provide a way for health authorities to seize the opportunity climate change presents (Watts et al., 2018) to build more equitable and effective health systems. This may be accomplished, for example, by developing and implementing systems-level changes and by refining targeted actions, such as early warning systems, including HARS. Such actions build social capital and networks (e.g., buddy system to check on neighbours requiring assistance) and remove barriers to treatment and recovery during and after climate events for disadvantaged populations.

Health adaptation is most effective when it is anticipatory and proactive given that the climate continues to change in Canada at an increasing rate creating greater risks to health, some of which may surprise, disrupt, and challenge health authority activities. It is also evidence-informed and future-facing, to include measures that protect populations from more severe projected health risks, which may occur earlier than expected. Iterative processes for adaptation risk management (e.g., regular climate change and health vulnerability and adaptation assessments, evaluation of adaptation effectiveness, Indigenous partnerships, stakeholder engagement) help to ensure that adaptation actions address uncertainty of timing, severity, and geographical extent of future climate change impacts, including the potential for non-linear risks to health (Ebi et al., 2016a; Hess & Ebi, 2016; Ebi & del Barrio, 2017). Non-linear risks to health arise from much more severe climate impacts that are low probability but potentially high consequence events. The extreme heat event that affected northwestern United States and British Columbia in July 2021 and that is likely to have contributed to over 700 deaths in that province (Roffel, 2021) was estimated to be a 1 in 1000 year event (Philip et al., 2021).

Knowledge of how health authorities undertake adaptation has increased (Lesnikowski, 2011; Paterson et al., 2012; Ebi & del Barrio, 2017). Effective health adaptation plans and measures are grounded in the following considerations:

- The adaptation process is instigated and energized by increased awareness and knowledge of climate change risks to health in a jurisdiction (Lesnikowski, 2011; Eyzaguirre & Warren, 2014).
- National and international health authorities and research institutions identify climate change as a priority and provide adequate funding to enable understanding of complex drivers of health outcomes across environmental, social, and human systems (Ebi et al., 2016b).

- Groundwork activities (e.g., capacity building, monitoring and surveillance, research) often precede and support concrete adaptation actions (e.g., information-sharing, infrastructure development, technology and innovation, management and planning, policy development, resource transfers and funding support) (Lesnikowski, 2011; Shah et al., 2018).
- Health adaptation measures are informed by scientific and/or Indigenous knowledge[2] gained through a climate change and health vulnerability and adaptation assessment or other knowledge-development activities (Shin & Ha, 2012; WHO, 2013; Berry et al., 2018; Watts et al., 2018).
- Health adaptation activities are developed and implemented with knowledge and consideration of linkages to complementary GHG mitigation measures (ACT, 2018), as there are significant opportunities to increase health co-benefits of actions and to reduce possible health risks (Haines et al., 2009; Martinez et al., 2018; Haines & Ebi, 2019).
- Adaptations to protect health are mainstreamed into existing policies, plans, programs, and budgets and are iterative and subject to regular monitoring for effectiveness and enhancement opportunities through adaptive management (Ebi, 2011a; WHO, 2013; Wheeler & Watts, 2018). The climate and other important drivers of health outcomes (e.g., health systems, demographics) will continue to change, resulting in uncertain futures (Sellers & Ebi, 2017).
- Health adaptation actions are most effective when they are undertaken to advance health system resilience and root causes of vulnerability, and when they consider maximizing public health and health equity co-benefits. They are identified through community consultations with a range of partners that are either highly exposed to climate hazards and/or may lack capacity to adapt. These populations can include First Nations, Inuit, and Métis peoples, women, people living with disability, seniors, immigrants, low-income residents, minority language communities, outdoor workers, people exposed to environmental pollution, people with preexisting illnesses, people without access to insurance, public housing residents, refugees, lone-parent households, students, those experiencing homelessness, and young children (Gould & Rudolph, 2015; Deas et al., 2017; Dodd et al., 2018; NASEM, 2018).
- Adaptations to protect health are intentionally and specifically focused on climate change impacts (Dupuis & Biesbroek, 2013) and strive to reduce risks from current climate hazards as well as future more severe and frequent impacts, including the possibility of compounding and cascading events (Sellers & Ebi, 2017; Glasser, 2019).
- Health authorities take a broad health systems approach to adaptation, to identify and address vulnerabilities existing in any and all components of health systems to make them climate-resilient to withstand possible impacts on health facilities (WHO, 2015; Balbus et al., 2016; Ebi et al., 2018b).
- Collaboration among a multitude of sectors that support and maintain the determinants of health (e.g., social housing, water systems managers) is required to prepare successfully for climate change impacts on health.

2 Discussion of the contribution of Indigenous knowledge toward addressing climate change risks to health is found in Chapter 2: Climate Change and Indigenous Peoples' Health in Canada

Figure 10.1 presents a framework that highlights the stages health decision makers go through when adapting to climate change risks, informed and initiated by a vulnerability and adaptation assessment for climate change and health. Table 10.1 proposes indicators of climate-resilient health system adaptation for Canada based on this framework.

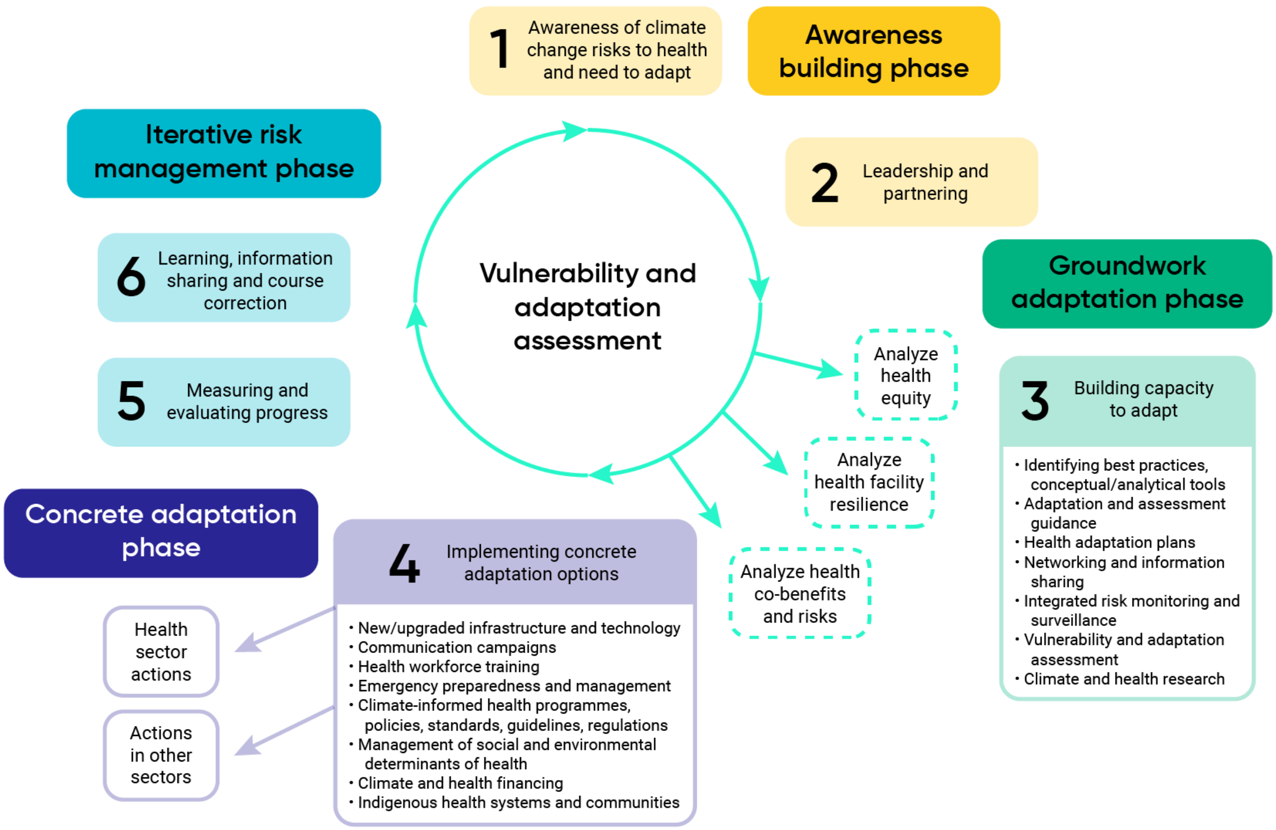


Figure 10.1 Framework for assessment and adaptation to create climate-resilient health systems.

Table 10.1 Sample indicators of climate-resilient health system adaptation

ADAPTATION PHASE	ADAPTATION ACTION	EXAMPLE INDICATORS[3]
Awareness building phase	Communication campaigns	Uptake of climate change and health communication campaigns (e.g., page or video views, observable changes in behaviour, etc.) Climate change and health information on health authority websites (e.g., climate change impacts to health and suggestions for behavioural changes that may reduce negative health outcomes) Number of climate change and health research projects completed relative to peer jurisdictions with results disseminated Media coverage of climate change and health issues Social media engagement on climate change and health issues
Groundwork adaptation phase	Leadership and partnering	Proportion of jurisdictions (e.g., communities, provinces, territories and/or regions) with climate change action plans that include measures to protect health Proportion of jurisdictions (e.g., communities, provinces, territories and/or regions with climate change and health offices/focal points) Number of key stakeholders (e.g., water authorities, community housing groups, assisted-living facilities, school boards, etc.) including climate change and health information in risk assessments
	Vulnerability and adaptation assessment	Proportion of local to national health authorities that have completed climate change and health vulnerability and adaptation assessments Proportion of local to national adaptation and mitigation policies with health impact assessments

3 When possible indicators should be measurable or quantifiable, though in some cases qualitative information may be more meaningful to knowledge users. In all cases, indicators should reflect progress towards a meaningful objective. Example indicators may need to be adapted to reflect jurisdictional goals and realities.

ADAPTATION PHASE	ADAPTATION ACTION	EXAMPLE INDICATORS[3]
Groundwork adaptation phase (continued)	Integrated risk monitoring and surveillance	Proportion of local to national health authorities with integrated early detection tools and surveillance systems to identify changing health risks and impacts (for example, see Chapter 6: Infectious Diseases) Proportion of local to national health authorities with established climate-informed early warning systems for extreme weather events and disease outbreaks (e.g., droughts, floods, zoonotic and vector-borne diseases)
	Climate and health research	Coordinated national research agenda on climate change and health Number of climate change and health research programs and networks Number of academic publications on climate change and health relative to peer jurisdictions Completion of health research sex- and gender-based analysis training
Concrete adaptation phase	Health workforce training and education	Proportion of health professional education and training programs (e.g., medical school, nursing, and public health programs) with course offerings on climate change and health Proportion of health professionals (e.g., doctors, nurses, pharmacists, public health officials) who have received climate change and health training
	New/upgraded infrastructure and technology	Proportion of health facilities with contingency plans (e.g., surge capacity) for the deployment of sufficient health personnel in case of acute shocks Proportion of health facilities that have reported the completion of a climate resilience assessment Proportion of health facilities with climate resilience informed programming Proportion of health facilities that report adaptation of new technologies and products to improve resilience

ADAPTATION PHASE	ADAPTATION ACTION	EXAMPLE INDICATORS[3]
Concrete adaptation phase (continued)	Indigenous health systems and communities	Surveillance and early warning capacity for Indigenous communities Availability of comprehensive, reliable, and culturally specific climate change and health indicators Access to diagnosis and treatment for physical and mental health conditions, including climate-sensitive diseases Established climate change and health focal point in regional to national health authorities Community knowledge and awareness of climate change impacts on health Public health work force available and trained in culturally appropriate climate change research, surveillance, and adaptation Status of water and food security and sovereignty Resilience of health care facilities in Indigenous communities
	Climate and health funding	Local to national funding for climate change and health research by issue, region, and population (e.g., Indigenous populations, seniors, children, immigrants) Local to national funding for climate change and health action plans, strategies, and adaptation measures Local to national funding for climate change and health organization capacity (e.g., office/focal point for climate change and health)
	Climate-informed health programs, policies, standards, guidelines, regulations	Proportion of health authorities with public health programs addressing key climate risks and hazards using most recent climate projection information Proportion of health authorities with public health programs addressing at-risk populations (e.g., children, seniors, immigrants) using the most recent climate projection information Proportion of sectors important to health (e.g., industry, energy, agriculture, housing, urban design, water, transportation) integrating climate change and health information into adaptation and GHG mitigation plans, strategies, and measures

ADAPTATION PHASE	ADAPTATION ACTION	EXAMPLE INDICATORS[3]
Concrete adaptation phase (continued)	Emergency preparedness and management	Proportion of local to national public health and health care authorities and facilities with emergency plans that address climate-related hazards and growing risks Proportion of local to national strategies for disaster risk reduction that include consideration of risks to health from climate-related hazards
	Management of social and environmental determinants of health	Robust local to national plans to reduce GHGs to meet agreed-upon international targets Established integrated monitoring systems for analysis of environmental hazards and health risks from climate change Existence and enforcement of regulatory standards on air quality, water quality, chemical discharges, and waste disposal and management Food security rates among climate-sensitive populations Access to services that support environmental and social determinants of health (e.g., access to safe water, adequate housing, employment, energy, and food security) among Indigenous populations
	Identifying best practices, conceptual/ analytical tools	Number of tools developed and implemented to support health adaptation actions
	Adaptation and assessment guidance	Climate change and health vulnerability and adaptation assessment guidance developed and disseminated for use by health authorities
	Health adaptation plans	Number of climate change and health adaptation plans or strategies developed

ADAPTATION PHASE	ADAPTATION ACTION	EXAMPLE INDICATORS[3]
Concrete adaptation phase (continued)	Networking and information-sharing	Number of climate change and health networking and information-sharing mechanisms (e.g., communities of practice) being used to support health adaptation
Iterative risk management phase	Measuring and evaluating progress	Proportion of completed local to national climate change and health vulnerability and adaptation assessments that have a monitoring and evaluation plan Proportion of local to national health authorities that have completed more than one climate change and health vulnerability and adaptation assessment under an ongoing schedule Number of local to national health authorities that include climate change and health indicators in regular health reports to the public
	Learning, information-sharing, and course correction	Existence of and participation in local to national initiatives for information and knowledge-building on climate change and health (e.g., communities of practice)

Source: Lesnikowski, 2011; Watts et al., 2015; WHO, 2015; Elliot et al., 2017

10.3.3 Health Adaptation Challenges and Opportunities

Health decision makers can find adapting to climate change challenging if they do not have the required technologies (e.g., new vaccines, communications, data sharing), information and skills (e.g., projections of health risks, training of health authorities), infrastructure (e.g., climate-resilient health facilities), resources, and institutional arrangements (e.g., a climate change and health focal point) (Frumkin, 2011). Barriers can also include a lack of authority and leadership for action, a narrow framing for public health interventions that omits action on root causes of vulnerability, legal obstacles, and failures in collective decision making (Ford & King, 2015; Gould & Rudolph, 2015). Some health systems in rural, remote, and/or Indigenous communities are already affected by existing vulnerabilities that increase risks from climate change impacts, for example, higher rates of all-cause mortality, less surge capacity during emergencies, reduced access to health facilities, and difficulty in retaining health professionals and accessing specialized health care (DesMeules & Pong, 2006; Vodden & Cunsolo, 2021) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Health systems and communities with fewer resources have greater difficulties responding to impacts and recovering in ways that protect the health of populations. In Canada, federal and provincial/territorial levels of government have a key role to play in supporting preparedness activities for local health authorities by building capacity through information-sharing, coordination, developing and disseminating scientific information, and financial contributions (Austin et al., 2019). Adaptation to the effects of climate change will be much greater and ability to protect health will be much more limited without strong measures to reduce GHGs (IPCC, 2014; Wheeler & Watts, 2018).

No population group or Canadian region should bear an unreasonable portion of the costs associated with the health and social impacts of climate change. Existing social inequities within a community (e.g., income, water insecurity, food insecurity, chronic health disparities) and/or higher rates of disease burdens can reduce the adaptive capacity of specific subpopulations (UNEP, 2018; Friel, 2019). Populations and communities that lack the capacity to plan for, respond to, and recover from climate change impacts will remain disproportionately affected by climate hazards (Berry et al., 2014a; Crump et al., 2019). In Canada, this may include rural and remote communities, Indigenous Peoples and communities, racialized populations, low-income populations, people with mobility challenges, people who are socially isolated, immigrants, renters, outdoor workers, minority language communities, seniors, and people with chronic diseases. In some cases, individuals may be subject to multiple, possibly intersecting, vulnerability factors. For instance, rural and remote residents, in addition to being more geographically exposed to some climatic hazards (e.g., wildfires), are more likely to be elderly, to work outdoors, to have lower average incomes, to have less internet access, and to have higher rates of chronic health conditions. Policies and programs to address existing social inequities and the root causes of vulnerability are needed to plan for climate change impacts on health (CICC, 2021) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada and Chapter 9: Climate Change and Health Equity).

Other challenges to adaptation can arise when efforts to address climate change impacts by decision makers, in or outside of the health sector, are not coordinated and well planned, leading to maladaptation — unintentionally increasing risks to other sectors, social groups, or systems (Austin et al., 2016) (Table 10.2). Insufficient information and/or limited awareness of risk trade-offs can also lead to maladaptation or to insufficient adaptation among individuals to protect themselves and/or their families from the health effects of multiple climate hazards. For example, exercising during cooler parts of the day (e.g., night) or staying in shady areas to reduce risks from heat may lead to greater exposure to mosquitos and ticks that carry vector-borne diseases (Hill, 2012). Actions to plant vegetation like trees on the south side of a home to cool the building may be maladaptive if the trees produce pollen and are located near the intake of the furnace or air conditioner. They may also be maladaptive if vegetation, including leaves and fallen branches, is not maintained and serves to increase the presence of combustible materials near a home or structure that connects to a home, such as a fence. In some contexts vegetation may also harbour disease vectors. Efforts to conserve energy by opening blinds to take advantage of natural light whenever possible may increase risks of heat illness. As well, the use of cooling facilities (e.g., community centres, pools, libraries, malls) and public spaces during extreme heat events to protect health may increase risks from COVID-19 if necessary physical distancing, hand hygiene, and related measures are not taken (Shumake-Guillemot et al., 2020).

Maladaptation to climate change increases the risk that health decision makers will become trapped in a cycle of responding to and treating ever-increasing negative health outcomes in the population. Poorly designed or maladaptive measures may also exacerbate existing inequities, for example, if public information campaigns and funding are lacking (Paavola, 2017). Table 10.2 provides examples of maladaptive actions that can affect health.

Table 10.2 Potential maladaptive actions in efforts to protect health from climate change impacts

BROAD TYPE OF MALADAPTIVE ACTION	POSSIBLE HEALTH SECTOR EXAMPLES
Failure to anticipate future climates	Health-related infrastructure (e.g., hospitals, drinking water systems) built or renovated without resilience to future climates
Adaptation actions not taking wider impacts into account	Pollen-producing trees to reduce the urban heat island in urban areas GHG and air pollutant emission reductions that lead to minimal air quality benefits for disadvantaged neighbourhoods
Engineered defences that preclude alternative approaches and are designed without a health equity lens	Adaptation of infrastructure in other sectors that do not maximize health co-benefits in short or longer term
Awaiting more information, or not doing so, and eventually acting either too early or too late	Awaiting better projections and health data to complete or use results from a climate change and health assessment, thereby forgoing the opportunity for proactive adaptation
Forgoing longer-term benefits in favour of immediate adaptive actions	Focus on treating health outcomes and insufficient efforts to build healthy and climate-resilient communities (e.g., greening to reduce urban heat island effect)
Moral hazard	Encouraging risk taking (e.g., lack of insurance, social safety net, aid backup) such as moving to flood plain or urban/forest interface prone to wildfires
Adopting actions that ignore local relationships, traditions, Indigenous knowledge, or property rights, leading to eventual failure	Development of health adaptation plans without broad consultations and engagement with diverse and representative populations, leading to actions that do not respect unique cultural needs and values (e.g., interventions imposed on Indigenous communities)

BROAD TYPE OF MALADAPTIVE ACTION	POSSIBLE HEALTH SECTOR EXAMPLES
Adopting actions that favour one group over others, directly or indirectly, leading to breakdown and possible conflict	Implementation of health adaptations that are not accessible to low-income individuals or those experiencing homelessness (e.g., no heatwave cooling centres in low-income neighbourhoods, social services not accessible by public transit)
Retaining traditional responses that are no longer appropriate	Failure to expand monitoring and surveillance systems to detect new, emerging, or exotic risks to health
Source: Adapted from Noble et al., 2014	

There are opportunities for robust adaptation through collaboration among officials in a range of sectors (e.g., health, water, agriculture, energy, housing, environment, conservation, planning, transport, disaster management, and infrastructure) on monitoring and surveillance of climate change impacts on health; identifying higher-risk populations; addressing barriers that limit preparedness (e.g., poverty, inadequate housing and infrastructure, ineffective communications); reducing uncertainty through increased research on impacts; educating the public and decision makers about potential impacts and the benefits of preparedness; and funding needed actions (Séguin, 2008; WHO, 2010; Ebi, 2011b; Frumkin, 2011; Ebi & del Barrio, 2017). For example, technical and operational synergies can be achieved when health authorities and disaster management officials collaborate to improve disaster preparedness and response, communicate risks to the public, and undertake risk and vulnerability assessments and health system resilience-building (Banwell et al., 2018). The Emergency Management Framework for Canada recognizes the linkages between climate change and emergency management and the benefits of multisectoral approaches to resilience-building (PSC, 2017). At the individual level, preparing for climate hazards and taking action to avert impending threats requires information about risks and effective personal protective measures, resources to take action, and a supportive social network, particularly for people who require assistance.

Given increasing risks and potentially severe impacts on health, adaptation activities need to be rapidly scaled up outside of normal health ministry activities (Ebi, 2016). Box 10.1 provides an example of collaboration on adaptation among public health and infrastructure decision makers to reduce risks from climate change affecting children. A major benefit of collaboration among sectors on the design, implementation, and monitoring of adaptation and of GHG mitigation measures is that co-benefits to health from such actions can be maximized (e.g., improved mental health from increased social capital, reduced obesity from active infrastructure), while potential risks to health of the measures can be reduced (Cheng & Berry, 2013; WHO, 2018c) (see section 10.6 Health Co-Benefits of Adaptation and GHG Mitigation Measures).

Box 10.1 Preventive adaptation to keep children safe from climate hazards in playgrounds

Children are at increased risk of heat illness and death because of their physiology and because of their dependence on caregivers. Developing safer outdoor playspaces for children with preventive measures can reduce health risks, particularly as the climate continues to warm and extreme heat events become more frequent. As part of a broader Government of Canada initiative to adapt infrastructure to the changing climate, the Standards Council of Canada and Health Canada partnered with the National Program for Playground Safety (NPPS) to develop guidance to improve the climate resilience of playgrounds. This guidance was included as an Annex in the Canadian Standard Association's Children's Playspaces and Equipment Standard (CAN/CSA-Z614-14). The updated standard supports practical and evidence-based options for climate mainstreaming by municipalities, affordable housing providers, and schools when new playgrounds are built or existing ones are renovated. The recommended changes in design include planting shade trees, selecting cooler materials for structures and surfaces, and adding water features. The guidance applies for all seasons of play, with a particular emphasis on keeping playgrounds cooler and comfortable for children and caregivers in the summer to help prevent overheating and injuries to children such as burns from metal slides.

Source: Kennedy et al., 2021

Partnerships with Indigenous Peoples and use of Indigenous knowledge, local context, and values — and incorporating sex, gender, and equity considerations into decision-making — support more effective measures through a respectful and meaningful adaptation process. Such collaboration can increase the relevance of the resulting measures, build capacity, and strengthen resilience through more inclusive and dynamic climate change networks within communities. Community-based adaptation research in Indigenous communities can be conducted through team-building approaches that identify common goals, support the meaningful engagement of knowledge users, and continuously monitor and evaluate progress (Ford et al., 2018) (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada).

In recent years, the understanding of adaptation options that modify public health interventions for existing climate-related health hazards or address new and emerging risks, thereby building resilience to climate change impacts on health, has increased (Paterson et al., 2012; WHO, 2015; UNEP, 2018; ISC, 2019). Each chapter of this assessment provides information about adaptation measures to address specific climate change health concerns facing Canadians. Several tools to assess adaptation can be used to examine options for reducing risks, such as forecasting by analogy, screening, multi-criteria decision analysis, comparative risk assessment, benefit cost analysis, cost-effective analysis, and implementation analysis (WHO, 2013). However, using such tools and prioritizing measures to reduce health risks from climate change can be difficult if there is insufficient information about current and/or projected impacts on health and of the possibility of surprise or unanticipated impacts (Wardekker et al., 2012).

10.3.4 Effectiveness of Health Adaptation

Over the last several decades, the success of public health measures in reducing the health impacts of environmental hazards suggests that adaptations to address climate-related health risks can be effective in protecting populations. Adaptation can delay the increase in health risks from climate hazards at higher levels of warming (CCA, 2019; Ebi et al., 2021). Greater actions to prepare populations and health systems for climate change, and to reduce GHGs, would reduce the future burden of disease (Haines & Ebi, 2019). However, there is a paucity of information on the effectiveness of specific health adaptation measures in and outside of Canada, presenting a significant challenge to decision makers (Bouzid et al., 2013; Anderson et al., 2017). One study that reviewed the effectiveness of 56 specific interventions spanning 14 health issues of concern related to climate change revealed wide divergence among adaptations in terms of evidence (Anderson et al., 2017). Box 10.2 describes how the Texas Medical Centre undertook effective measures to increase its resilience to severe storms.

Box 10.2 Improving the climate resilience of Texas Medical Centre

Texas Medical Centre (TMC) in Houston is the largest medical complex in the United States, comprising 23 hospitals. In 2001, this medical complex experienced very severe impacts from Tropical Storm Allison, a historic thousand-year flood, which caused 22 deaths, cost almost 5 billion USD in damage to the county, and resulted in a complete power outage due to damage to emergency generators and electrical switchgear. It also led to more than 1000 patients being evacuated and 2 billion USD in research losses.

After the devastation caused by Tropical Storm Allison, TMC hospitals came together to invest 50 million USD in measures to enhance the resilience of their facilities, including a new flood alert system, improved disaster mitigation planning, and creation of flood management groups. In addition, infrastructure upgrades were undertaken, such as installation of a new on-site combined heat and power plant to eliminate dependence on the city's energy grid and elevation of power service to reduce the risk that it would be flooded. Since the upgrades, TMC was struck by Hurricane Rita in 2005, Hurricane Ike in 2008, and Hurricane Harvey in August 2017. In all of these storms, the medical complex escaped the devastating impacts felt in 2001 that so greatly affected patients and staff. In fact, during record-breaking Hurricane Harvey, all TMC hospitals and emergency rooms remained operational, although the storm flooded the Houston area.

Source: Health Care Without Harm, 2018

More investigation has been conducted on the effectiveness of measures to reduce health risks from extreme heat than on health risks from other climate hazards. The scope of discussion in this chapter does not permit review of the effectiveness of all health adaptation measures. Information on the current state of knowledge on the effectiveness of measures to reduce heat-health risks is presented to highlight the importance of regularly evaluating actions to protect health and of integrating uncertainty into the decision-making process.

Several studies suggest that, even with a warming climate, population susceptibility to extreme heat events has not been increasing, or has even been decreasing, in a number of countries (Fouillet et al., 2008; Kyselý & Plavcová, 2012; Schifano et al., 2012; Heudorf & Schade, 2014; Hondula et al., 2015; Arbuthnott et al., 2016; Barreca et al., 2016; Sheridan & Dixon, 2016). Research in regionally and economically diverse countries also indicates that HARS, components of which can include heat-health warning systems (McGregor et al., 2015) and heatwave action plans (HAPs) (Casanueva, et.al., 2019; Jay et al., 2021) can reduce poor health outcomes associated with extreme heat events (Hess & Ebi, 2016; Anderson et al., 2017; Lee, et al., 2019). In 2017, an estimated 47 countries had national or subnational HAPs in place (GHHIN, 2018), including Canada, which has HAPs in many communities and regions.

Sheridan and Allen (2018) suggest that implementation of HARS, greater awareness of heat-health risks, and improved quality of life have helped reduce the health impacts of heat in the developed world. These systems have been shown to be protective in Europe (Matthies et al., 2008; Martinez et al., 2019), France (Fouillet et al., 2008), Italy (Michelozzi et al., 2006; Baccini et al., 2011; Morabito et al., 2012), India (Das & Smith, 2012; Hess et al., 2018), Shanghai (Tan et al., 2007), Hong Kong (Chau et la., 2009), and Milwaukee (Weisskopf et al., 2002). It was estimated that implementing a heat action plan in Ahmedabad, India, in 2010 avoided an estimated 1190 average annualized deaths in 2014–2015 (Hess et al., 2018). However, some studies argue that robust evidence showing that such systems have a discernable influence on health outcomes is lacking (Boeckmann & Rohn, 2014; de' Donato et al., 2015; Hondula et al., 2015; Weinberger et al., 2018). Well-designed HARS can result in significant economic savings when the costs of systems are compared with their economic benefits. For example, Hunt et al. (2017) calculated the benefit-to-cost ratios of alert systems to be 913 for Madrid, 308 for Prague, and 11 for London.

Many existing health sector policies, programs, and measures aimed at protecting people from extreme heat and other climate hazards and health outcomes (e.g., air pollution, infectious diseases, water-borne diseases, food-borne diseases, extreme weather events) were not designed incorporating information about increasing risks from climate change and so will have limited effectiveness in the future, unless they are modified (Haines & Ebi, 2019). In fact, many HARS are not designed to address increased risks posed by a changing climate, such as alterations in the onset, duration, and intensity of extreme temperatures and resulting health outcomes (Lee et al., 2019). HARS need to be regularly reviewed and evaluated through an iterative process to ensure they are fully protective under new climate conditions and hazards (Health Canada, 2012; Hess & Ebi, 2016; Lee et al., 2019).

In Canada, researchers in Quebec reported that heat alert systems can be effective (Poitras, 2018) and that local and provincial HAPs reduced mortality associated with a severe heat event in 2010 (Bustinza et al., 2013) and in 2018 (Lebel et al., 2019). Benmarhnia et al. (2016) reported that improvements to the Montréal HAP have decreased the number of daily deaths five-fold (see Chapter 3: Natural Hazards). In addition, efforts to warn the public about hazardous heat conditions and poor air quality have been found to be effective in getting people to take protective measures and in reducing costs to the health system (Gosselin et al., 2018; Mehiriz et al., 2018; Mehiriz & Gosselin, 2019). Health authorities in Toronto and Montréal reported that alert systems led to an increased awareness of risks to health from heat and to the uptake of health protective behaviours, such as drinking water, checking for alerts, wearing looser clothing, and seeking cooler locations (Health Canada, 2012; City of Toronto, 2019).

Additionally, preventive adaptation measures to reduce urban heat islands in Quebec (e.g., reduction of concrete/asphalt surfaces, increasing vegetation) were found to be effective in cooling communities and reducing health risks (Beaudoin & Gosselin, 2016; Health Canada, 2020d). From an economic perspective, the benefits of actions to reduce risks to health from extreme heat can justify implementation (Hunt et al., 2017) and may reap large cost savings. Tröltzsch et al. (2012) estimated that, between 2071 and 2100, implementation of a heat alert system in Germany would result in a value of EUR 2.36 billion in avoided deaths and EUR 165 million in hospital savings annually.

More research is required to better understand the effectiveness of adaptations to extreme heat events and to other climate hazards projected to increase in the future (Bouzid et al., 2013; Berry et al., 2014a). National estimates of heat-related morbidity and mortality would benefit from greater standardization of surveillance definitions and practices to enable comparisons among provinces. This evidence base would benefit the design, evaluation, and reporting of future climate change and health adaptation interventions (Hess & Ebi, 2016). For example, Valois et al. (2017) developed a behavioural index composed of 12 adaptations to gauge whether individuals in urban areas are adapting well to high summer temperatures. Studies of effectiveness are important because current health adaptations may not reflect important changes in exposure due to climate change, such as the longer heat season in many regions (Ebi et al., 2016c), including Canada (Zhang et al., 2019).

10.3.5 Status of Health Adaptation

At the global level, some adaptation progress has been made; for example, at least 92 countries have completed vulnerability and adaptation assessments for climate change and health (Berry et al., 2018). However, a health adaptation gap exists that increases the vulnerability of people to climate change impacts (Watts et al., 2015; Martinez et al., 2018; Watts et al., 2018). The World Health Organization (WHO) collects global data every two years on a number of indicators to gauge progress toward preparing for climate change impacts on health. The data are reported through the WHO/United Nations Framework Convention on Climate Change (UNFCCC) Climate and Health Country Profiles (WHO, 2018a). The most recent survey, undertaken in 2017/2018, indicated that there has been progress on climate change and health adaptation internationally, but that adaptation plans and strategies vary widely in terms of their scope and that implementation of specific actions remains a key challenge (WHO, 2019). In addition, the results of vulnerability and adaptation assessments for climate change and health are influencing policy decisions in health ministries in various countries, and many health authorities are increasing collaboration with decision makers on adaptation in other sectors (WHO, 2019).

Analysis of Canada's progress in addressing climate change risks to health, based on the WHO indicators, suggests that further actions are needed in some areas (Table 10.3).

Table 10.3 Canadian performance on WHO climate change and health resilience indicators

INDICATOR	STATUS IN CANADA[4]	SOURCE/COMMENT
A national focal point for climate change has been identified in the Ministry of Health	Yes	The Climate Change and Innovation Bureau at Health Canada is the national focal point for climate change and health issues (Government of Canada, 2019).
Projects or programs on health adaptation to climate change have been implemented	Yes	Though gaps remain, Health Canada, the Public Health Agency of Canada, the Canadian Institutes for Health Research, and Indigenous Services Canada are undertaking a range of measures to reduce risks to Canadians from climate change associated with extreme heat events, air pollution, and infectious diseases, and to address special challenges faced by Indigenous Peoples living in Northern and Southern communities (Government of Canada, 2019; Government of Canada, 2020a). Numerous provinces and territories are undertaking climate change and health programming within their jurisdictions.
A national assessment of climate change impacts, vulnerability, and adaptation for health has been conducted	Yes	Séguin, 2008; Berry et al., 2014a

4 Yes = completed or substantially completed; Partially = actions underway but more effort needed; No = not completed or started

INDICATOR	STATUS IN CANADA[4]	SOURCE/COMMENT
Climate information has been included in the Integrated Disease Surveillance and Response System, including development of early warning and response systems for climate-sensitive health risks	Partially	Early warning systems for climate change health risks are generally the mandate of provincial/territorial and local health authorities. A number of health authorities have developed warning systems for extreme heat events, floods, and air pollution, including real-time surveillance systems that use data on multiple vulnerability factors. Understanding of climate-driven changes affecting infectious disease distribution in Canada are still emerging. However, a number of infectious diseases known to be climate-sensitive (e.g., Lyme disease) are tracked at the national level.
Estimated costs to implement health resilience to climate change have been included in planned allocations from domestic funds in the last financial biennium	Partially	In Canada, health is primarily the responsibility of provinces/territories. Many provinces and territories have begun work to build climate resilience, including through the allocation of financial resources. Federally, through Budget 2016 and Budget 2017, the Government of Canada committed $125 million over 11 years to help protect the health of Canadians from the impacts of climate change and to increase the resilience of our health systems. These investments support needed activities such as research, education and capacity building. Budget 2021 allocated $22.7 million to support First Nations and Inuit communities in responding to the health impacts of climate change.
National Communication submitted to UNFCCC has included health implications of climate change mitigation policies	Partially	Canada's seventh National Communication (2017) recognizes the economic and social consequences (including on health) of measures to address climate change but does not provide detailed information or analysis in this regard (Government of Canada, 2017).

INDICATOR	STATUS IN CANADA[4]	SOURCE/COMMENT
Activities to increase climate resilience of health infrastructure have been implemented	Partially	Some health authorities have begun investigating or requiring the assessment of the climate resilience of health infrastructure (BC Health Authorities, 2020; Lower Mainland Facilities Management, 2020).
A National Health Adaptation Strategy has been approved by the relevant government entity	Partially	Canada's pan-Canadian Framework on Clean Growth and Climate Change includes a range of actions to address health risks from climate change (Government of Canada, 2015). The Government of Canada has committed to developing a National Adaptation Strategy (Government of Canada, 2020b).
Actions to build institutional and technical capacities to work on climate change and health have been implemented	Yes	The HealthADAPT program (2019–2022) is building the capacity of 10 health authorities in regions across Canada to increase knowledge of climate change impacts on populations and develop needed adaptation actions (Health Canada, 2019).
The national strategy for climate change mitigation has included consideration of the health implications (risks or co-benefits) of climate change mitigation actions	Partially	The Government of Canada has recognized the need to achieve health co-benefits in the implementation of GHG mitigation measures (Government of Canada, 2020b).
A valuation of co-benefits of health implications of climate mitigation policies has been conducted	Partially	The Government of Canada develops Regulatory Impact Analysis Statements for each proposed GHG regulation that provides information on its objectives and its expected costs and benefits (Government of Canada, 2021). Not all proposed, or implemented, GHG-reduction measures include analysis of health risks or co-benefits.

INDICATOR	STATUS IN CANADA[4]	SOURCE/COMMENT
Estimated costs to implement health resilience to climate change have been included in planned allocations from international funds in the last financial biennium	Not applicable	Canada does not receive funds from international sources to implement actions to protect health from climate change.

Similarly, the Lancet Countdown on Health and Climate Change regularly tracks 41 indicators in five areas to gauge efforts to address climate change impacts on health globally. They include (1) climate change impacts, exposures, and vulnerability; (2) adaptation, planning, and resilience for health; (3) mitigation actions and health co-benefits; (4) finance and economics; and (5) public and political engagement (Watts et al., 2018). Following the methods and indicators of the Lancet Countdown, major medical organizations in Canada, including the Canadian Medical Association, Canadian Public Health Association, and the Canadian Association of Physicians for the Environment began in 2017 to report annually on actions undertaken in Canada (Howard et al., 2017; Howard et al., 2018). To improve Canada's ability to tackle climate change specific to the health sector, recommendations include support for tele-commuting and telehealth options; creating curricula for all medical and health science faculties related to climate change; communicating the links between climate change and human health to the public; funding research on mental health impacts of climate change; and enhancing efforts to protect Canadians from extreme heat (Howard et al., 2017; Howard et al., 2018).

Two stakeholder workshops were hosted by Health Canada, including one in 2018 to discuss development of a pan-Canadian climate change and health surveillance system, and another in 2016, that brought together provincial and territorial health and environment officials, municipal health units, researchers, non-governmental organizations, and Indigenous partners from across Canada, to explore priority health issues, research gaps, and adaptation needs to prepare Canadians and health systems for climate change. Recommendations and needed actions from the meetings are presented below (Brettle et al., 2016; Knowledge Management, 2018).

Knowledge and data

- Develop a pan-Canadian monitoring and surveillance system that is specific for climate change health outcomes and serves the needs of health authorities.
- Key climate change and health indicators adopted across Canada and at specific locations that are consistent and standardized with procedures to identify data quality issues.
- Increased data on indicators of climate change and health vulnerability, resilience benchmarks, and support for understanding regional vulnerabilities and risk.
- Climate change and health vulnerability and adaptation assessments by each province and territory to identify opportunities to decrease risks to health.

- Increased surveillance and monitoring of climate-related diseases, and evaluation of the efficacy of adaptation and GHG mitigation interventions.
- Provide data that can alert stakeholders in real or near-real time to emergencies as well as provide data for understanding long-term trends.

Program and policy development

- A national "Trees for Health" campaign (e.g., trees planted for patients and caregivers at health care facilities).
- Funding for sustainable health sector infrastructure.
- Guidance on standards for building codes and zoning regulations for the health sector.
- Actions to increase health co-benefits of GHG mitigation and adaptation efforts to address climate change.

Northern and Indigenous community considerations

- Increased actions to address the health challenges and capacity issues Northern and Indigenous communities face from climate change.
- Increased collaboration with Indigenous communities to support education efforts, communicate research findings, and support resilience-building.

Communication and information-sharing

- Collaborate on climate change and health communications with the health care community and non-governmental organizations.
- Increased public health education using evidence-based advice and targeted messaging.
- Incorporate information on climate change and health into educational curricula (e.g., health professionals).
- Develop a single window to provide easy access to climate change and health communication materials and messages.

Mechanisms for coordination and collaboration

Increase efforts by federal departments and agencies to support:

- Improved preparation of communities for emergency response/disaster recovery.
- Improved coordination on climate change and health activities among all federal health departments and agencies, provincial/territorial/local health authorities, and Indigenous partners with needed mechanisms (e.g., climate change and health committee, regional working groups, monthly webinars, collaborative research projects).

- Establish a platform to share best practices across provinces and territories (e.g., tool for open-sourcing plans and policies, guidance on developing adaptation options, checklists to assess vulnerability, economic analysis of actions).
- Map initiatives on climate change and health and provide funding to support needed actions.
- Work more closely with U.S. agencies on climate change and health, taking into consideration important cross-border agreements (e.g., air quality, water quality).

Progress has been made in some of these areas. For example, since 2007, Health Canada has led a heat-health program that is providing support and guidance to local, provincial, and territorial health authorities to develop HARS to protect Canadians from extreme heat events. The program provides public health authorities with guidance on assessing heat-health vulnerabilities at the community level, and on developing heat alert protocols, community response plans, and communications plans. To communicate heat-health risks to Canadians, including to those most vulnerable to the impacts, Health Canada has developed information brochures, infographics, and videos (Health Canada, 2020a; Health Canada, 2020b; Health Canada, 2020c; Health Canada, 2021). Health Canada has also collaborated with a number of communities in Ontario (Windsor, Ottawa, London, and the Regions of Peel and York) and British Columbia (Vancouver) on innovative projects to reduce the urban heat island effect, thereby reducing people's exposure to higher temperatures in urban areas. The projects helped inform development of a guide for public health officials in Canada on how to engage with partners to address effects of urban health islands on health (Health Canada, 2020d).

Through the HealthADAPT program, launched in 2019, Health Canada is providing funding, information, and expertise to 10 local and regional health authorities across Canada to help build their capacity to understand climate change impacts on populations, develop needed adaptation actions, and communicate with the public and stakeholders on these issues. Many of the projects are examining current and future projected climate change impacts associated with extreme weather events, including on mental health (Health Canada, 2019). Project results and learnings are being shared through a pan-Canadian community of practice that includes public health officials from all levels of government.

Previous climate change and health assessments documented adaptation options for protecting health, roles and responsibilities for health adaptation, and measures being undertaken by health authorities in Canada (Séguin, 2008; Berry et al., 2014a). The following sections provide more detailed information on the current state of adaptation in Canada and describe the range of measures being taken at the regional and local level.

10.3.5.1 Adaptation by Regional and Local Canadian Health Authorities

Efforts are underway by a number of Canadian health authorities and partners in other sectors to prepare for climate change impacts on health, including, for example, risks related to extreme heat (Guilbault et al., 2016), extreme weather (Kovacs et al., 2018), and wildfires (Kovacs et al., 2020). A survey of 80 health sector officials from all regions of Canada conducted in 2018–2019 included respondents from Ontario (34), Quebec (11), the Atlantic provinces (7), the Prairie provinces (13), British Columbia (13), and the territories (2). It revealed that large majorities (80% or higher) reported taking some kind of action on health risks of concern due to climate change that were identified in previous assessment reports. These risks of concern included infectious diseases, air quality, extreme heat, other extreme events, and water safety and security, water quality and quantity, and food safety and security. Fewer, but still about four in 10 respondents, indicated they are taking action on climate-related mental health risks (see Figure 10.2) (Survey Research Centre, 2019).

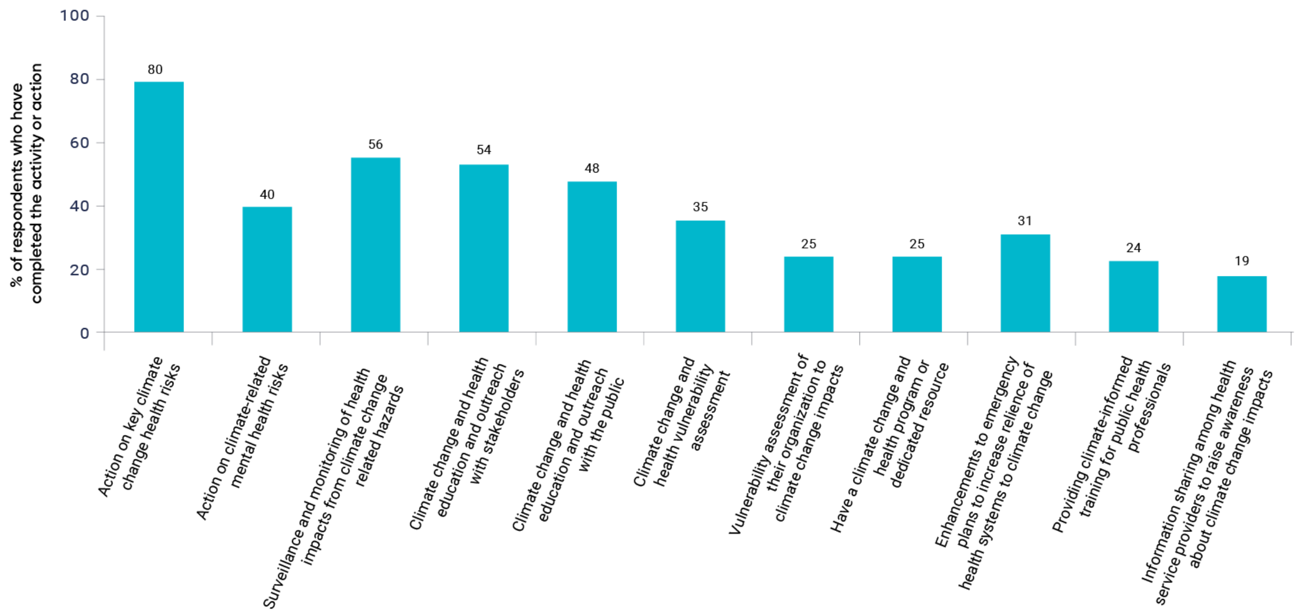


Figure 10.2 Awareness and groundwork activities and actions on climate change and health undertaken by Canadian health authorities. Source: Data from Survey Research Centre, 2019.

Many of the activities health authorities have engaged in are awareness-building or groundwork. Just over half of respondents (56.3%) indicated they undertake surveillance and monitoring of the health impacts from hazards related to climate change. In addition, 53.8% reported undertaking climate change and health education and outreach with stakeholders, while just under half (47.5%) have done so with the public. In addition, 35% have undertaken a vulnerability and adaptation assessment for climate change and health, while fewer have undertaken an assessment of the vulnerability of their organization to climate change impacts (25%). Only 21.3% report that they have a climate change and health adaptation strategy, and 10% have a climate change and health research plan (Survey Research Centre, 2019).

Box 10.3 Health adaptation in Arviat, Nunavut

In Nunavut, climate change has been identified as a major threat to food security and people in this region already experience challenges in accessing nutritious foods (see Chapter 8: Food Safety and Security). A community research program in Arviat, Nunavut, identified climate change threats to hunting, sharing, and consuming country foods and impacts on individual and community well-being, including on culture and identity. Researchers explored options to increase access to healthy foods through local production, including introducing a community organic composting program to improve local soil quality and establishing a research greenhouse to assess the viability of commercial food production. Subsequent research on the greenhouse focused on enhancing the capacity of community youth to support its ongoing operation and necessary monitoring and data collection.

The projects were very successful and had positive impacts on the community through changes in dietary and cooking habits. As a result of lessons learned, the Hamlet of Arviat built two hydroponic commercial greenhouses (<www.greeniglu.com>). The *Community Climate Change Manual*[5] developed by the Aqqiumavvik Arviat Wellness Society provides information that other communities can use to plan similar projects. It includes information on building partnerships, engaging youth, reaching out to community stakeholders, building capacity, establishing a sustainable planning process, and communications, among other topics.

Generally, health authorities are undertaking fewer concrete climate change and health actions in response to growing risks to Canadians, and there is a need to quickly scale up effective measures. Only one in four health authorities surveyed reported having a climate change and health program or dedicated resource, and this dropped to one in five for those reporting increasing resources (e.g., funding, human resources) to support adaptation measures (Survey Research Centre, 2019). This suggests that the health programs responsible for protecting the health of Canadians could themselves be vulnerable to climate change impacts and that many health authorities still do not see this issue as a priority, or do not have the resources to address climate issues due to competing priorities. Just over one in three (31.3%) indicated they have integrated climate change requirements into organizational or corporate health standards. Interestingly, 86% of health authorities indicated that they consider the needs of populations at higher risk when developing adaptation strategies. Far fewer consider implications for Indigenous Peoples (37.3%) or the use of Indigenous knowledge and perspectives in such activities (25.4%). Less than one in five (17.9%) consider sex and gender implications when developing measures to reduce climate change risks to health (Survey Research Centre, 2019).

Broader adaptation actions for health system readiness to prepare for climate change are not yet common among Canadian health authorities. For example, only 31% indicated enhancing emergency plans and programs to increase the resilience of the health system and associated health services to climate change impacts (Survey Research Centre, 2019). In addition, just under a quarter (23.8%) reported providing climate-informed training for public health professionals, and just less than one in five (18.8%) shared information among health service providers to raise awareness of possible climate change impacts on staff and/or infrastructure, and to share examples of adaptation options being undertaken. Current levels of education and

5 The manual is available at <https://www.aqqiumavvik.com/climate-change> or at Arviat Goes Green <https://www.facebook.com/Arviat-Goes-Green-359227010893368/>.

training activities among Canadian health officials are insufficient to provide them with information needed to proactively prepare for climate change impacts on health (Hacket et al., 2020). New information is available for health authorities and health professionals to use to protect high-risk populations from climate change impacts (see Box 10.4), for example, preparing people with spinal cord injuries for more extreme weather events (Shapiro et al., 2020).

Box 10.4 Climate change toolkit for Canadian health professionals

Developed by the Canadian Association of Physicians for the Environment and funded by Environment and Climate Change Canada, the *Climate Change Toolkit for Health Professionals*[6] includes a series of complementary modules designed for health professionals and students in health-related fields who wish to explore the impacts of climate change on health-related issues. The report provides professionals and students with information to help them educate and advocate for programs, practices, and policies required to mitigate GHGs and prepare for climate change, especially as these initiatives affect their workplaces and communities (Perotta, 2019). The report provides evidence-based information on:

- global health impacts of climate change;
- impacts of climate change on Canadians;
- GHG emissions in Canada by sector and region;
- climate change solutions with immediate health benefits;
- action on climate change that can be taken at health care facilities;
- preparation for climate change in communities; and
- engagement in climate change as health professionals.

Information in the toolkit can help health professionals and students in the health care and public health sectors engage with patients, peers, and community partners on climate change issues.

Important limitations of the survey study include the much higher response by health officials in certain regions (Ontario versus the territories and Atlantic provinces) and challenges in accurately identifying officials responsible for climate change and health activities in health authorities.

Another study of public health unit officials in Ontario in 2016 revealed similar results. In particular, 61% of respondents (representing 26 of 36 health units that participated) indicated that they are undertaking activities to raise awareness of climate change impacts on health or of the need to reduce GHGs. As well, 42% reported monitoring climate hazards such as extreme weather, but only 19% indicated they are

6 The toolkit can be accessed at <https://cape.ca/wp-content/uploads/2019/05/Climate-Change-Toolkit-for-Health-Professionals-Updated-April-2019-2.pdf>

monitoring climate change impacts on health. One-half of respondents confirmed being involved in research on climate change and health, with 38% indicating their health units have undertaken a climate change and health assessment. Similar to the national survey, but with somewhat higher proportions, 42% of health units reported using a health equity lens to identify, prioritize, and address climate change health risks (Doyle et al., 2017).

Researchers in Quebec have also examined the level of climate change and health adaptation in that province through the Quebec Observatory for Adaptation to Climate Change. For a number of concrete adaptations that help prepare for climate change impacts, health officials in that province are taking more action. For example, 64% (nine of 14) public health departments offer training to staff on climate change and health. In addition, 67% have developed prevention plans to reduce risks from extreme heat and 56% have done so for floods. However, many public health departments are still in the stages of early adaptation, as they are just beginning to allocate budget specifically to adaptation and to develop collaborations with partners in and outside of the health sector (e.g., school boards, community organizations, Hydro Québec) (Valois et al., 2018).

Many health authorities in Canada have not sufficiently scaled up climate change and health adaptation efforts to protect Canadians from current climate variability and from more severe impacts. Significantly ramped-up efforts are needed to train health care professionals, monitor climate change impacts and the effectiveness of adaptation measures, prioritize adaptation with sufficient resources, educate the public and stakeholders, and integrate considerations and information about higher-risk populations into activities.

10.3.5.2 Health in Climate Change Plans and Strategies

Many jurisdictions, from local to national levels, in Canada have climate change plans or strategies that include adaptation, and a greater number now include actions to protect human health and well-being (Kuchmij et al., 2020). Table 10.4 highlights that most provincial or territorial plans now include some reference to human health impacts. However, there is wide variation in the climate change and health activities by health authorities at all levels. Most Canadian provinces and territories are still in the early stages of adapting to the health impacts of climate change, with responses still being fragmented (Austin et al., 2016).

Currently, few provinces and territories have comprehensive or substantive (e.g., covering a wide range of likely risks to health) actions to address climate change and health adaptation as part of their broader climate change strategies. Few jurisdictions have a separate action plan or strategy that focuses exclusively on climate change and health. Given that analysis in other chapters of this assessment suggest wide-ranging health risks and vulnerabilities in communities across Canada, the lack of comprehensive strategies, and the wide diversity and inconsistency of health adaptation planning among many health authorities, increase the vulnerability of Canadians to current and future projected impacts on health.

Table 10.4 Examples of Canadian climate change strategies, action plans, and reports that include human health

JURISDICTION	STRATEGY/ACTION PLAN/ FRAMEWORK	EXAMPLES OF HEALTH RISKS AND/OR DETERMINANTS OF HEALTH	RECENT ADAPTATION EXAMPLES
Yukon	Our Clean Future: A Yukon Strategy for Climate Change, Energy and Green Economy <https://yukon.ca/sites/yukon.ca/files/env/env-our-clean-future.pdf>	Permafrost melt; food security; cultures; flooding; wildfires; glacier melt; wildlife and aquatic health	Monitoring and planning for the health impacts of extreme events, including wildfires
Northwest Territories	2030 NWT Climate Change Strategic Framework (2018) <https://www.enr.gov.nt.ca/sites/enr/files/resources/128-climate_change_strategic_framework_web.pdf>	Food security; air quality; vector-borne diseases; mental health	Completed a climate change and health assessment
	2030 NWT Climate Change Strategic Framework 2019–2023 Action Plan (2018) <https://www.enr.gov.nt.ca/sites/enr/files/resources/128-climate_change_ap_proof.pdf>	Water quality, wildlife, marine life, forests	Completed emergency evacuation plans for each major territorial health-related facility, and clean air shelter assessments for all but one community to provide safe zones for extreme events such as wildfires
Nunavut	Upagiaqtavut: Setting the Course – Climate Change Impacts and Adaptation in Nunavut (2011) <https://climatechangenunavut.ca/sites/default/files/3154-315_climate_english_reduced_size_1_0.pdf>	Food security; vector-borne diseases; extreme weather events	Niqivut Silalu Asijjipalliajuq “Our Food and Climate Change” initiative to support individual projects related to food security and climate change

JURISDICTION	STRATEGY/ACTION PLAN/ FRAMEWORK	EXAMPLES OF HEALTH RISKS AND/OR DETERMINANTS OF HEALTH	RECENT ADAPTATION EXAMPLES
Assembly of First Nations	National Climate Gathering Report: Drive Change, Leading Solutions <https://www.afn.ca/wp-content/uploads/2021/04/Climate_Gathering_Report_ENG.pdf>	Social determinants of First Nations health; way of life, cultures; mental health; physical health; food security; wildlife health; biodiversity	Discussion and engagement on climate change impacts and needed actions include related to human health
Inuit Tapiriit Kanatami	National Inuit Climate Change Strategy <https://www.itk.ca/wp-content/uploads/2019/06/ITK_Climate-Change-Strategy_English.pdf>	Social determinants of Inuit health; gender-specific health and wellness indicators; cultural and harvesting activities; mental health	Developed a climate change strategy that includes human health
Métis National Council	Métis National Climate Change and Health Vulnerability Assessment (2020)[7]	Social determinants of Métis health; wildfires; flooding; landslides; extreme heat; drought; vector-borne diseases; glacial retreat; sea-level rise; ocean acidification	Completed a climate change and health assessment
Ontario	Ontario Climate Change Strategy (2015) <https://dr6j45jk9xcmk.cloudfront.net/documents/4928/climate-change-strategy-en.pdf>	Heat; air quality; vector-borne diseases; food; water quality; forestry; Indigenous communities	Healthy Environments and Climate Change Guideline (2018) to support the Ontario Public Health Standards: Requirements for Programs, Services, and Accountability

7 JF Consulting. (2020). Metis National Climate Change and Health Vulnerability Assessment. Not publicly available.

JURISDICTION	STRATEGY/ACTION PLAN/ FRAMEWORK	EXAMPLES OF HEALTH RISKS AND/OR DETERMINANTS OF HEALTH	RECENT ADAPTATION EXAMPLES
Ontario (continued)	Preserving and Protecting our Environment for Future Generations (A Made-in-Ontario Environment Plan) (2018) <https://prod-environmental-registry.s3.amazonaws.com/2018-11/EnvironmentPlan.pdf>		
Quebec	Quebec in Action: Greener by 2020 (2012) <http://www.environnement.gouv.qc.ca/changements/plan_action/pacc2020-en.pdf>	Air quality; socio-economic conditions; heat; UV radiation; mental health; vector-borne diseases	A Massive Online Open Course on climate change and health developed and distributed in 2019 along with a book
British Columbia	Preparing for Climate Change (2012) <https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/adaptation_strategy.pdf>	Drought; wildfires	Interactive air quality map that increases understanding of air pollution, including wildfire smoke, and provides advice for reducing risk
	Health Authority Perceptions and Capacity for Action: Health Impacts of Climate Change in BC (2013) <http://bchealthycommunities.ca/health-impacts-climate-change-ha-perceptions/>	Temperature-related morbidity and mortality; natural hazards; air; water quality; food safety and security; zoonotic diseases; extreme heat; sun exposure	

JURISDICTION	STRATEGY/ACTION PLAN/ FRAMEWORK	EXAMPLES OF HEALTH RISKS AND/OR DETERMINANTS OF HEALTH	RECENT ADAPTATION EXAMPLES
British Columbia (continued)	Climate Preparedness and Adaptation Strategy (Draft Strategy and Phase 1 Actions for 2021–2022) <https://engage.gov.bc.ca/app/uploads/sites/568/2021/06/Climate-Preparedness-and-Adaptation-Strategy-2021.pdf>		
Alberta	Focusing on Outcomes: An Action Plan for Climate Leadership Innovation (2018) <https://albertainnovates.ca/wp-content/uploads/2018/02/Action-Plan-for-Climate-Leadership_FINAL_Feb2018.pdf>	Air quality	Climate Change Adaptation Plan to help municipalities learn about climate adaptation, assess how vulnerable they are to events like floods, droughts and severe storms, and build adaptation plans
Manitoba	A Made-in-Manitoba Climate and Green Plan: Hearing from Manitobans (2017) <https://www.gov.mb.ca/asset_library/en/climatechange/climategreenplandiscussionpaper.pdf>	Flood; drought; water quality	Provincial coordination of efforts to reduce risks from extreme heat through a Heat Alert and Response System Advisory Group
Saskatchewan	A Made-in-Saskatchewan Climate Change Strategy (2017) <https://www.saskatchewan.ca/business/environmental-protection-and-sustainability/a-made-in-saskatchewan-climate-change-strategy>	Water quality; vector-borne diseases	Surveillance and public education and outreach on vector-borne diseases (e.g., Lyme disease and West Nile virus)

JURISDICTION	STRATEGY/ACTION PLAN/ FRAMEWORK	EXAMPLES OF HEALTH RISKS AND/OR DETERMINANTS OF HEALTH	RECENT ADAPTATION EXAMPLES
New Brunswick	Climate Change Action Plan 2014–2020 (2016) <https://www.nben.ca/en/cons-pub-climate-change-action-plan?download=2018:new-brunswick-climate-change-action-plan-2014-2020-government-of-new-brunswick-april-2014>	Water quality; extreme weather events; vector-borne diseases	Implemented and supported a provincial HARS with specific heat-alert criteria based on health evidence and region-specific weather patterns
	Transitioning to a Low Carbon Economy: New Brunswick's Climate Change Action Plan (2016) <https://www2.gnb.ca/content/dam/gnb/Departments/env/pdf/Climate-Climatiques/TransitioningToALowCarbonEconomy.pdf>		
Nova Scotia	Toward a Greener Future: Nova Scotia's Climate Change Action Plan (2009) <https://climatechange.novascotia.ca/sites/default/files/uploads/ccap.pdf>	Air quality; water quality	Developed a climate-readiness scan for the Department of Health and Wellness's Continuing Care Sector
Newfoundland and Labrador	The Way Forward on Climate Change in Newfoundland and Labrador (2019) <https://www.gov.nl.ca/ecc/files/publications-the-way-forward-climate-change.pdf>	Travel safety; Lyme disease; mental health; food security; Indigenous communities	Investigated the environmental burden of Lyme disease and introduced new heat advisory criteria for the province

JURISDICTION	STRATEGY/ACTION PLAN/ FRAMEWORK	EXAMPLES OF HEALTH RISKS AND/OR DETERMINANTS OF HEALTH	RECENT ADAPTATION EXAMPLES
Prince Edward Island	Taking Action: A Climate Change Action Plan for Prince Edward Island 2018–2023 (2018) <https://www.gov.nl.ca/ecc/files/publications-the-way-forward-climate-change.pdf>	Climate projections for emergency management; coastal erosion; flooding; infrastructure resilience; water resource management	Province-wide climate change risk assessment to include public health and safety

Source: Adapted from Kuchmij et al., 2020

10.3.5.3 Learning from the Quebec Experience

As a leader on health adaptation, the province of Quebec and its health authorities have been preparing for climate change impacts for almost 20 years (Demers-Bouffard, 2021). A formal requirement to prevent and mitigate the impacts of climate change on public health and safety was included in the Plan d'action sur les changements climatiques (PACC 2006-2012), led by the Quebec Ministère de l'environnement.

In 2012, the Government of Quebec adopted its Plan d'action 2013-2020 sur les changements climatiques (PACC 2013-2020) and the accompanying Stratégie d'adaptation aux changements climatiques 2013-2020, spending $200 million on adaptation (Government of Québec, 2012a; Government of Québec, 2012b). These include several adaptation objectives related to human health, including:

- considering climate change adaptation in land-use planning and other planning decisions;
- reducing risks and mitigating the consequences of disasters related to climate change;
- preventing excess diseases, injuries, and mortality associated with climate change;
- maintaining continuity of health and emergency services during disasters related to climate change; and
- limiting the psychosocial impacts of climate change.

Through this plan, $22 million was allocated to prevent and limit diseases, injuries, mortality, and psychosocial impacts (Demers-Bouffard, 2021). Led by the INSPQ and with the participation of many partners, a range of adaptation and knowledge development measures have been implemented by the existing Quebec health network. These include an observatory assessing the population's level of adaptation to climate change; a multi-stakeholder zoonotic observatory; a weather and health warning and monitoring system; emergency response plans; an allergen-pollens reduction strategy; comprehensive research programs on climate change impacts and adaptations; several dozen urban greening pilot projects; and several knowledge transfer tools (websites, online courses, manuals, toolkits for surveys and evaluations, etc.). For example, the INSPQ, along with other partners, launched a Massive Open Online Course on climate change and health for health and social service professionals and for the general public. Other more targeted training is available for doctors, nurses, park workers, and other professions. The *Mon climat, ma santé* and MSSS websites provide information on the effects of climate change on health, populations at increased risk, and adaptation measures. Detailed clinical guidance is available to physicians for treating illnesses and diseases related to climate change and health in their daily practice (Gosselin et al., 2021).

An evaluation of efforts in Quebec to address climate change impacts on health identified important factors that facilitate such efforts and those that can act as barriers. Factors that supported climate change and health adaptation progress included (Demers-Bouffard, 2021):

- major extreme weather events;
- prioritization of climate change in government planning;
- funding for targeted actions;
- clarity of the roles and responsibilities of each of the stakeholders;
- availability of local climate and population data; and
- identification of external resources to support actions.

Important barriers to protecting health effectively included:

- public health resources being monopolized for other priorities;
- competition with other public health issues;
- organizational focus on the health protection role;
- lack of reliable and consistent funding;
- ambiguity of roles and responsibilities; and
- lack of guidance on the various adaptation measures to be implemented.

Ultimately, political, legal, social, regional, and organizational contexts matter for ensuring that government and regional health authorities can act to adapt to climate change. The political and legal contexts empower the health sector to respond to climate change by providing objectives and resources, while the social and regional contexts influence the development of partnerships and the effectiveness of implementing adaptation measures. The organizational context makes it possible to take advantage of the opportunities provided (Demers-Bouffard, 2021).

10.3.5.4 Individual-Level Health Adaptation

Individual Canadians have a primary responsibility for adapting to the health impacts of climate change by adopting protective behaviours. Educating the public and health professionals about climate change impacts on health is a key function of public health officials, and greater efforts are required to reduce risks (Hathaway &

Maibach, 2018). Efforts in and outside of Canada to communicate climate change risks and get people to take protective behaviours have had mixed success and have faced significant challenges (MacIntyre et al., 2019; Maibach, 2019). Many Canadians are aware of climate change impacts on health and concerned about these impacts. In 2017, a survey of Canadians found that 79% of people reported being convinced that climate change is happening, and, of these, 53% indicated that it is a current health risk and 40% believe it will be a health risk in the future (Environics Research Group, 2017). However, concern about impacts is not translating into the adoption of protective behaviours; large numbers of Canadians are not taking actions to protect themselves, or their family members, from climate change impacts on health, putting themselves at higher risk. For example, the survey in 2017 revealed that (Environics Research Group, 2017):

- 43% of Canadians reported that they had taken steps in the past year to protect themselves and family members against the bite of an infected mosquito or tick (e.g., using insect repellent, wearing long pants and long sleeves, checking for ticks on skin after being outdoors);
- 37% reported that they had an emergency household plan for what to do during a natural disaster or emergency, down from 42% that reported having one in 2008;
- 77% reported that they regularly (51%) or occasionally (26%) check for extreme weather alerts, which is down from 2008 when 81% reported doing so;
- 53% reported that they either regularly (21%) or occasionally (32%) change daily routines as a result of an extreme weather alert; and
- 51% reported ever having taken action or changed plans as a result of hearing a heat warning.

Interestingly, when respondents were also asked a separate, more general question about whether they had taken steps in the past year to protect themselves or family members from the potential health risks or impacts of climate change, only 37% indicated that they had done so. There were very low rates of reported actions for some possible health adaptations, such as watching the weather more closely (5%), installing air conditioning (2%), having an emergency kit/plan (1%), preparing for storms (1%), and being vigilant for ticks on person/pets (1%) (Environics Research Group, 2017). The difference in responses suggests that many Canadians do not associate these measures with interventions that can protect them from climate change health impacts. In addition, some of the responses to this more general question included "better eating habits/gardening," "recycling," "increasing a home's energy efficiency," and "driving less," which are actions to reduce GHGs. Although better home insulation and driving less can help reduce urban heat islands and attendant health risks, there is likely significant confusion among the public of the difference between some GHG mitigation and health adaptation measures.

The media plays an important role in influencing public perception of climate change risks and in influencing behaviours to address climate change (Watts et al., 2018; King et al., 2019). Callison and Tindall (2017) suggested that media coverage of climate change in Canada has tended to focus on national policy making and energy and economic issues, but has often omitted climate justice considerations, including those related to Indigenous Peoples and impacts in the Arctic. A review of climate change impacts on health covered by Canadian newspapers between 2005 and 2015 suggested that coverage over this time period has actually decreased, with greater information being provided to the public on negative climate change impacts on health and significantly less on climate change and health adaptation solutions. In fact, only 26% of the articles reviewed included information on actions that can be taken to protect health (King et al., 2019). The authors suggest that recent trends in media coverage of climate change in Canada may be partly responsible for a lack of public support and actions to address climate change, including preparing for the impacts (King et al., 2019). Adaptation by individual Canadians may also be significantly influenced by constraints on their ability to take protective actions due to existing inequities in society (see Chapter 9: Climate Change and Health Equity).

10.4 Health System Vulnerability and Resilience to Climate Change Impacts

10.4.1 Health System Vulnerability

A range of impacts from extreme weather events and public health emergencies related to climate change can affect health facilities and systems (WHO, 2015; Balbus et al., 2016; Curtis et al., 2017; Ribesse & Varangu, 2019). The ability of these systems to mitigate climate change impacts on populations will be increasingly challenged in the future (Ebi & del Barrio, 2017). For example, cancer care can be disrupted by climate-related disasters that affect infrastructure, communications systems, availability of medications, and medical records (Man et al., 2018). The Lancet Countdown on Health and Climate Change suggested that health systems are unprepared to manage the impacts of climate change. Specifically, it reported that "A lack of progress in reducing emissions and building adaptive capacity threatens both human lives and the viability of national health systems they depend on, with the potential to disrupt core public health infrastructure and overwhelm health services" (Watts et al., 2018, p. 2479). Globally, between 2005 and 2019, an average of 412 health facilities were damaged or destroyed by climate-related disasters annually, and such impacts are increasing (UNDRR, 2019). Many decision makers expect climate change to worsen these risks; a survey of 814 global cities in 2019 indicted that 67% of respondents believed that climate change would seriously affect their public health assets and infrastructure (Watts et al., 2021).

Health care officials, including first responders, can be affected physically and suffer mental health impacts from extreme weather and disaster events. Health infrastructure, such as building envelopes, can be damaged or destroyed by wind storms, floods, wildfires, and extreme heat events. Reduced access to critical support services, including transportation, power, water supply, and telecommunications, can affect the normal operations of a health care facility (Scott et al., 2020; WHO, 2020). Medical and non-medical supplies and services (e.g., medications and medical products, blood services, food, linen and site cleaning, waste disposal storage and services, data management and patient record systems, and sterilization services) can be disrupted by severe weather events in or even outside of Canada. Patient safety can be compromised when access to critical health and clinical services, such as surgery or radiation therapy (Xiu-Gee Man et al., 2018), are reduced or when outpatient services, such as dialysis, are affected.

During disasters, increased hospital admissions and emergency services in health facilities can create stress on operations, particularly where surge capacity is lacking, where there are ongoing requirements for medication or treatment, and when patients are transferred from other affected facilities (Ebi et al., 2017; WHO, 2020). The activation of the emergency plan within the health care facility is a significant undertaking, and health care facilities experiencing climate change-related impacts will incur increased costs (Ribesse & Varangu, 2019).

Climate change is expected to increase future risks to health facility and health system staff, operations, and infrastructure in Canada from a range of hazards (Ribesse & Varangu, 2019). Some hazards, such as flooding, could affect critical health infrastructure, leading to severe health and socio-economic impacts on Canadians (Scott et al., 2020). Scott et al., (2020) examined the risks to health and emergency facilities (e.g., hospitals, long-term care centres, outpatient clinics, community health centres, police, fire) from floods due to river overflow, extreme rain events, and storm surge. Across Canada, 15.2% (17,177) of all health and emergency facilities (112,910) have some exposure to flood hazards, increasing their vulnerability to the impacts of this type of extreme event. Health care services constituted 94% or 16,240 of the health and emergency facilities that are at risk (Scott et al., 2020). In addition, a study of the climate resilience of facilities at Fraser Canyon Hospital in Hope, British Columbia, found that elevated temperatures are already being observed in the buildings. The projected quadrupling of hot days (>30°C) between 2016 and 2050 due to climate change will exceed the capacity of the heating, ventilation, and air conditioning (HVAC) systems to maintain thermal comfort, necessitating retrofits, such as building envelope upgrades and horizontal shading elements above windows (Bartko & Macdonald, 2017).

Discernable effects of climate change on health and on health systems are already evident and will increase in the absence of efforts to address existing vulnerabilities and close the "health adaptation gap" (Martinez et al., 2018; Haines & Ebi, 2019). In the United States, Superstorm Sandy, which struck in November 2012, severely affected health services in New York, with 3.1 billion USD in recovery costs (Health Care Climate Council, 2018). Health facilities in Canada are already being affected by climate hazards (Waddington et al., 2013; Canadian Coalition for Green Health Care, 2019b). Health authorities have reported impacts of climate-related events on the following health facility functions: damage to infrastructure, reduced access to medical supplies and products, reduced access to critical support services (including transportation, power, water supply, and telecommunications), and activation of emergency services (Canadian Coalition for Green Health Care, 2019b).

Table 10.5 provides information on Canadian health facility vulnerabilities to specific climate change hazards. It includes examples of climate-related impacts on health facilities. As there is no comprehensive and centralized surveillance system for monitoring such impacts, these types of impacts are likely significantly under-reported.

Table 10.5 Canadian health facility vulnerabilities to climate change hazards

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Temperature extremes: extreme heat events including longer periods, hotter nights, and high humidity	• Disruption/closure of specific departments (e.g., operating theatres) • Patient transfers • Increased patient admissions • Increased mortality and therefore strain on morgue use	• Patients, staff, and visitors require safe temperatures to maintain good health • Some medical services and procedures (e.g., operating theatres) require temperature and humidity levels to be maintained within specific levels • Warmer temperatures bring increased risk of food-, water-, and vector-borne diseases • Influx of community members to hospitals for use as cooling areas	• **Royal Victoria Hospital, Barrie, Ontario, 2019:** Heat and humidity caused the air conditioning to break down in the older portion of the hospital, forcing the cancellation of 130 non-emergency surgeries, patient transfers, resterilization of medical equipment and linens (CTV Barrie, 2019). • **Nine health regions in Quebec, 2018:** A period of extreme heat resulted in 86 excess deaths reported. Significant increases in hospitalizations, ambulance transports, and emergency admissions observed in several regions. Lack of air conditioning in patient rooms caused concern for patient health (Poitras, 2018). • **Eight health regions in Quebec, 2010:** July 2010 heatwave resulted in a significant increase in emergency department admissions (4%) and 33% increase in death rates for all of the health regions affected. • **Toronto, Ontario, area hospitals, 2002–2010:** A 29% increase in emergency room visits for specific mental and behavioural diseases was observed over a cumulative period of seven days after exposure to high ambient temperature (mean daily temperature of 28°C or higher). • **Regina General Hospital, Regina, Saskatchewan, 2007:** Operating theatre closed for eight days due to high heat and humidity levels.

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Temperature extremes: cold snaps, including ice storms and extreme snowfalls	• Disruption/closure of specific services and departments (e.g., operating theatres) • Patient transfers • Increased patient admissions • Power outages • Staff shortages • Disruption to transportation networks • Shortages of blood supplies	• Influx of community members to hospitals for use as warming areas • Energy systems in health facilities can be affected by cold snaps and ice storms • Winter storms can affect transportation networks vital for the functioning of health care facilities	• **Eastern Health, St. John's, Newfoundland and Labrador, 2020:** Extreme snowfall resulted in the City of St. John's declaring a State of Emergency for eight days. Emergency and urgent services at five health facilities in St. John's were delayed, while all other services at these sites were cancelled for a few days. Closures also included family doctor and specialty clinics, pharmacies, outpatient blood collections, and interruptions in patient services, such as appointments, procedures, and surgeries; some health professionals stayed on the job for 60 hours. • **Sunnybrook Health Sciences, Toronto, Ontario, 2013:** A power grid failure from an ice storm lasted 39 hours. Emergency power enabled continued activity in trauma bays, emergency rooms, and intensive care units. However, some less critical services to patients were affected — medical imaging appointments were cancelled, lab tests were delayed, food delivery to inpatients was delayed, retail food operations were without power, and computer networks and email systems were disrupted. As a precaution, six infants in the Neonatal Intensive Care Unit were relocated to other hospitals. Community members gathered in the hospital for warmth (Canadian Coalition for Green Health Care, 2017).
Flooding caused by extreme rainfall, river flooding, freezing water pipes, and storm surges resulting from hurricanes	• Transfer of patients from affected health care facilities • Staff shortages due to health impacts and disruptions to transportation routes • Boil water advisories • Power outages	• Hurricanes, storm surges, and flooding can damage critical health facility infrastructure and interrupt supply chains for food, water, energy and medical supplies • During weather emergencies, roads may be destroyed or closed to discourage travel	• **Hotel-Dieu of St. Joseph Hospital, Perth-Andover, New Brunswick, 2012:** Flooding by more than 1 m of water led to the temporary closure of the hospital and the transfer of 21 patients to other facilities (Canadian Broadcasting Corporation, 2012; Government of New Brunswick, 2012). Construction of a new essential services building was part of a $7.65 million investment to restore, preserve, and protect critical infrastructure at the hospital (Government of New Brunswick, 2018).

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Flooding caused by extreme rainfall, river flooding, freezing water pipes, and storm surges resulting from hurricanes (continued)	• Disruption/closure of specific departments (emergency, clinics) • Infrastructure damage (roof being torn off due to high winds) • Internal flooding, including basements • Mental health impacts on staff • Shortages of blood supplies • Damage to medical equipment	• Post-event or post-disaster clean-up can reduce or prevent access to health care facilities • Impacts on blood donations by the public • Physical and mental health of health facility staff can be affected by floods	• **Kings County Memorial Hospital, Montague, Prince Edward Island, 2010:** Heavy rain and a malfunctioning roof drainage system resulted in water coming in through the ceiling. The emergency department was shut down, and cases were diverted to the Queen Elizabeth Hospital in Charlottetown (Canadian Broadcasting Corporation, 2010). • **Quebec hospitals around Montréal, Quebec, 2017:** Flooding in the cities of Montréal and Laval resulted in evacuation of three health care centres (Presse Canadienne, 2017). Patients also had to be transferred from a long-term care centre (Canadian Broadcasting Corporation, 2017). The Ministry of Health and Social Services provided psychosocial support services throughout Quebec (Presse Canadienne, 2017). • **Winnipeg Health Sciences Centre, Manitoba, 2014:** Storm rain resulted in basement flooding of the Ann Thomas Building, which housed the medical device reprocessing area. In addition, numerous equipment storage rooms were flooded and patient food services were affected, resulting in service delays for patients and visitors. The incident did not create any surgery delays, given the ability of the department, maintenance, and cleaning crews to work through the night to remove water, repair ceilings, and reprocess supplies (Canadian Coalition for Green Health Care, 2015a).

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Flooding caused by extreme rainfall, river flooding, freezing water pipes, and storm surges resulting from hurricanes (continued)			• **Alberta Health Services Facilities, Alberta, 2013:** Floods resulted in evacuations, isolations, and/or damage to multiple hospitals, urgent care centres, continuing care and long-term care sites, as well as Alberta Health Services corporate, community, emergency medical services facilities, and physician offices (Alberta Health Services, 2013a; Canadian Broadcasting Corporation, 2013; MNP LLP, 2013; United Nurses of Alberta, 2013; Alberta Health Services, 2014; Watts, 2014). More than 1000 patients were evacuated in the Calgary Zone in the first 24 hours (Alberta Health Services, 2013b). Staff were displaced from places of work, and many had their own homes damaged or destroyed (Watts, 2014). A number of flood-related boil-water orders were issued across the province (Alberta Health Services, 2013a). Mobile mental health teams were dispatched to High River to facilitate access to services and provide mental health support (Alberta Health Services, 2013b). • **Hurricane Maria, Puerto Rico, U.S., 2017:** Hurricane Maria caused global shortages of medical supplies. The destructive forces of hurricanes can have a dual impact on health care facilities — first, they have physical impacts on the local facilities and the resources they require (Panditharatne, 2018), and, second, they can have an impact on global supply chains for medical products (GEP, 2017; Kodjak, 2017). Widespread devastation of the critical infrastructure, including power and water supplies, resulted in manufacturing challenges (GEP, 2017; Kodjak, 2017). Puerto Rico is home to over 50 medical device manufacturers and over 80 pharmaceutical manufacturers (GEP, 2017) that supply products to Canadian hospitals.

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Extreme winds, including those caused by tornadoes and hurricanes	• Interruptions to information technology and communications • Transfer of patients from affected health care facilities • Staff shortages due to health impacts and disruptions to transportation routes • Increase in admissions • Boil water advisories • Disruption/closure of specific departments (emergency, clinics) • Infrastructure damage (roof being torn off due to high winds, basement flooding) • Mental health impacts on staff • Shortages of blood supplies • Power outages	• Tornadoes can damage critical health facility infrastructure and interrupt supply chains for food, water, energy, and medical supplies • During weather emergencies, roads may be destroyed or closed to discourage travel • Post-event or post-disaster clean-up can reduce or prevent access to health care facilities • Physical and mental health of health facility staff can be affected by severe storms	• **Nova Scotia Health Authority, Nova Scotia, 2019:** Hurricane Dorian generated high winds, causing power outages at many hospitals and service locations, which had to operate on emergency generator power. Some sites experienced additional impacts, including phone, internet, and network issues; water damage; temporary closures; and cancellation of patient appointments and procedures (Nova Scotia Health Authority, 2019a; Nova Scotia Health Authority 2019b). • **Victoria General Hospital, Halifax, Nova Scotia, 2003:** High winds from Hurricane Juan created power outages and tore off parts of the hospital roof, requiring the evacuation of 51 patients. The event left the entire health care system with a backlog of hundreds of operations and appointments. Transportation issues complicated the work of Emergency Health Services, and Public Health Services were concerned with monitoring food and water safety and the possible spread of communicable diseases (Globe and Mail, 2003; Nova Scotia, 2003). • **Memorial Hospital, Sudbury, Ontario, 1970:** Tornado winds in the city resulted in six deaths, 200 injured, and hundreds left homeless. The winds ripped off the roof of a partly completed wing of the Memorial Hospital (Commito, 2018).

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Wildfires	• Transfer of patients from affected health care facilities • Staff shortages due to health impacts and disruptions to transportation routes • Boil water advisories • Disruption/closure of specific departments due to air contamination (e.g., emergency, clinics) • Infrastructure damage (roof torn off by high winds, basement flooding) • Mental health impacts on staff • Shortages of blood supplies	• During wildfires, roads may be destroyed or closed to discourage travel • Post-event or post-disaster clean-up can reduce or prevent access to health care facilities • Physical and mental health of health facility staff can be affected by wildfires	• **Interior Health, British Columbia, 2017:** Wildfires resulted in air quality warnings due to very high health risk from the smoke, and in the temporary closure of 19 health care facilities or sites. Additionally, 880 patients were evacuated from facilities, and more than 700 health services staff displaced, with a total cost to the health authority of $2.7 million. Many patients were evacuated to neighbouring Northern Health facilities, straining health care resources in Kamloops and Prince George (Canadian Healthcare Facilities, 2017; Interior Health, 2017). • **Northern Lights Regional Health Centre, Fort McMurray, Alberta, 2016:** A wildfire resulted in 73 acute care patients, including nine babies in the neonatal unit and their mothers, and 32 continuing care patients who were wheelchair-bound, being moved to three different reception areas outside Fort McMurray via ambulances and buses (Warr, 2016). Alberta Health Services reserved 92 hotel rooms in Edmonton for the health care workers attending to these patients. Other impacts on the hospital included smoke damage and air quality concerns (Drinkwater, 2016; KPMG, 2017).
Landslides and avalanches	• Interruptions to information technology and communications • Transportation routes blocked	• Medical operations are postponed	• **British Columbia, 2020:** Rockslides after heavy rain damaged cell towers, which caused widespread disruptions to phone service across British Columbia, including communications with health care staff (Boynton, 2020).

CLIMATE HAZARD	POTENTIAL IMPACTS ON HEALTH FACILITY	EXAMPLES OF VULNERABILITY/ RISK FACTORS	EXAMPLES OF IMPACTS ON CANADIAN HEALTH FACILITIES
Melting permafrost	• Building infrastructure destabilized • Transportation routes (including airstrips) built on permafrost are unstable; winter ice roads less reliable • Damage to pipelines and power lines	• Health care facilities and other health system buildings require stable ground	• **Canadian Arctic:** Rising temperatures in the Far North are melting permafrost, requiring a number of health care facility buildings to be structurally supported with thermosyphons to prevent them from sinking (Holubec, 2008).

Source: Adapted from Balbus et al., 2016, with data from the Canadian Coalition for Green Health Care, 2020

Climate impacts are not all acute events. Impacts can be less drastic and longer-term, but such cumulative impacts can also be significant. More frequent rainfall or gradual increase of day- and night-time temperatures and humidity levels can strain the physical plant (i.e., air conditioning and ventilation systems) while increasing the need for health services (i.e., more patients with heat stress). As another example, permafrost melt in Canada's Far North is damaging the foundations of some medical clinics, and continued warming will require remediation to prevent further damage to these structures (Holubec, 2008). Permafrost maps were developed for health authorities in Nunavik to guide future decisions about planning new buildings and renovating those at structural risk by thawing (L'Hérault et al., 2013).

Climate hazards can also combine, or cascade, as happened in Dunrobin, Ontario, which was affected by record flooding in 2017, devastating tornadoes in 2018, and further severe flooding in 2019. Similarly, flooding in Japan in 2018 killed more than 200 people and was followed during the clean-up efforts less than a month later by record-breaking extreme heat that resulted in at least 30 deaths and 10,000 hospital admissions (ABC News, 2018). Whether acute climate shocks or chronic stresses, climate impacts will require health systems to respond and adapt (Ebi et al., 2018b).

Impacts on health systems in Canada can be very severe, as was the case with the 2013 Southern Alberta floods, when some hospitals were forced to close, patients were evacuated, and significant infrastructure damage occurred (MNP LLP, 2013; Roles, 2013). The catastrophic wildfires in British Columbia in 2017 and 2018 also resulted in facility closures, patient transfers, and major disruptions to care (Legassic, 2018). Climate events can have disproportionate impacts on Indigenous communities. For example, almost 2000 people displaced from four First Nations communities in Manitoba after extensive flooding in 2011 were still unable to return to their homes in 2017 (Lambert, 2018).

A major challenge facing health systems in Canada from climate change are possible surprises or unexpected hazards, events, or developments; these present new or much more severe threats to the health of Canadians or to health systems. For example, significant uncertainty exists about the impacts of climate change on human migration, and very little research has been conducted in the Canadian context. However, some evidence suggests that climate change could lead to large movements of populations seeking respite from climate-related disasters and other impacts. A U.S. National Intelligence Council study warned that climate change will continue to threaten the stability of many countries through climate-induced disruptions that can overwhelm response capacity (NIC, 2016). Missirian and Schlenker (2017) suggest that, under a high emissions scenario, the European Union could see annually an additional 660,000 asylum applications by the end of the century, a 175% increase from the present day.

Evidence suggests that many health facilities — a critical component of health systems in efforts to reduce climate change impacts — are not taking needed actions to prepare for current risks and future warming. A survey of health care facility staff, such as facility directors or managers, sustainability coordinators, and energy managers, representing 102 facilities, was undertaken by the Canadian Coalition for Green Health Care in 2019 through the Green Hospitals Scorecard questionnaire (Canadian Coalition for Green Health Care, 2019b). The respondents were primarily located in Ontario but also at some facilities in British Columbia, Manitoba, and Nova Scotia. The survey revealed that health authorities are recognizing climate change as an issue of concern, and some are taking adaptation measures. For example, 55% reported that senior leadership had assigned at least one person with some climate change responsibility in their health authority. However, only a small percentage of health care facilities (8%) had acknowledged climate change in their strategic plan or had identified climate risks in specific policies. A smaller number of facilities (4%) reported that the impacts of climate-related events, such as flooding and severe weather events, had been recognized in other ways. In addition, almost one-third (27%) of facilities had not recognized climate change as an issue of concern, and 10% responded that they did not know whether it was an issue of concern (Canadian Coalition for Green Health Care, 2019b).

Awareness of the need to examine the possible impacts of climate change on health facilities is relatively new. Therefore, few health facilities in Canada have undertaken assessments of vulnerability or have a good understanding of what vulnerability assessments would entail. Of the health care facility staff respondents (99 respondents), 9% reported having completed resilience assessments, while only 4% had completed vulnerability assessments (Canadian Coalition for Green Health Care, 2019b).

Use of on-site renewable energy systems can improve the resilience of the health care facility during grid-based power outages and reduce the generation of GHGs from the use of fossil fuels. Just over a quarter (27%) of health care facilities reported that they currently had some form of renewable energy in place, with many reporting multiple types of systems (100 participants provided multiple responses for a total of 245) (Canadian Coalition for Green Health Care, 2019b). Of the renewable energy systems currently in place, photovoltaic systems are currently the most popular (9%), followed by deep lake cooling (4%), with other numerous renewable energy system types at much smaller numbers. The potential growth of renewable energy systems in the future is significant, with 46% hoping to implement some renewable energy options in the future (Canadian Coalition for Green Health Care, 2019b). The renewable energy types of highest future interest are photovoltaic systems (45%), geothermal systems (14%), deep lake cooling (13%), and solar hot water (12%) (Canadian Coalition for Green Health Care, 2019b).

Given that the health system and health facilities are the first and last defence from climate change impacts on the health of Canadians, the limited number of existing efforts to build health facility resilience across Canada and educate and train health officials suggests ample opportunity to reduce existing vulnerability to health impacts.

10.4.2 Economic Impacts of Climate Change Effects on Health and Health Systems

When climate change increases mortality or morbidity, there is a loss of welfare to society and forgone income and/or wealth creation. Climate change may also disrupt labour productivity, educational attainment and other determinants of health, eroding economic output and future potential. Although limited evidence is available, climate change-driven impacts to various economic sectors (e.g., resource extraction) may disrupt future government revenues, including those that fund health and social services. In addition, more illnesses, injuries, and disease may increase stresses and costs to health systems and result in general impacts on economic productivity, with more sick leave and absenteeism (Campbell-Lendrum et al., n.d.; Martinez et al., 2018). To manage growing health risks effectively, decision makers need to know the following information about adaptation options: (1) the economic costs of climate change impacts on health in the absence of interventions; (2) the costs of implementing adaptation actions to protect health, including measures in and outside of the health sector; and (3) the costs of health impacts that are residual or that still occur after actions are taken (Campbell-Lendrum et al., n.d.).

There is a paucity of information about the economic costs of current climate variability and projected climate change on the health of individuals and on health systems internationally (Hutton & Menne, 2014; Martinez et al., 2018) and in Canada (Berry et al., 2014a). However, climate change is expected to result in tangible and significant economic costs to health systems and broader society (Kovats et al., 2011; Watkiss, 2015; Ebi et al., 2017).

Projections of future economic costs of climate change on health are uncertain and vary widely, depending on availability of data and methods used. The WHO has projected that a narrow range of direct climate change impacts on health would result in economic costs of 2 billion to 4 billion USD by 2030 (WHO, 2018b). Another study, with a broader set of health outcomes and including indirect costs, suggested that European Union countries alone might expect health costs between EUR 9 billion and 106 billion for the period 2041–2070 (Ciscar et al., 2014). In the United States, one study estimated the health costs of 10 climate-sensitive events that struck in 2012, including heatwaves, hurricanes, wildfires, flooding, outbreaks of infectious diseases, and ozone pollution. The total cost was at least 10 billion USD, related to 900 deaths, 21,000 hospitalizations, 18,000 emergency room visits, and 37,000 outpatient visits (Limaye et al., 2019). The very severe wildfires in Washington and Colorado in that year resulted in 419 deaths and 627 hospital admissions, for a total cost of 3.9 billion USD (Limaye et al., 2019).

Recent research in Quebec suggested that, from 2015 to 2065, the projected costs of the increase in health effects of ragweed allergies due to climate change are $360 million for governments in that province and $475 million for society as a whole. For extreme heat, the study estimated costs of $370 million for governments and over $33 billion for society. In addition, increases in Lyme disease due to climate change are projected to cost governments $60 million to $95 million, depending on the level of public health preparation (Larrivée et al., 2015).

The health care costs will not be borne evenly among the population. For example, evidence suggests that the most vulnerable in society bear disproportionate health care costs from the impacts from extreme heat (Wondmagegn et al., 2019). Box 10.5 describes the health system impacts and economic costs of recent severe wildfire seasons in British Columbia.

Box 10.5 Impacts of the 2017 and 2018 wildfires on health systems in British Columbia

The 2017 and 2018 wildfire seasons in British Columbia were two of the worst seasons on record. In 2018, 2117 fires consumed 1,354,284 ha of land, with a total cost of fire suppression of $615 million (Government of British Columbia, 2019). The 2017 fires resulted in the evacuation of 65,000 people and a provincial state of emergency lasting 70 days (July 7 to September 15) (Government of British Columbia, 2019). Fortunately, there were no deaths reported from the fires. However, significant impacts were felt by health systems in efforts to protect people. For example, the 2017 wildfires affected 19 health facilities or sites in the Interior Health Authority and resulted in 880 patients being evacuated and 700 health services staff being displaced, costing the health authority an estimated $2.7 million (Toews, 2018). These fires also resulted in more than 10,000 evacuees being received by the Northern Health Authority, resulting in over $4.5 million in health service delivery costs (Northern Health, 2018a; Northern Health, 2018b).

In 2018, a number of communities in the Northern Health Authority had to be evacuated because of wildfires, including the pre-emptive transfer of patients from the Stuart Lake Hospital in Fort St. James (Northern Health, 2018b). The region suffered from wildfires and the associated smoky conditions much of the summer, but the experience gained by Northern Health's staff in supporting Interior Health during the 2017 wildfires helped the health authority prepare for and respond to wildfires the following year (Northern Health, 2018c). The value of this experience highlighted the role that staff exchanges, knowledge translation, and inter-organizational collaboration can have in building climate resilience.

Some of the costs to health and health care systems from climate change are avoidable through adaptation, but these actions often require upfront development and subsequent maintenance costs. Greater research is needed on the costs and benefits of various adaptations to reduce risks to Canadians from extreme heat and other climate change hazards.

10.5 Climate-Resilient Health Systems

Because of the increasing severity and frequency of climate-related emergencies and disasters, health authorities need to prepare health and emergency services to be able to respond during such events (UNDRR, 2015; Watts et al., 2018; WHO, 2018c). Strengthening health systems is a "no-regrets" strategy that can reduce climate risks while also protecting health from other global challenges, such as pandemics (Banwell et al., 2018). Human health and well-being are most effectively protected from the impacts of climate change when health authorities take measures to increase the climate resilience of whole health systems (WHO, 2015; WHO, 2018c; Ebi et al., 2019). The "health system" refers broadly to the organizations of people, institutions, and resources that work to protect and promote population health (Ebi et al., 2019), encompassing health care planning, facilities, and services as well as traditional public health functions (e.g., health promotion through social participation and empowerment; disease surveillance and response; emergency preparedness; health research; and health information systems) (WHO, 2015). A climate-resilient health system has the capacity to monitor, anticipate, manage, and adapt to the health risks of climate change to maintain efficiencies and the ability to improve population health, and to reduce inequities and vulnerabilities as climate change impacts increase (WHO, 2015) (Figure 10.3).

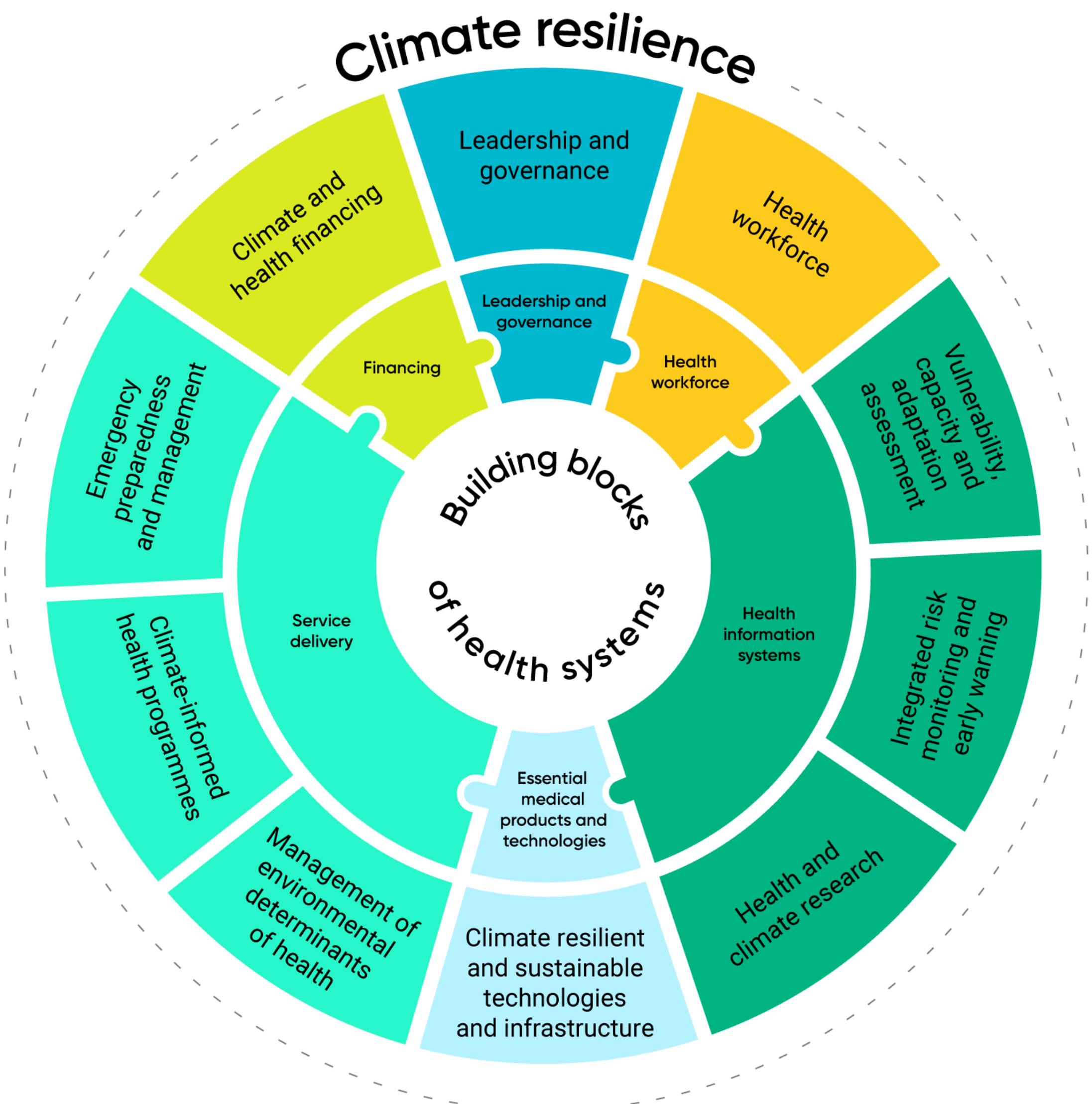


Figure 10.3 Ten components comprising the WHO operational framework for building climate-resilient health systems. Source: WHO, 2015.

Currently, a number of health authorities in non-governmental organizations, bilateral agencies, and national and subnational ministries of health are using the WHO Operational Framework to build the capacity and information base to mainstream climate change into health policies and programs (Ebi et al., 2019).

There is greater recognition among health authorities that health facilities play a critical role in protecting people from the impacts of climate change, given that they are the last resort for treating illnesses and injuries (WHO, 2015; Balbus et al., 2016; Miller et al., 2018). Health facility officials, and broader health systems, can prepare for climate change impacts and reduce risks from current hazards by (Balbus et al., 2016; WHO & World Bank, 2018; Ribesse & Varangu, 2019):

- developing initiatives to become more climate resilient, including adapting policies and processes as needed to meet challenges of the changing climate;
- leading by example by reducing GHG emissions while promoting sustainability in the entire medical supply chain;
- making health care facilities safer and more environmentally sustainable;
- training health personnel to recognize and understand the effects of climate change; and
- encouraging health personnel to advocate and act to reduce the carbon footprint and build resilience.

Health systems in Canada have an opportunity to contribute to efforts to slow climate change while increasing resilience to the impacts (Miller et al., 2018). Challenges to adapting to the effects of climate change will be much greater without stronger measures to reduce GHGs (IPCC, 2014). Preparing Canadians for climate change impacts on health requires robust knowledge of risks to health facilities and health care services in the context of broader vulnerabilities facing communities and populations at higher risk. Investigations of health facility vulnerability can provide useful data, including estimates of current and future climate resilience of buildings and clinical services, and information on patient admissions, to understand the needs for improving patient care during climate-related emergencies. For example, Haines and Ebi (2019) suggest that efforts to modify current health policies and measures to protect health from climate change must consider needed adjustments to new building codes and to the optimal location of new buildings, including health facilities, to reduce risks from impacts associated with rising temperatures and flooding.

New assessment tools and methods exist to help officials in health care facilities in Canada undertake studies that gauge their resilience to climate change impacts and inform actions to increase their sustainability (Balbus et al., 2016; Ribesse & Varangu, 2019; BC Health Authorities, 2020). For example, in partnership with Health Canada, the Canadian Coalition for Green Health Care developed a Health Care Facility Climate Change Resilience Checklist (Paterson et al., 2014) that poses questions on emergency management, facilities management, health care services, and supply chain management. The Coalition also delivered a Climate Change Resilience Mentoring Program, which included online learning resources.

In addition, a process to assess the vulnerability of infrastructure to climate-related impacts, known as the Public Infrastructure Engineering Vulnerability Committee protocol, was developed by Engineers Canada in partnership with Natural Resources Canada. This tool guides a review of past climate information to project the nature, severity, and probability of future climate-related events and the impacts of these events on infrastructure, in terms of deterioration, damage, or destruction, to identify higher-risk components (PIEVC, n.d.). This process was applied to the Nanaimo Regional General Hospital in British Columbia, and the report provided information to prioritize components requiring adaptation, as well as to understand the best ways of adapting them, through design adjustments or changes to operational and/or maintenance procedures (RDH Building Science, 2018).

Most local to national vulnerability and adaptation assessments for climate change and health that have been completed in Canada have not examined, or have not included in detail, information on risks and vulnerabilities facing health facilities and adaptation options (Séguin, 2008; Gosselin, 2010; Berry et al., 2014a; Berry et al., 2014b; Levison et al., 2018). Future assessments would benefit from examination of climate change risks to health facilities and the engagement of representatives from the health care sector (Ebi et al., 2018b; Ribesse & Varangu, 2019). In British Columbia, a study by the Fraser Basin Council in 2016 found that a very severe coastal flood (currently a once in 500-year event) could affect three wastewater treatment facilities and 15% of health care facilities, including three hospitals, while displacing approximately 238,000 people (Fraser Basin Council, 2016).

Climate change and health stress-testing of health facilities and other critical parts of the health system can be undertaken as part of broader assessments of disruptive climate-related shocks and stresses that could overwhelm the capacity to respond to these events. Health authorities can use hypothetical scenarios and simulation exercises in workshop settings to learn about possible resilience tipping points affecting facilities to develop and implement appropriate adaptation measures (Ebi et al., 2018b). Stress-testing exercises have been undertaken to examine the resilience of hospitals in Vancouver Coastal Health Authority, British Columbia (Lower Mainland Facilities Management, 2020). Integrating health facility considerations and information in assessments supports broader community preparedness for climate change impacts, given the importance of transportation, power, water, and wastewater services to hospitals during emergencies and the critical role these facilities play in reducing climate-sensitive injuries, illnesses, and diseases in communities (Ribesse & Varangu, 2019).

Resilience indicator categories for health care facilities in Canada that may be used in assessments have been proposed using the WHO Operational Framework (Table 10.6) (Canadian Coalition for Green Health Care, 2018).

Table 10.6 Proposed climate resilience indicator categories for health care facilities in Canada

PROPOSED HEALTH CARE FACILITY FRAMEWORK COMPONENTS	PROPOSED HEALTH CARE FACILITY RESILIENCE INDICATOR CATEGORIES
Leadership and governance	• Executive responsibility for climate change
Health workforce	• Staff awareness and knowledge of climate impacts on health and the health system and of clinical interventions • Workforce preparation for and support during climate events • Readiness to communicate internally and externally on climate change • Coordination and collaboration on climate change with outside agencies
Vulnerability, capacity, adaptation, and resilience assessment	• Identification of vulnerabilities to climate change by health care facility • Resilience assessment used to develop Health Care Facility Resilience Plan • Participation in vulnerability and adaptation assessments with local public health and community organizations • Capacity-building plans to address gaps in human resources and institutional capacity
Risk monitoring and early warning	• Early warning systems and other tools for extreme weather events and climate-sensitive diseases
Health and climate research	• Climate change health research at health care facility
Climate-resilient and sustainable supply chain and supporting logistics	• Sustainability and resilience to climate-related impacts considered in selecting products and services

PROPOSED HEALTH CARE FACILITY FRAMEWORK COMPONENTS	PROPOSED HEALTH CARE FACILITY RESILIENCE INDICATOR CATEGORIES
Climate-resilient and sustainable facility infrastructure	• Assessment of health care facility's impact on environment, including carbon emissions • Climate-related impacts included in scoping new construction and development • Use of new technologies to address GHG mitigation, resilience, adaptation, and emergency management • Health impact assessments for new mitigation and adaptation initiatives
Health facility service delivery[8]	• Staff awareness of climate impacts on health and the health system • Workforce preparation for and support during climate events • Readiness to communicate internally and externally on climate change • Coordination and collaboration on climate change with outside agencies • Staff awareness of climate impacts on health and the health system • Early warning systems and other tools for extreme weather events and climate-sensitive diseases • Sustainability and resilience to climate-related impacts considered in selecting products and services
Emergency preparedness and management	• Emergency management and continuity plan that has a climate change lens and includes actions that anticipate, respond to, cope with, recover from, and adapt to climate change • Emergency management and continuity plan based on stakeholder engagement and collaboration, with community input, buy-in, and approval
Climate and health funding	• Resources available and allocated to increase resilience, environmental sustainability, low-carbon mitigation, and adaptation
Source: Adapted from Canadian Coalition for Green Health Care, 2018	

8 Resilience indicators are shared with other categories.

Many health sector officials are willing to take actions to prepare health facilities for climate change threats when they have the required information about current and future climate change impacts and vulnerabilities. A snapshot of the types of actions that health care facilities in Canada have undertaken following a climate change resilience assessment was obtained from surveys of participants in the Health Care Facility Climate Change Resilience Mentoring Program (2016–2019). A total of 31 participants from 21 health care facilities took part in this program, with 13 participants from Ontario-based health care organizations, and others from British Columbia, Manitoba, and New Brunswick (Canadian Coalition for Green Health Care, 2019a). The majority (77%) of survey respondents implemented resilience practices in their facilities. These included sharing climate-related assessment reports with colleagues; undertaking infrastructure and equipment upgrades; exploring renewable energy options; instituting new response codes for climate-related impacts; undertaking vulnerability assessments; updating contingency/disaster plan(s) and disaster preparedness supply lists; and providing advice to patients on how to stay safe in extreme heat. Many of the participants also began a discussion of climate change with senior leaders. The reported primary barriers to undertaking climate change resilience assessments were a lack of support from senior leaders and a lack of funds and resources (Canadian Coalition for Green Health Care, 2019b).

Box 10.6 Health care facility resilience to climate change: Nanaimo Regional General Hospital in British Columbia

The Nanaimo Regional General Hospital in British Columbia has recognized the importance of preparing for future climate risks by renovating its 247-bed facility for resilience. The hospital, originally constructed in 1960 to 1963, underwent numerous renovations and added a new emergency department in 2012 to sustainably mitigate risk in the event of an extreme weather event, and meet the demands of serving central Vancouver Island's 160,000 residents and an additional 400,000 referrals (Canadian Coalition for Green Health Care, 2015b).

To reduce energy costs while also lowering GHG emissions, the building's design incorporates several sustainability measures. During daylight hours, the majority of the building relies extensively on the use of day lighting and natural light from windows and courtyards, even in the trauma room, while operable windows allow for natural ventilation (Canadian Coalition for Green Health Care, 2015b). This decreases the reliance on electricity and allows for redundancy in the case of an emergency to improve patient outcomes and reduce staff stress. The building's heat recovery chiller features a below-ground labyrinth for heat storage, which can be used to pre-heat domestic hot water and to provide heating to exterior zones if needed, such as during an extreme weather event. Other measures include displacement ventilation, wood products associated with lower GHG emissions, extra roof insulation, solar shading, and digital controls (Canadian Coalition for Green Health Care, 2015b).

Major cost savings may accrue to health care facilities that take actions to prepare for climate change. A study examining a scenario in which a hospital in the United States invested in climate resilience found that it would have stayed operational during a hypothetical strike by a major hurricane, avoiding a revenue loss of 10% (estimated for a facility that did not prepare). It would also have experienced a 5% increase in costs due to minor repairs (versus a 20% increase for an unprepared facility) and saved an overall $100 million thanks to its climate adaptation actions (Health Care Without Harm, 2018).

10.6 Health Co-Benefits of Adaptation and GHG Mitigation Measures

Because GHG mitigation and a range of adaptation measures have the potential to make great strides in advancing population health, the Lancet Countdown on Health and Climate Change suggested that "tackling climate change could be the greatest global health opportunity of the 21st century" (Watts et al., 2015). Well-designed approaches to addressing climate change that engage a wide range of sectors (e.g., energy, water, housing, urban planning, transportation, insurance, agriculture, and food systems) through a "health-in-all-policies" approach[9] can result in very large immediate and long-term health co-benefits and cost savings to the health system (Haines et al., 2009; Friel et al., 2011; Jarrett et al., 2012; Cheng & Berry, 2013; Springmann et al., 2016; NASEM, 2018; WHO, 2018b; Hamilton et al., 2021). For example, GHG mitigation and adaptation efforts that significantly reduce fossil fuel use (e.g., changes to the design of transportation infrastructure in communities to improve thermal comfort; use of low-emission vehicles; promotion of active and public transportation) also improve air quality by reducing fine particulate matter, including black carbon and tropospheric ozone; these efforts can have multiple co-benefits, including reductions in cardiovascular and respiratory diseases (see Chapter 5: Air Quality). Greening communities to cool them can also have multiple knock-on health benefits, such as reducing chronic diseases and improving mental health (Health Canada, 2020a), as can other measures to make communities more livable, such as walking and biking paths (Green et al., 2018). These measures can also have positive impacts by reducing social isolation and crime in some neighbourhoods (Beaudoin & Levasseur, 2017). The Government of Canada committed to considering health co-benefits, such as reduced air pollutant emissions, when developing policies and measures to reduce GHG emissions (Government of Canada, 2016).

9 The health-in-all-policies approach requires decision makers in all sectors to integrate human health considerations and information into the development of policies and programs (PHAC, 2017).

Box 10.7 Decision support tool to transform the built environment for healthier communities

Public health officials and urban planners require information in order to design or modify the built environment in communities for the dual goals of reducing GHG emissions and benefiting human health. Developed for application in England, the Impacts of Cycling Tool (ICT)[10] allows users to visualize travel patterns and analyze various scenarios for the adoption of cycling behaviours. It provides an open-source model with a web-based interface that supports visualization of individual and trip-level data, based on the English National Travel Survey, 2004–2014. Users can compare scenarios based on modelled increases in the proportion of the population who cycle regularly and then estimate likely impacts on travel patterns, health, and GHG emissions. The ICT also enables users to investigate the likely outcomes of scenarios with a more equitable uptake of cycling behaviours (based on age and gender categories) than the profile of current cyclists (Woodcock et al., 2018).

The value of possible health co-benefits of actions is very large. Non-communicable diseases are estimated to cost $68 billion in health care spending per year (PHAC, 2011 as cited in Chronic Disease Prevention Alliance of Canada, 2017), while insufficient physical activity has been estimated to cost the health system $2 billion in direct treatment costs (Janssen, 2012). Therefore, relatively modest reductions in these diseases through efforts to achieve health co-benefits could reap large cost savings. In the United States, it has been estimated that clean-energy policies to reduce GHGs consistent with the Paris Agreement target could result in lower particulate matter and ozone levels, preventing 175,000 premature deaths by 2030 and approximately 22,000 deaths each year into the future (Shindell et al., 2016). A similar global analysis of health co-benefits from 2020 to 2100 in urban centres included calculations for Toronto (11,000 avoided deaths) and Montréal (4000 avoided deaths) (Shindell et al., 2018). In addition, a health-impact analysis conducted for the introduction of Tier 3 vehicle and fuel standards in Canada in 2015 estimated that, by 2030, the resulting air quality improvements would prevent 1400 premature deaths, almost 200,000 days of asthma symptoms, and 2.8 million days of acute respiratory problems, with cumulative health and environmental benefits of $7.5 billion (Government of Canada, 2015). Figure 10.4 provides an overview of potential health co-benefits and risks associated with a range of GHG mitigation sectors and measures.

10 The tool is available at <http://www.pct.bike/ict>.

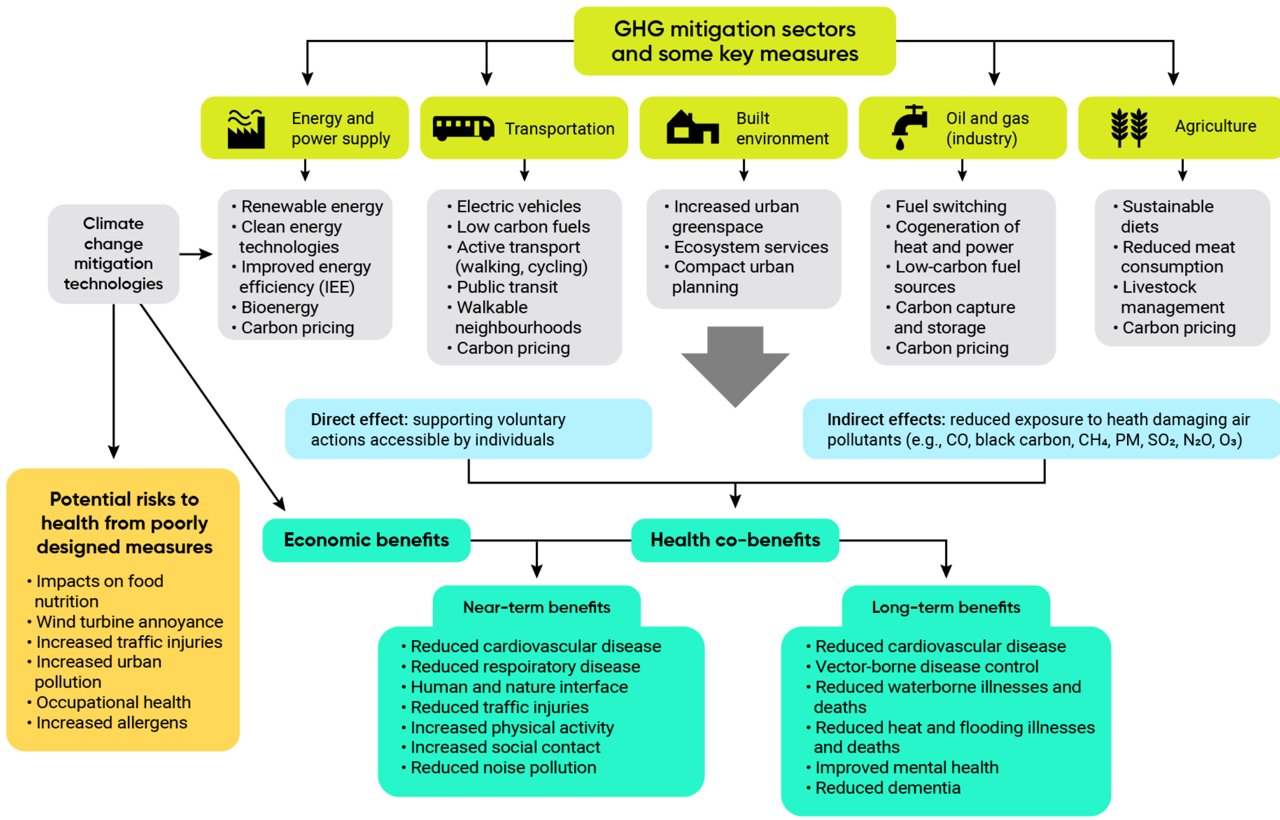


Figure 10.4 Potential health co-benefits and risks of GHG mitigation measures. Source: Adapted from Luehr, 2018.

Adaptation and GHG mitigation measures that do not consider human health implications can lead to negative health outcomes among the population, thus eroding climate resilience (Haines et al., 2009; Haines & Ebi, 2019). They may also lead to greater health inequities in the population, increasing the vulnerability of individuals and communities to future climate change (see Chapter 9: Climate Change and Health Equity). For example, a number of features of neighbourhoods can worsen health equity, including (PHAC, 2017):

- lack of transportation options;
- limited access to healthy food, housing, and health care;
- lack of parks and recreation facilities;
- empty buildings and vacant lots;
- poor air or water quality;
- lack of safety and higher crime;
- increased social isolation; and
- residential segregation.

Compared with GHG mitigation, there has been significantly less study of the potential health co-benefits and risks of climate change adaptation measures (Cheng & Berry, 2013). Health officials are recognizing the need for a systems-based approach to address climate change through GHG mitigation and adaptation; such an approach requires active and purposeful collaboration with other sectors, assessment of local vulnerabilities and capabilities, and the co-design of policies and programs based on this information (Ebi et al., 2016a; Ebi et al., 2016c). Efforts to achieve health co-benefits in the health sector by reducing GHGs and increasing climate resilience through adaptation offer a triple dividend for Canadians, specifically by (1) helping to make patients, staff, and communities safer during climate-related disasters and emergencies, (2) contributing to the slowing of climate change through the reduction of GHGs, and (3) achieving economic savings at health facilities that undertake adaptation efforts. The potential benefits are very large; in 2014, there were 798 hospitals across Canada with approximately 90,000 beds (CIHI, 2018). Health care facilities (particularly hospital campuses) have the highest intensity of energy use of all commercial and institutional buildings in Canada, and direct emissions increased between 2009 and 2015 at double the rate of the national average (Ribesse & Varangu, 2019). Figure 10.5 illustrates examples of features of low-carbon and resilient health care systems that overlap.

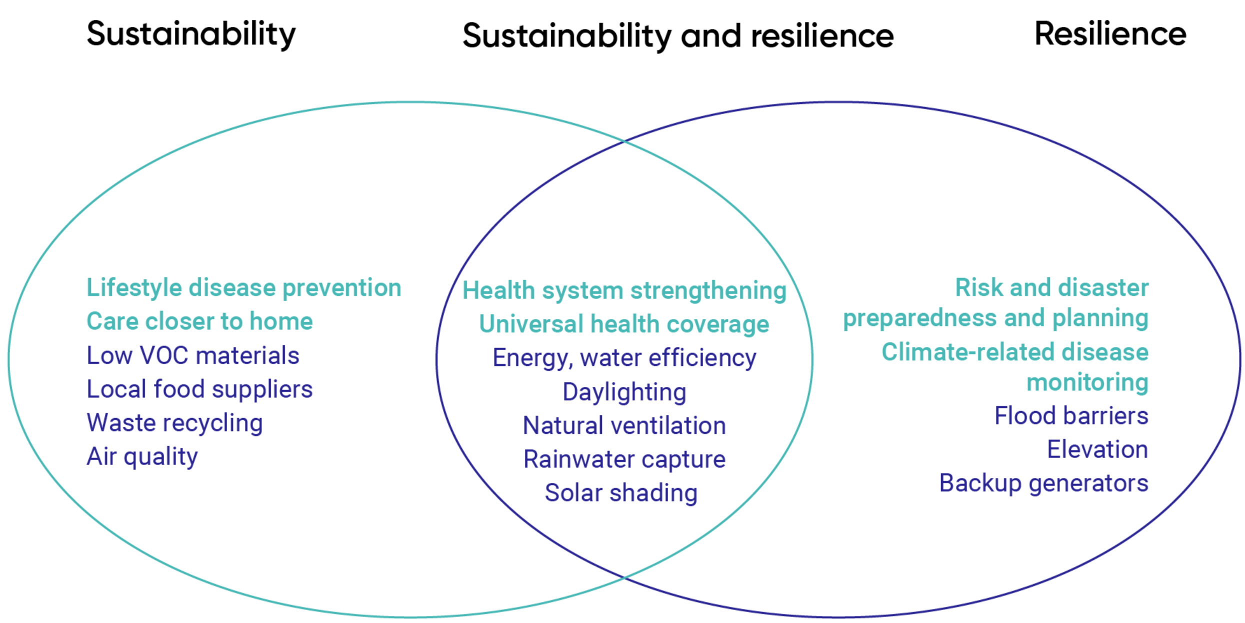


Figure 10.5 Climate-smart health care: the intersection of low-carbon health care and resilience. Source: World Bank, 2017.

Globally, the average emissions per capita for health care activities is reported as 0.28 tonnes of carbon dioxide (tCO_2) equivalent (Health Care Without Harm & ARUP, 2019). Canada's health system has been identified as one of the top four emitters among countries, based on per capita emission of 1.1 tCO_2

equivalent per capita (Health Care Without Harm & ARUP, 2019). The Canadian health sector as a whole, primarily hospitals, pharmaceuticals, and physician services, is estimated to have emitted between 4.6% and 5.1% (29.6–33 Mt CO_2 equivalent) annually from 2009 to 2014, or 4.6% of total national GHG emissions in 2014 (Eckelman et al., 2018). Pichler et al. (2019) estimated the health carbon footprint of Organisation for Economic Co-operation and Development countries, which includes CO_2 emissions related to providers of goods and services for health care, such as medical retailers, hospitals, ambulatory, long-term, or preventive health care. The health carbon footprint in Canada in 2014 was estimated to be 5.1% of the total national carbon footprint (Pichler et al., 2019). In 2017, at least 16 Canadian hospitals emitted more than 10 kt of GHGs (ECCC, 2019).

In Canada, 26% of health sector emissions arise directly from health care facilities and health care–owned vehicles and 13% indirectly from purchased energy sources, such as electricity, steam, cooling, and heating. The majority (61%) of GHGs from the health sector are attributed to the supply chain, which includes the production, transport, and disposal of goods and services, such as pharmaceuticals and other chemicals, food and agricultural products, medical devices, hospital equipment, and instruments (Health Care Without Harm, 2019). An estimated 68% of these carbon emissions are generated domestically, indicating that imported goods are also a significant contributor to these emissions.

Box 10.8 Reducing GHGs and increasing climate resilience at the University Health Network

The University Health Network (UHN) in Toronto, Ontario, has reduced its direct GHG emissions (from on-site combustion of natural gas) and indirect GHG emissions (from consumption of purchased electricity, heat, or steam) by 19% from 2010 to 2019 (Vanlint, 2019). Much of the savings arose from 214 energy projects completed between 2013 and 2018, saving UHN $18.9 million in utility costs (Vanlint, 2019). UHN is reducing carbon emissions by addressing the carbon intensity of its cooling system, which has been described as a significant source of global CO_2 equivalent emissions from the health sector (Kigali Cooling Efficiency Program, 2018). UHN has replaced traditional chillers with deep lake cooling technology, which uses water cooled by Lake Ontario, at some of its facilities. This new technology increases capacity, resilience, and reliability of UHN's chilled water system and saves more than $22 million over 20 years, 67 million L of water per year, 7 million kWh of electricity per year, and 269 Mt of GHG emissions per year (Vanlint, 2019).

Additional planned actions to reduce UHN's carbon footprint will include development of the world's largest raw wastewater energy transfer (WET) system at Toronto Western Hospital and the Krembil Discovery Tower. By harnessing thermal energy from wastewater flowing through the nearby campus sewer, it is estimated that the new WET system will result in a reduction of 250,000 metric tonnes of GHGs over the next 30 years (UHN, 2021).

Given the large amount of energy and supplies used by organizations in the health sector, such as hospitals, efforts to become more sustainable can result in huge economic and health dividends. The U.S.

Environmental Protection Agency has estimated that health care facilities in the United States have saved more than 192 billion USD in energy costs over the last 20 years (Ribesse & Varangu, 2019). In another study, the Health Care Climate Council (2018) found that, if the U.S. health system reduced electricity use and carbon pollution by 30%, it would prevent 4130 premature deaths, 85,000 asthma attacks, 4 million respiratory symptom events, and 3750 hospital visits by 2030, resulting in savings of approximately 1.2 billion USD. Initiatives to improve energy conservation and reduce GHG emissions through adopting appropriate building design, purchasing energy efficient products, and incorporating renewable energy systems have potentially very large savings for Canadian hospitals; one study which is likely an underestimate suggested a savings of a cumulative $150 million per year in utility spending with an average payback period of seven years (Waddington & Varangu, 2016). Currently, Health Canada is working with the Standards Council of Canada to explore opportunities to integrate climate change information into building codes for hospitals.

Some hospitals in Canada are taking action to reduce their fossil fuel use and GHG emissions and therefore become more resilient (Waddington & Varangu, 2016). By reducing on-site energy use, hospitals can cope with longer periods of power outages using their limited standby power. One of the challenges in understanding GHG emissions reported from hospitals is the lack of consistency in how this information is tracked and reported. These inconsistencies make it difficult to consolidate information on progress in the health sector.

Canada can learn from actions taken by a number of international partners in efforts to reduce GHGs in the health sector and build climate resilience. Pichler et al. (2019) reported that 14 countries, mainly in Europe, have been able to reduce the health sector carbon footprint even while real expenditure continues to grow. The large potential to benefit human health and the environment is illustrated through the efforts taken by the U.K. National Health Service (NHS), which was the first health care system in the world to routinely report on GHG emissions. Similar to Canada, the NHS contributes between 4% and 5% of the country's carbon footprint. The NHS has undertaken a concerted effort to understand where the GHGs are generated in the health system and has developed a carbon reduction strategy and a roadmap to reduce these emissions.

In 2016, the NHS Sustainable Development Unit for NHS England and Public Health England reported that the NHS reduced its carbon emissions by 11% between 2007 and 2015, exceeding the 10% target set in 2009 (National Health Service, 2016). The wider sector, which also includes public health and social care, saw a 13% reduction over the same period. These emission reductions occurred despite an 18% increase in health and social care activity. Carbon emissions reductions included a 16% reduction in relation to procurement, such as improvements to the footprint of pharmaceuticals; a 4% reduction in energy emissions through energy efficiency and conservation; and a 5% reduction in travel (National Health Service, 2016).

10.7 Knowledge Gaps

New knowledge, partnerships, and capacity-building on climate change and health in the health sector in Canada have increased opportunities to use evidence-based information to make greater strides in efforts to protect Canadians from future impacts. Assessment tools and methods have been developed, for example, to examine the impacts of projected stresses and strains from climate change on health systems and facilities to gauge their resilience to climate change impacts. However, much research on climate change and health adaptation is not accessible and practical for decision making; few studies exist on the effectiveness of measures to protect health, the ease of implementation, and the capacity required for action (Banwell et al., 2018).

Previous national assessments and reports in Canada since 1995 have identified knowledge gaps that need to be filled to support decision makers' efforts to prepare for climate change impacts on health (Royal Society of Canada, 1995; Health Canada, 1999; Health Canada, 2001; Health Canada, 2004; Séguin, 2008; Berry et al., 2014a; Brettle et al., 2016; Maguet, 2020). Disparities exist in the levels of research on climate change and health within each province and territory and across the country (Brettle et al., 2016). A review of Canadian research on climate change and health conducted from 2006 to 2016 found research on all of the identified gaps, but with wide variation in terms of the issue or region of Canada, focus, scale of research, and stage of knowledge maturation (e.g., limited numbers of field studies have been conducted and few interventions have been evaluated) (Kolnick, 2016). A much greater percentage of the 672 articles on climate change and health analyzed populations at increased risk, assessments, natural hazards, and food safety and/or security, compared to air quality, toxic substances, or psychosocial impacts. Only 11% of the articles focused on adaptation strategies and measures. In addition, the regional focus of research was also quite disparate, with many more articles examining climate change and health issues in Quebec, British Columbia, and Ontario, fewer in the North, and the least in other parts of Canada, particularly Nova Scotia, New Brunswick, and Prince Edward Island (Kolnick, 2016). A large proportion of the research addressed climate change and health from a national perspective. This may increase the relevance of these studies to a wider range of stakeholders but, in some cases, may decrease the capacity for these studies to inform local-level decision making and assessments.

The study likely did not capture research that incorporated Indigenous knowledge and so does not represent a complete picture of climate change and health research in Canada. However, significant knowledge gaps exist related to climate change and First Nations, Inuit, and Métis peoples' health in Canada, including adaptation options (see Chapter 2: Climate Change and Indigenous Peoples' Health in Canada). Many communities in Northern Canada have increased their capacity and expertise related to research management, research design, and interpretation and communication of study results (Abele & Gladstone, n.d.).

Further research is required in the following areas to support efforts to protect health and build climate-resilient health systems in Canada:

Adaptation measures

- Identification of equitable, effective (including cost-effective) adaptation measures for reducing health risks from current climate variability and projected climate change.

- Adaptation measures to address the health challenges and capacity issues First Nations, Inuit, and Métis peoples face from climate change, including rural, remote, and Northern communities.
- Adaptation measures tailored for specific populations, for example, people experiencing homelessness (Kidd et al., 2020), children, and older populations and those living in rural, remote and Northern communities.
- Adaptation measures to reduce risks to individuals and health systems from compounding and cascading events, including from possible non-linear changes in weather and future climate (Ebi et al., 2016a).
- Technical and operational synergies among actions to reduce disaster risk and options to adapt to climate change and health (e.g., health facility emergency preparedness plans) (Banwell et al., 2018).
- Novel, integrated, and multidisciplinary surveillance and monitoring for climate change and health (e.g., data collection and analysis, citizen science, laboratory diagnostics, meta-genomics, and geospatial mapping) (ECCC, 2020).
- Standardized indicators of health risks posed by climate change, along with means of verification, similar to the indicators used to measure meteorological and climatological variables, to establish baselines for monitoring the effectiveness of adaptations (Cheng & Berry, 2013; Ebi et al., 2018a).
- Identification of risk trade-offs associated with various health adaptations (e.g., can breathable fabric protect against bites by ticks and mosquitos?; ensuring green spaces that help cool health care facilities are designed to not attract disease-bearing vectors).
- Identification of effective tools, dissemination methods, and approaches to communicate climate change and health to decision makers and the public (WHO, 2009).
- Effective strategies for aligning climate change and health promotion efforts with communication activities to support the reduction of GHGs.
- Information to support education efforts, communication of research findings, and resilience-building in First Nations, Inuit, and Métis communities, while supporting and strengthening the sharing and application of Indigenous knowledges including adaptation experiences.

Health system resilience

- Current and projected climate-related impacts, vulnerabilities, and costs to health systems and facilities (e.g., health policies, programs, services, and infrastructure; health human resources planning, management, and training; and supply chains critical for health), including to rural, remote, and Northern health systems.
- Current and projected climate-related impacts, vulnerabilities, and costs to health systems and facilities that serve First Nations, Inuit, and Métis communities.
- Effective adaptation and resilience-building measures for health systems and facilities, including rural, remote, and Northern health systems and those serving First Nations, Inuit, and Métis peoples.
- Standardized GHG measurement methodologies (e.g., life-cycle assessment) for tracking health system and hospital GHG emissions to support targets and goals for the sector to reduce its carbon footprint and improve resilience.

- Best approaches for reducing the carbon footprint of the health sector, for example, by retrofitting existing health care facilities.
- Effective actions to address GHG emissions from the health sector supply chain, including evaluation of current purchasing practices in the Canadian health system and opportunities for suppliers to develop new, low-carbon products and services for the health sector.
- Synergies between actions that support climate change resilience, adaptation, and environmental sustainability in the health system and those that support financial sustainability (i.e., savings from energy efficiency investments; telemedicine and virtual health care; electronic health care records; supply chain costs).
- Easily accessible cooling technologies and practices that are not fossil-fuel-based for health care facilities, public cooling centres, and cooling for homes, both for new-builds and for retrofits of existing buildings.

Health co-benefits and risks of measures

- Synergistic health co-benefits of various strategies to reduce GHG emissions to national targets that also reduce air pollution.
- Direct and indirect health co-benefits and risks of measures taken by other sectors (e.g., water, agriculture, housing, transportation, insurance, energy, urban planning) to adapt to impacts (ECCC, 2020), including for First Nations, Inuit, and Métis peoples and rural, remote, and Northern communities.
- Strategies that support health, including those that address the root causes of vulnerability and health inequities, and support the transition to a low-carbon economy in energy, agriculture, transportation, manufacturing, buildings, and other sectors.

Economic costs and benefits

- Economic costs of the impacts of current climate variability and projected climate change on human health and health systems in Canada, as well as on social services that support the determinants of health.
- Assessments of the economic costs and health co-benefits of GHG mitigation and adaptation activities (WHO, 2009; Huang et al., 2013).
- Economic, social and health benefits of actions to build climate-resilient health systems (ECCC, 2020).

These research gaps cover a broad spectrum of climate change hazards and impacts on health as well as common public health and health system interventions to protect populations. Addressing these information needs would likely contribute to reducing threats to Canadians from other health risks such as pandemic disease, facilitating adaptation and resilience to a wide range of hazards.

10.8 Conclusion

Climate change is a growing threat to the health of Canadians, communities, and health systems. Health systems and facilities in Canada are vulnerable to climate change, and many are already being affected by weather- and climate-related hazards. Climate change is increasing risks to health facility and health system staff, operations, and infrastructure. While many factors, such as future levels of inequity, social cohesion, and technological innovation will influence how the health of Canadians and their communities are affected by climate change, a major driver will be the resilience of health systems and the willingness and capacity of decision makers to take needed adaptive actions, in concert with partners in other sectors.

Adaptation actions to prepare Canadians, including those at higher risk, can be effective in reducing health impacts. For example, the recent response to the growing danger of extreme heat events through the development of HARS has reduced health risks and poor health outcomes in some countries. Robust adaptation to reduce health risks requires adaptation by a wide range of actors in society at multiple temporal and geographic scales that take into account complex drivers of poor health outcomes.

Analysis in this chapter suggests that a number of health authorities, from local to national levels, in Canada are taking adaptation actions to reduce health risks. However, fewer are taking concrete actions, such as developing a climate change and health program, dedicating targeted resources to adaptation, assessing resilience of critical health infrastructure, or training health professionals and staff. In addition, few provinces and territories have comprehensive (e.g., covering a wide range of likely risks to health) or substantive climate change and health adaptation actions as part of their broader climate change strategies, and no jurisdictions have a separate action plan or strategy that focuses exclusively on climate change and health. The wide diversity in efforts among health authorities, from local to national levels, with some taking aggressive action and others doing less, suggests many communities and health systems are at increased vulnerability to current and future projected impacts on health, including potentially very severe effects from compounding or cascading events.

10.8.1 Scaling Up Health Adaptation

Rapidly scaling up health adaptation measures is needed to help protect Canadians from current health hazards and to reduce risks from climate change impacts in the future, such as extreme weather events that exceed adaptive thresholds. Health authorities should build upon past and current efforts to prepare for a warmer world, such as undertaking vulnerability and adaptation assessments for climate change and health, examining risks to health facilities from climate change, and implementing targeted adaptations such as early warning systems. This may require going outside of normal approaches used by ministries of health, such as expanding integrated monitoring and surveillance activities, mainstreaming information about climate risk into new programs and policies, as well as training clinicians, health researchers, and public health professionals about how to protect health in a changing climate.

10.8.2 Indigenous Leadership and Collaboration

Progress in efforts to protect Canadians from climate change requires a commitment to upholding Indigenous leadership and partnership in research development and adaptation, including recognizing and using Indigenous knowledge in a respectful way. Inherent in these efforts is an openness to diverse ways of knowing and of learning from complementary and/or contrasting perspectives for adaptation decision-making. Respectful collaboration will ensure that actions to protect health are based on meaningful engagement informed by the unique circumstances and opportunities of Indigenous Peoples and Northern, remote, and rural communities, thereby respecting, upholding, and advancing the rights of Indigenous peoples.

10.8.3 Working with Other Sectors

Adaptation progress will also require working more closely with decision makers outside of the health sector (e.g., water, agriculture, insurance, housing, energy, environment, emergency management, urban planning, transport, and infrastructure) to implement preventive and equitable measures to protect Canadians including by more vigorously addressing the social and environmental determinants of health. These activities should focus on opportunities to address barriers that limit preparedness (e.g., poverty, inadequate housing and infrastructure, ineffective communications), and to reduce uncertainty through increased collaborative research on impacts and effectiveness of adaptation.

Strong measures to reduce GHGs are needed to protect health and ensure that the ability of Canadians to adapt is not limited due to the severity of impacts. Very large health co-benefits can be achieved through multi-sectoral climate change adaptation to build resilience and through well-designed GHG mitigation efforts. Health decision makers have an important leadership role to play in raising awareness of these benefits and providing needed information to support robust efforts to address climate change through GHG mitigation (PHAC, 2017), including reducing the carbon footprint of the health sector, which is a major emitter of GHGs.

10.8.4 A National Health Adaptation Strategy

National adaptation strategies for climate change and health must provide a comprehensive framework identifying key actors, accountabilities, priority areas of action, and clear goals and objectives. Such strategies can reduce future costs of preparedness through greater sharing of information and through more robust collaboration and coordination of efforts (WHO, 2021). The Government of Canada is developing its first ever national adaptation strategy that is expected to be released in 2023 (Government of Canada, 2021). A strong health component of a national strategy would include efforts to provide assistance to people and communities at highest risk through equitable adaptation measures. Actions would address the physical and operational risks of climate change to health systems and their infrastructure by supporting facility assessments, preparedness, and resilience-building, considering the special challenges faced by rural, remote and Indigenous health services and through efforts to update relevant codes and standards. It would enhance capacity for climate change and health modelling, forecasting, and state of the art early warning systems informed by surveillance of climate change and health indicators. A core component of a health adaptation strategy would be to work with other sectors to incorporate the perspectives, needs, and voices of equity-seeking groups and the general public. Considerations of social justice and integration of a gendered perspective into future climate change and health activities are needed to support resilience-building efforts; these considerations include empowering people disproportionately affected by climate change (e.g., Indigenous Peoples, women, people of low socio-economic status, immigrants) as educators, caregivers, holders of knowledge and agents of social change (Sorensen et al., 2018).

Greater efforts are needed to educate the public and decision makers about potential impacts and the benefits of preparedness to support scaled-up actions. This can include collaborating on climate change and health communications with the health care community and non-governmental organizations; increasing public health education using evidence-based advice and social marketing approaches; and developing a single window to provide easy access to climate change and health communication materials and messages (Brettle et al., 2016). Such activities would help Canadians, communities and their health systems move beyond responsive and more costly adaptation toward transformational adaptation that builds resilience to future climate change.

A national strategy could address many existing barriers to health adaptation, including limited social capital and ability to engage health relevant sectors, cognitive limits to behavioural change (Huang et al., 2011), a narrow framing of public health interventions that omits action on root causes of vulnerability (Gould & Rudolph, 2015) and the absence of coordinated planning among health sector partners at all levels of government. Through close collaboration, health decision makers, civil society partners, researchers, and members of the public can meet the challenge of climate change head-on, building more resilient health systems and communities to better protect health, now and in the future.

10.9 References

ABC News. (2018). *Japan heatwave kills 30 and hospitalises thousands as authorities continue flood clean-up*. Retrieved from <https://www.abc.net.au/news/2018-07-22/japan-heatwave-kills-30-and-sees-thousands-in-hospital/10022488>

Abele, F., & Gladstone, J. (n.d.). *Health Canada Climate Change Health Adaptation Program: Synthesis report and impact analysis.* Climate Telling. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/cchap_final_report.pdf>

Adaptation to Climate Change Team (ACT). (2018). *LCR conceptual process model*. Retrieved from <http://act-adapt.org/wp-content/uploads/2018/12/2.2._lcr_best_practices_web.pdf>

Alberta Health Services. (2013a). *AHS Update: Medicine Hat field hospital to close as waters recede; focus on safe return home for evacuees*. Retrieved from <https://www.albertahealthservices.ca/news/releases/2013/Page8677.aspx>

Alberta Health Services. (2013b). *100 days after the flood*. Retrieved from <https://www.albertahealthservices.ca/news/features/2013/Page9142.aspx>

Alberta Health Services. (2014). *Alberta Health Services Annual Report 2013-2014*. Alberta, ON. Retrieved from <https://www.albertahealthservices.ca/Publications/ahs-pub-2013-2014-annual-report.pdf>

Anderson, H., Brown, C., Cameron, L. L., Christenson, M., Conlon, K. C., Dorevitch, S., Dumas, J., Eidson, M., Ferguson, A., Grossman, E., Hanson, A., Hess, J. J., Hoppe, B., Horton, J., Jagger, M., Krueger, S., Largo, T. W., Losurdo, G. M., Mack, S. R., Moran, C., … Walker, R. (2017). *Climate and Health Intervention Assessment: Evidence on Public Health Interventions to Prevent the Negative Health Effects of Climate Change.* Climate and Health Technical Report Series. Centers for Disease Control and Prevention. Retrieved from <https://www.cdc.gov/climateandhealth/docs/ClimateAndHealthInterventionAssessment_508.pdf>

Arbuthnott, K., Hajat, S., & Heaviside, C. (2016). Changes in population susceptibility to heat and cold over time: assessing adaptation to climate change. *Environmental Health, 15*(S33). <https://doi.org/10.1186/s12940-016-0102-7>

Austin, S. E., Biesbroek, R., Berrang-Ford, L., Ford, J. D., Parker, S., & Fleury, M. D. (2016). Public Health Adaptation to Climate Change in OECD Countries. *International Journal of Environmental Research and Public Health*, *13*(9), 889. <https://doi.org/10.3390/ijerph13090889>

Austin, S. E., Ford, J. D., Berrang-Ford, L., Biesbroek, R., & Ross, N. A. (2019). Enabling local public health adaptation to climate change. *Social Science & Medicine (1982)*, *220*, 236–244. <https://doi.org/10.1016/j.socscimed.2018.11.002>

Baccini, M., Kosatsky, T., Analitis, A., Anderson, H. R., D'Ovidio, M., Menne, B., … Biggeri, A. (2011).

Impact of heat on mortality in 15 European cities: Attributable deaths under different weather scenarios. *Journal of Epidemiology and Community Health*, *65*(1), 64–70. <https://doi.org/10.1136/jech.2008.085639>

Balbus, J., Berry, P., Brettle, M., Jagnarine-Azan, S., Soares, A., Ugarte, C., Varangu, L., & Prats, E. V. (2016). Enhancing the sustainability and climate resiliency of health care facilities: a comparison of initiatives and toolkits. *Revista Panamericana de Salud Publica = Pan American Journal of Public Health*, *40*(3), 174–180.

Banwell, N., Rutherford, S., Mackey, B., & Chu, C. (2018). Towards Improved Linkage of Disaster Risk Reduction and Climate Change Adaptation in Health: A Review. *International Journal of Environmental Research and Public Health, 15*(4), 793. <https://doi.org/10.3390/ijerph15040793>

Barreca, A., Clay, K., Deschenes, O., Greenstone, M., & Shapiro, J. S. (2016). Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. *Journal of Political Economy*, *124*(1), 105-159.

Bartko, M., & Macdonald, I. (2017). *Climate resilience feasibility study of facilities at Fraser Canyon Hospital.* National Research Council Canada, A1-010678.2. Retrieved from <https://bcgreencare.ca/system/files/resource-files/Fraser%20Health%20Final%20Report%2010%20November.pdf>

BC Health Authorities. (2020). *Climate resilience guidelines for BC health facility planning & design.* Retrieved from <https://bcgreencare.ca/system/files/resource-files/Climate resilience-Guidelines-Health-Facilities_v1-1.pdf>

Beaudoin, M., & Gosselin, P. (2016). An effective public health program to reduce urban heat islands in Québec, Canada. *Revista Panamericana de Salud Publica = Pan American Journal of Public Health*, *40*(3), 160–166.

Beaudoin, M., & Levasseur, M.-E. (2017). *Verdir les villes pour la santé de la population Verdir les villes pour la santé de la population*. Institut National De Santé Publique Du Québec. Retrieved from <https://www.inspq.qc.ca/sites/default/files/publications/2265_verdir_villes_sante_population.pdf>

Benmarhnia, T., Bailey, Z., Kaiser, D., Auger, N., King, N., & Kaufman, J. S. (2016). A Difference-in-Differences Approach to Assess the Effect of a Heat Action Plan on Heat-Related Mortality, and Differences in Effectiveness According to Sex, Age, and Socioeconomic Status (Montreal, Quebec). *Environmental Health Perspectives*, *124*(11), 1694–1699. <https://doi.org/10.1289/EHP203>

Benmarhnia, T., Zhao, X., Wang, J., Macdonald, M., & Chen, H. (2019). Evaluating the potential public health impacts of the Toronto cold weather program. *Environment International*, *127*, 381–386. <https://doi.org/10.1016/j.envint.2019.03.042>

Berry, P. (2008). Vulnerabilities, adaptation and adaptive capacity. In J. Séguin (Ed.), *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity.* Ottawa, ON: Health Canada. Retrieved from <https://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Berry, P., Clarke, K., Fleury, M. D., & Parker, S. (2014a). Human health. In F. J. Warren, & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation*. Ottawa, ON: Government of Canada.

Berry, P., Paterson, J., & Buse, C. (2014b). *Assessment of vulnerability to the health impacts of climate change in Middlesex-London.* Report prepared for the Middlesex-London Health Unit. London, United Kingdom. Retrieved from <https://www.healthunit.com/climate-change>

Berry, P., Enright, P. M., Shumake-Guillemot, J., Villalobos Prats, E., & Campbell-Lendrum, D. (2018). Assessing Health Vulnerabilities and Adaptation to Climate Change: A Review of International Progress. *International Journal of Environmental Research and Public Health*, *15*(12), 2626. <https://doi.org/10.3390/ijerph15122626>

Boeckmann, M., & Rohn, I. (2014). Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. *BMC public health*, *14*, 1112. <https://doi.org/10.1186/1471-2458-14-1112>

Bouzid, M., Hooper, L., & Hunter, P. R. (2013). The effectiveness of public health interventions to reduce the health impact of climate change: a systematic review of systematic reviews. *PloS One*, *8*(4), e62041. <https://doi.org/10.1371/journal.pone.0062041>

Boynton, S. (2020). Landslides created by B.C. storm lead to phone service outages across province. *Global News.* Retrieved from <https://globalnews.ca/news/6495369/bc-landslides-cell-service-roads/>

Brettle, M., MacMillan, K-A., Kolnick, L., & Berry, P. (2016). *Climate change and health resiliency collaboration: Workshop report.* Ottawa, ON: Health Canada.

Bustinza, R., Lebel, G., Gosselin, P., Bélanger, D., & Chebana, F. (2013). Health impacts of the July 2010 heatwave in Québec, Canada. *BMC Public Health*, *13*, 56. <https://doi.org/10.1186/1471-2458-13-56>

Callison, C., & Tindall, D. B. (2017). Climate change communication in Canada. *Oxford Research Encyclopidia of Climate Science*. <https://doi.org/10.1093/acrefore/9780190228620.013.477>

Campbell-Lendrum, D., Guillemot, J., & Ebi, K. L. (2015). Climate change and health vulnerability assessments: A Practical Approach. In G. Luber, & J. Lemery (Eds.), *Global Climate Change and Human Health: From Science to Practice*. San Francisco, CA: Jossey-Bass.

Campbell-Lendrum, D., Villalobas Prats, E., & Kendrovski, V. (n.d.). Estimating the cost of health adaptation [Webinar Presentation]. World Health Organization. Retrieved from <https://unfccc.int/sites/default/files/resource/CGE_wenbinar%236_presentation.pdf>

Canadian Broadcasting Corporation. (2010). Emergency room shut down by flooding. *CBC News.* Retrieved from <https://www.cbc.ca/news/canada/prince-edward-island/emergency-room-shut-down-by-flooding-1.905581>

Canadian Broadcasting Corporation. (2012). Flooding causes state of emergency in N.B. community. *CBC News.* Retrieved from <https://www.cbc.ca/news/canada/new-brunswick/flooding-causes-state-of-emergency-in-n-b-community-1.1196731>

Canadian Broadcasting Corporation. (2013). Flood in High River destroyed many medical files. CBC News. Retrieved from <https://www.cbc.ca/news/canada/calgary/flood-in-high-river-destroyed-many-medical-files-1.1329905>

Canadian Broadcasting Corporation. (2017). Maniwaki long-term care home to be evacuated due to floods. CBC News. Retrieved from <https://www.cbc.ca/news/canada/ottawa/maniwaki-seniors-home-evacuated-due-to-floods-1.5133108>

Canadian Coalition for Green Health Care. (2015a). *Resiliency Profile 1: Health Sciences Centre Well Equipped to Handle Flooding Events on Urban Campus.* Retrieved from <https://greenhealthcare.ca/resiliency/images/publications/1-Resiliency-Profile-Winnipeg.pdf>

Canadian Coalition for Green Health Care. (2015b). *Resiliency Profile 2: Nanaimo Hospital Builds resiliency into new Emergency Department.* Retrieved from <https://greenhealthcare.ca/resiliency/images/publications/2-Resiliency-Profile-Nanaimo.pdf>

Canadian Coalition for Green Health Care. (2017). *Resiliency Profile 7: Ice storm and backup generator failures combine for unparalleled challenges.* Retrieved from <https://greenhealthcare.ca/wp-content/uploads/2017/04/7-Resiliency-Profile-Sunnybrook-ice-March24-2017-FINAL.pdf>

Canadian Coalition for Green Health Care. (2018). *Identifying methods, data sources and indicators of climate change impacts for assessing the resiliency of Canadian health care facilities.* Report prepared for Health Canada.

Canadian Coalition for Green Health Care. (2019a). *Climate Change Resiliency Mentoring*. Retrieved from <http://greenhealthcare.ca/mentoring/>

Canadian Coalition for Green Health Care. (2019b). *Green Hospital Scorecard 2018 Survey Results*. Retrieved from <https://greenhealthcare.ca/ghs/>

Canadian Coalition for Green Health Care. (2020). *Green Health Leaders' Initiative*. Retrieved from <https://greenhealthcare.ca/ghli/>

Canadian Healthcare Facilities. (2017). In the face of Fire. *Journal of Canadian Healthcare Engineering Society, 38*(1), 28-29.

Canadian Institute for Climate Choices (CICC). (2021). *The health costs of climate change: How Canada can adapt, prepare and save lives.* Retrieved from <https://climatechoices.ca/wp-content/uploads/2021/06/ClimateChoices_Health-report_Final_June2021.pdf>

Canadian Institute for Health Information (CIHI). (2018). *Quick Stats*. Retrieved from <https://www.cihi.ca/en/quick-stats>

Casanueva, A., Burgstall, A., Kotlarski, S., Messeri, A., Morabito, M., Flouris, A. D., Nybo, L., Spirig, C., & Schwierz, C. (2019). Overview of Existing Heat-Health Warning Systems in Europe. *International Journal of Environmental Research and Public Health*, *16*(15), 2657. <https://doi.org/10.3390/ijerph16152657>

Chau, P. H., Chan, K. C., & Woo, J. (2009). Hot weather warning might help to reduce elderly mortality in Hong Kong. *International Journal of Biometeorology*, *53*(5), 461–468. <https://doi.org/10.1007/s00484-009-0232-5>

Cheng, J. J., & Berry, P. (2013). Health co-benefits and risks of public health adaptation strategies to climate change: a review of current literature. *International journal of public health*, *58*(2), 305–311. <https://doi.org/10.1007/s00038-012-0422-5>

Chronic Disease Prevention Alliance of Canada. (2017). *Submission to SOCI regarding Bill S-228, An Act to amend the Food and Drugs Act (prohibiting food and beverage marketing directed at children).* Retrieved from <https://sencanada.ca/content/sen/committee/421/SOCI/Briefs/ChronicDiseasePreventionAlliance_e.pdf>

Ciscar, J. C., Feyen, L., Soria, A., Lavalle, C., Raes, F., Perry, M., Nemry, F., Demirel, H., Rozsai, M., Dosio, A., Donatelli, M., Srivastava, A., Fumagalli, D., Niemeyer, S., Shrestha, S., Ciaian, P., Himics, M., Van Doorslaer, B., Barrios, S., Ibáñez, N.,… Ibarreta, D. (2014). *Climate Impacts in Europe.* The JRC PESETA II Project. Luxembourg, Luxembourg: Publications Office of the European Union. Retrieved from <https://publications.jrc.ec.europa.eu/repository/handle/JRC87011>

City of Toronto. (2019). *City of Toronto Hot Weather Response Framework 2019.* Retrieved from <https://www.toronto.ca/wp-content/uploads/2019/05/9030-2019-HWR-Framework-updated-05-22-19.AODA_.pdf>

Commito, M. (2018). Six dead, hundreds of homes destroyed: Today's the anniversary of the deadly 1970 tornado. *Sudbury Local News*. Retrieved from <https://www.sudbury.com/local-news/today-marks-anniversary-of-1970-tornado-699382>

Council of Canadian Academies (CCA). (2019). *Canada's Top Climate Change Risks: The Expert Panel on Climate Change Risks and Adaptation Potential*. Ottawa, ON. Retrieved from <https://cca-reports.ca/wp-content/uploads/2019/07/Report-Canada-top-climate-change-risks.pdf>

Crump, J., Jacob, K., King, P., Mangalagiu, D., Zickgraf, C., Abiodun, B. J., Armiento, G., Bailey, R., Baker, E., Bowen, K. J., Dankelman, I., Djalante, R., Dutta, M., Hurley, F., Iraola, M. J., Kim, R. E., King, R., Kirilenko, A., dos Santos Lucon, O., Lyne, K., Martino, D., … Wright, C. Y. (2019). Systemic Policy Approaches for Cross-cutting Issues. In P. Ekins, J. Gupta, & P. Boileau (Eds.), *Global Environment Outlook GEO-6: Healthy Planet, Healthy People* (p. 425-448). Cambridge, United Kingdom: Cambridge University Press. Retrieved from <https://wedocs.unep.org/handle/20.500.11822/27539>

CTV Barrie. (2019). 130 surgeries cancelled at RVH due to A/C malfunction. *CTV News*. Retrieved from <https://barrie.ctvnews.ca/130-surgeries-cancelled-at-rvh-due-to-a-c-malfunction-1.4499225>

Curtis, S., Fair, A., Wistow, J., Val, D. V., & Oven, K. (2017). Impact of extreme weather events and climate change for health and social care systems. *Environmental Health : A Global Access Science Source*, *16*(Suppl 1), 128. <https://doi.org/10.1186/s12940-017-0324-3>

Das, S., & Smith, S. C. (2012). Awareness as an adaptation strategy for reducing mortality from heatwaves: evidence from a disaster risk management program in India, *Climate Change Economics, 3*(2), 1250010. <https://doi.org/10.1142/S2010007812500108>

Deas, M., Grannis, J., Hoverter, S., & DeWeese, J. (2017). *Opportunities for equitable adaptation in cities: A workshop summary report.* Washington, DC: Georgetown Climate Centre. Retrieved from <https://www.georgetownclimate.org/files/report/GCC-Opportunities_for_Equitable_Adaptation-Feb_2017.pdf>

de' Donato, F. K., Leone, M., Scortichini, M., De Sario, M., Katsouyanni, K., Lanki, T., Basagaña, X., Ballester, F., Åström, C., Paldy, A., Pascal, M., Gasparrini, A., Menne, B., & Michelozzi, P. (2015). Changes in the Effect of Heat on Mortality in the Last 20 Years in Nine European Cities. Results from the PHASE Project. *International Journal of Environmental Research and Public Health*, *12*(12), 15567–15583. <https://doi.org/10.3390/ijerph121215006>

Demers-Bouffard, D. (2021). *L'adaptation aux changements climatiques dans le réseau de la santé au Québec : les progrès, les facteurs facilitants, les barrières et les besoins.* Institut national de santé publique du Québec. Retrieved from <https://www.inspq.qc.ca/publications/2719-adaptation-changements-climatiques-reseau-sante-quebec>

DesMeules, M., & Pong, R. (Eds.). (2006). *How healthy are rural Canadians? An assessment of their health status and health determinants.* Ottawa, ON: Canadian Institute of Health Information. Retrieved from <https://secure.cihi.ca/free_products/rural_canadians_2006_report_e.pdf>

Dodd, W., Scott, P., Howard, C., Scott, C., Rose, C., Cunsolo, A., & Orbinski, J. (2018). Lived experience of a record wildfire season in the Northwest Territories, Canada. *Canadian journal of public health = Revue canadienne de sante publique*, *109*(3), 327–337. <https://doi.org/10.17269/s41997-018-0070-5>

Doyle, H., Malim, S., & Tapinder, F. S. (2017). *Climate change and public health in Ontario*. Ontario Public Health Association.

Drinkwater, R. (2016). Fort McMurray fire: Hospital safely moves all 105 patients. *The Canadian Press.* Retrieved from <https://www.huffingtonpost.ca/entry/9843450>

Dupuis, J., & Biesbroek, R. (2013). Comparing apples and oranges: The dependent variable problem in comparing and evaluating climate change adaptation policies. *Global Environmental Change, 23*(6), 1476-1487. <https://doi.org/10.1016/j.gloenvcha.2013.07.022>

Ebi K. L. (2011a). Climate change and health risks: assessing and responding to them through 'adaptive management'. *Health affairs (Project Hope)*, *30*(5), 924–930. <https://doi.org/10.1377/hlthaff.2011.0071>

Ebi K. L. (2011b). Resilience to the health risks of extreme weather events in a changing climate in the United States. *International Journal of Environmental Research and Public Health*, *8*(12), 4582–4595. <https://doi.org/10.3390/ijerph8124582>

Ebi, K. L. (2016). Adaptation and resilience. *Public Health Reviews, 37*(17). <https://doi.org/10.1186/s40985-016-0032-5>

Ebi, K. L., & del Barrio, M. O. (2017). Lessons Learned on Health Adaptation to Climate Variability and Change: Experiences Across Low- and Middle-Income Countries. *Environmental Health Perspectives*, *125*(6), 065001. <https://doi.org/10.1289/EHP405>

Ebi, K. L., Berry, P., Campbell-Lendrum, D., Cissé, G., Hess, J., Ogden, N., & Schnitter, R. (2019). *Health System Adaptation to Climate Variability and Change.* Washington, DC: University of Washington. Retrieved from <https://gca.org/wp-content/uploads/2020/12/HealthSystemAdaptationToClimateVariabilityandChange_0.pdf>

Ebi, K. L., Berry, P., Hayes, K., Boyer, C., Sellers, S., Enright, P. M., & Hess, J. J. (2018b). Stress Testing the Capacity of Health Systems to Manage Climate Change-Related Shocks and Stresses. *International Journal of Environmental Research and Public Health*, *15*(11), 2370. <https://doi.org/10.3390/ijerph15112370>

Ebi, K. L., Boyer, C., Bowen, K. J., Frumkin, H., & Hess, J. (2018a). Monitoring and Evaluation Indicators for Climate Change-Related Health Impacts, Risks, Adaptation, and Resilience. *International Journal of Environmental Research and Public Health*, *15*(9), 1943. <https://doi.org/10.3390/ijerph15091943>

Ebi, K. L., Boyer, C., Ogden, N., Paz, S., Berry, P., Campbell-Lendrum, D., Hess, J. J., & Woodward, A. (2021). Burning embers: synthesis of the health risks of climate change. *Environmental Research Letters, 16*(4), 044042. doi:10.1088/1748-9326/abeadd

Ebi, K. L., Hess, J. J., & Isaksen, T. B. (2016c). Using Uncertain Climate and Development Information in Health Adaptation Planning. *Current Environmental Health Reports*, *3*(1), 99–105. <https://doi.org/10.1007/s40572-016-0077-0>

Ebi, K. L., Hess, J. J., & Watkiss, P. (2017). Health risks and costs of climate change variability and change. In C. N. Mock, R. Nugent, O. Kobusingye, & K. R. Smith (Eds.), *Injury prevention and environmental health: Disease control priorities* (3rd, ed.). Washington, DC: World Bank Group.

Ebi, K. L., & Semenza, J. C. (2008). Community-based adaptation to the health impacts of climate change. *American Journal of Preventive Medicine*, *35*(5), 501–507. <https://doi.org/10.1016/j.amepre.2008.08.018>

Ebi, K. L., Semenza, J. C., & Rocklöv, J. (2016b). Current medical research funding and frameworks are insufficient to address the health risks of global environmental change. *Environmental Health: A Global Access Science Source, 15*(1), 108. <https://doi.org/10.1186/s12940-016-0183-3>

Ebi, K. L., Ziska, L. H., & Yohe, G. W. (2016a). The shape of impacts to come: Lessons and opportunities for adaptation from uneven increases in global and regional temperatures. *Climatic Change, 139*(3), 341-349. <https://doi.org/10.1007/s10584-016-1816-9>

Environment and Climate Change Canada (ECCC). (2019). *Facility-report greenhouse gas data.* Retrieved from <https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/facility-reporting/data.html>

Eckelman, M. J., Sherman, J. D., & MacNeill, A. J. (2018). Life cycle environmental emissions and health damages from the Canadian healthcare system: An economic-environmental-epidemiological analysis. *PLoS Medicine*, *15*(7), e1002623. <https://doi.org/10.1371/journal.pmed.1002623>

Elliott, S. J., Bisung, E., Mulligan, K., & Wandel, J. (2017). *Assessing Resilience of the Canadian Health*

System to the Impacts of Climate Change: A Proposed Analytical Framework. Report prepared for Health Canada. Ottawa, ON.

Environics Research Group. (2017). *Public Perceptions of Climate Change – Final Report.* Report Prepared for Health Canada. Ottawa, ON.

Environment and Climate Change Canada (ECCC). (2020). *Climate Science 2050: Advancing Science and Knowledge on Climate Change*. Ottawa, ON. Retrieved from <https://publications.gc.ca/collections/collection_2020/eccc/En4-414-2020-eng.pdf>

Eyzaguirre, J., & Warren, F. J. (2014). Adapting: Linking Research and Practice. In F. J. Warren, & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 253–286). Ottawa, ON: Government of Canada.

Ford, J. D., & King, D. (2015). A framework for examining adaptation readiness. *Mitigation and Adaptation Strategies for Global Change, 20*, 505-526. <https://doi.org/10.1007/s11027-013-9505-8>

Ford, J. D., Sherman, M., Berrang-Ford, L., Llanos, A., Carcamo, C., Harper, S., Lwasa, S., Namanya, D., Marcello, T., Maillet, M., & Edge, V. (2018). Preparing for the health impacts of climate change in Indigenous communities: The role of community-based adaptation. *Global Environmental Change, 49,* 129-139. <https://doi.org/10.1016/j.gloenvcha.2018.02.006>

Fouillet, A., Rey, G., Wagner, V., Laaidi, K., Empereur-Bissonnet, P., Le Tertre, A., … Hémon, D. (2008). Has the impact of heatwaves on mortality changed in France since the European heatwave of summer 2003? A study of the 2006 heatwave. *International Journal of Epidemiology*, *37*(2), 309–17. <https://doi.org/10.1093/ije/dym253>

Fraser Basin Council. (2016). *Lower Mainland Flood Management Strategy: Phase 1 Summary Report.* Retrieved from <https://www.fraserbasin.bc.ca/_Library/Water_Flood_Strategy/FBC_LMFMS_Phase_1_Report_Web_May_2016.pdf>

Friel, S. (2019). *Climate Change and the People's Health* (N. Krieger, Ed). Oxford University Press.

Friel, S., Bowen, K., Campbell-Lendrum, D., Frumkin, H., McMichael, A. J., & Rasanathan, K. (2011). Climate change, noncommunicable diseases, and development: the relationships and common policy opportunities. *Annual Review of Public Health*, *32*, 133–147. <https://doi.org/10.1146/annurev-publhealth-071910-140612>

Frumkin, H. (2011). Bumps on the road to preparedness. *American journal of preventive medicine*, *40*(2), 272–273. <https://doi.org/10.1016/j.amepre.2010.11.001>

Frumkin, H., Hess, J., Luber, G., Malilay, J., & McGeehin, M. (2008). Climate change: the public health response. *American Journal of Public Health*, *98*(3), 435–445. <https://doi.org/10.2105/AJPH.2007.119362>

GEP. (2017). *Puerto Rico Crisis — Impact on Healthcare Supplies*. Retrieved from <https://www.gep.com/mind/blog/puerto-rico-crisis-impact-healthcare-supplies>

Glasser, R. (2019). *Special Report: Preparing for the Era of Disasters*. Australian Strategic Policy Institute. Retrieved from <https://www.aspi.org.au/report/preparing-era-disasters>

Global Heat Health Information Network (GHHIN). (2018). *Heat health action plans database.* Retrieved from <https://ghhin.org/heat-action-plans-and-case-studies/>

Globe and Mail. (2003). Halifax cleans up after the biggest storm in decades. *The Globe and Mail.* Retrieved from <https://www.theglobeandmail.com/news/national/halifax-cleans-up-after-biggest-storm-in-decades/article20451342/>

Gosselin, P. (2010). Health of populations. In C. DesJarlais, M. Allard, D. Bélanger, A. Blondlot, A. Bouffard, A. Bourque, D. Chaumont, P. Gosselin, D. Houle, C. Larrivée, N. Lease, A. T. Pham, R. Roy,

J.-P. Savard, R. Turcotte, & C. Villeneuve (Eds.), *Learning to adapt to climate change*. Montréal, QC: Ouranos. Retrieved from <https://www.ouranos.ca/wp-content/uploads/RapportDesjarlais2010_EN.pdf>

Gosselin, P., Mehiriz, K., Tardif, I., Lemieux, M-A., & Beaudoin, S. (2018). *Téléphone santé : un automate d'appel aux résultats prometteurs lors de vagues de chaleur ou de smog.* Institut National de Santé Publique du Québec. Retrieved from <https://www.inspq.qc.ca/bise/telephone-sante-un-automate-d-appel-aux-resultats-prometteurs-lors-de-vagues-de-chaleur-ou-de-smog>

Gosselin, P., Bustinza, R. & Bélanger, D. (2021). *Les changements climatiques Abrégé à l'intention des professionnels de la santé.* Institut national de santé publique du Québec. Retrieved from <https://www.inspq.qc.ca/sites/default/files/publications/2777-changements-climatiques-abrege-professionnels-sante.pdf>

Gould, S., & Rudolph, L. (2015). Challenges and Opportunities for Advancing Work on Climate Change and Public Health. *International Journal of Environmental Research and Public Health*, *12*(12), 15649–15672. <https://doi.org/10.3390/ijerph121215010>

Government of British Columbia. (2019). *Carbon Neutral Government Program Requirements.* Retrieved from <https://www2.gov.bc.ca/gov/content/environment/climate-change/public-sector/carbon-neutral>

Government of Canada. (2015). *Cleaner vehicles and fuels for Canadians: Final Tier 3 vehicle and fuel standards.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/news/archive/2015/07/cleaner-vehicles-fuels-canadians-final-tier-3-vehicle-fuel-standards.html>

Government of Canada. (2016). *Pan Canadian Framework on Clean Growth and Climate Change*. Ottawa, ON. Retrieved from <https://www.canada.ca/content/dam/themes/environment/documents/weather1/20170125-en.pdf>

Government of Canada. (2017). *Canada's Seventh National Communication on Climate Change and Third Biennial Report—Actions to meet commitments under the United Nations Framework Convention on Climate Change*. Ottawa, ON. Retrieved from <https://unfccc.int/files/national_reports/national_communications_and_biennial_reports/application/pdf/82051493_canada-nc7-br3-1-5108_eccc_can7thncomm3rdbi-report_en_04_web.pdf>

Government of Canada. (2019). *Climate change and health: Health effects.* Retrieved from <https://www.canada.ca/en/health-canada/services/climate-change-health.html>

Government of Canada. (2020a). *Climate change and health adaptation program.* Retrieved from <https://www.sac-isc.gc.ca/eng/1536238477403/1536780059794>

Government of Canada. (2020b). *A healthy environment and a healthy economy: Canada's strengthened climate plan to create jobs and support people, communities and the planet*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/healthy-environment-healthy-economy.html>

Government of Canada. (2021). *Greenhouse gas emissions: Drivers and impacts*. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions-drivers-impacts.html>

Government of New Brunswick. (2012). *Flood Details - 2012-03-23 - 2012-03-25*. Retrieved from <https://www.elgegl.gnb.ca/0001/en/Flood/Details/322>

Government of New Brunswick. (2018). *Perth-Andover hospital upgrades nearing completion*. Retrieved from <https://www2.snb.ca/content/gnb/en/news/news_release.2018.05.0629.html>

Government of Québec. (2012a). *Québec in Action: Greener by 2020 – 2013-2020 Climate Change Action Plan*. Québec, QC. Retrieved from <https://www.environnement.gouv.qc.ca/changements/plan_action/pacc2020-en.pdf>

Government of Québec. (2012b). *Québec in Action: Greener by 2020 – 2013-2020 Government Strategy for Climate change adaptation*. Québec, QC. Retrieved from <https://www.environnement.gouv.qc.ca/changements/plan_action/stategie-adaptation2013-2020-en.pdf>

Green, S., Kim, S., Gaudet, M., & Cheung, E. (2018). Doctor's prescription for cycling. *Canadian family Physician Medecin de Famille Canadien*, *64*(10), 715–716.

Guilbault, S., Kovacs, P., Berry, P., & Richardson, G. R. A. (2016). *Cities adapt to extreme heat: Celebrating local leadership. Institute for Catastrophic Loss Reduction.* Retrieved from <https://www.iclr.org/wp-content/uploads/PDFS/cities-adapt-to-extreme-heat.pdf>

Hackett, F., Got, T., Kitching, G. T., MacQueen, K., & Cohen, A. (2020). Training Canadian doctors for the health challenges of climate change. *The Lancet. Planetary health*, *4*(1), e2–e3. <https://doi.org/10.1016/S2542-5196(19)30242-6>

Haines, A., & Ebi, K. (2019). The Imperative for Climate Action to Protect Health. *The New England Journal of Medicine*, *380*(3), 263–273. <https://doi.org/10.1056/NEJMra1807873>

Haines, A., McMichael, A. J., Smith, K. R., Roberts, I., Woodcock, J., Markandya, A., Armstrong, B. G., Campbell-Lendrum, D., Dangour, A. D., Davies, M., Bruce, N., Tonne, C., Barrett, M., & Wilkinson, P. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: overview and implications for policy makers. *Lancet (London, England)*, *374*(9707), 2104–2114. <https://doi.org/10.1016/S0140-6736(09)61759-1>

Hamilton, I., Kennard, H., McGushin, A., Höglund-Isaksson, L., Kiesewetter, G., Lott, M., Milner, J., Purohit, P., Rafaj., P., Sharma, R., Springman, M., Woodcock, J., & Watts, N. (2021). The public health implications of the Paris Agreement: a modelling study. *Lancet Planetary Health*, *5*(2), e74-e83. <https://doi.org/10.1016/S2542-5196(20)30249-7>

Hathaway, J., & Maibach, E. W. (2018). Health Implications of Climate Change: a Review of the Literature About the Perception of the Public and Health Professionals. *Current Environmental Health Reports*, *5*(1), 197–204. <https://doi.org/10.1007/s40572-018-0190-3>

Health Canada. (1999). CAPITALizing on Science: Report of a Workshop on Climate Change, Science and Health. *Canadian Journal of Public Health.*

Health Canada. (2001). *How will climate change affect priorities for your health science and policy research?* [Conference]. First annual national health and climate change science and policy research consensus conference. Ottawa, ON.

Health Canada. (2004). *Climate change and health: Research report*. Ottawa, ON.

Health Canada. (2012). *Heat alert and response systems to protect health: Best practices guidebook.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/climate-change-health/heat-alert-response-systems-protect-health-best-practices-guidebook.html>

Health Canada. (2019a). *HealthADAPT.* Retrieved from <https://www.canada.ca/en/health-canada/programs/health-adapt.html>

Health Canada. (2020a). *Its much too hot: Protect yourself from extreme heat.* Ottawa, ON. Retrieved from <https://www.canada.ca/en/health-canada/services/publications/healthy-living/too-hot-protect-yourself-extreme-heat.html>

Health Canada. (2020b). *Keep children cool! Protect your child from extreme heat*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/health-canada/services/publications/healthy-living/keep-children-cool-extreme-heat.html>

Health Canada. (2020c). *You're active in the heat. You're at risk! Protect yourself from extreme heat*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/health-canada/services/environmental-workplace-health/reports-publications/climate-change-health/you-active-heat-you-risk-protect-yourself-extreme-heat-2011-health-canada-brochure.html>

Health Canada. (2020d). *Reducing urban heat islands to protect health in Canada. An introduction for public health professionals*. Ottawa, ON. Retrieved from <https://www.canada.ca/en/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada.html>

Health Canada. (2021). *Extreme heat and human health: Information for pharmacists and pharmacist technicians* [Factsheet]. Retrieved from <https://www.canada.ca/content/dam/hc-sc/documents/services/publications/healthy-living/extreme-heat-human-health-pharmacists-technicians/extreme-heat-human-health-pharmacists-technicians-eng.pdf>

Health Care Climate Council. (2018). *Climate action: A playbook for hospitals*. Retrieved from <https://climatecouncil.noharm.org/>

Health Care Without Harm. (2018). *Safe haven: Protecting lives and margins with climate-smart health care*. Retrieved from <https://noharm-uscanada.org/sites/default/files/documents-files/5146/Safe%20Haven.pdf>

Health Care Without Harm & ARUP. (2019). *Health Care's Climate Footprint: How the Health Sector Contributes to the Global Climate Crisis and Opportunities for Action.* Retrieved from <https://noharm-global.org/sites/default/files/documents-files/5961/HealthCaresClimateFootprint_092319.pdf>

Hess, J. J., & Ebi, K. L. (2016). Iterative management of heat early warning systems in a changing climate. *Annals of the New York Academy of Sciences*, *1382*(1), 21–30.

Hess, J., Lm, S., Knowlton, K., Saha, S., Dutta, P., Ganguly, P., Tiwari, A., Jaiswal, A., Sheffield, P., Sarkar, J., Bhan, S., Begda, A., Shah, T.A., Solanki, B., & Mavalankar, D. (2018). Building Resilience to Climate Change: Pilot Evaluation of the Impact of India's First Heat Action Plan on All-Cause Mortality. *Journal of Environmental and Public Health, 2018*(9). <https://doi.org/10.1155/2018/7973519>

Heudorf, U., & Schade, M. (2014). Heatwaves and mortality in Frankfurt am Main, Germany, 2003-2013: what effect do heat-health action plans and the heat warning system have?. *Zeitschrift fur Gerontologie und Geriatrie*, *47*(6), 475–482. <https://doi.org/10.1007/s00391-014-0673-2>

Hill, J. (2012). *Analysis of Climate Change and Health-Promotion Campaigns in Relation to Heat-Health Messages*. Report prepared for Health Canada. Ottawa, ON.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Dieghiou, A., Djalante, R., Ebi, K. L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S. I., Thomas, A., Warren, R., & Zhou, G. (2018). Impacts of 1.5°C Global Warming on Natural and Human Systems. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M.I.Gomis, E. Lonnoy, T.Maycock, M.Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Cambridge, United Kingdom: Cambridge University Press.

Holubec, I. (2008). *Flat Loop Thermosyphon Foundations in Warm Permafrost*. Prepared for Government of the NT Asset Management Division Public Works and Services and Climate Change Vulnerability Assessment Canadian Council of Professional Engineers. Retrieved from <https://pievc.ca/sites/default/files/appendix_b.6_northwest_territories_thermosyphon_foundations.pdf>

Hondula, D. M., Balling, R. C., Vanos, J. K., & Georgescu, M. (2015). Rising Temperatures, Human Health, and the Role of Adaptation. *Current Climate Change Reports, 1*(3), 144–154. <https://doi.org/10.1007/s40641-015-0016-4>

Howard, C., Rose, C., & Hancock, T. (2017). *Lancet countdown 2017 report: Briefing for Canadian policymakers.* Lancet Countdown, Canadian Medical Association, and Canadian Public Health Association. Retrieved from <https://www.cpha.ca/sites/default/files/uploads/advocacy/2017_lancet_canada_brief.pdf>

Howard, C., Rose, C., & Rivers, N. (2018). *Lancet countdown 2018 report: Briefing for Canadian policymakers.* Lancet Countdown, Canadian Medical Association, and Canadian Public Health Association. Retrieved from <https://cape.ca/wp-content/uploads/2018/11/2018-Lancet-Countdown-Policy-Brief-Canada.pdf>

Huang, C., Vaneckova, P., Wang, X., Fitzgerald, G., Guo, Y., & Tong, S. (2011). Constraints and barriers to public health adaptation to climate change: a review of the literature. *American Journal of Preventive Medicine*, *40*(2), 183–190. <https://doi.org/10.1016/j.amepre.2010.10.025>

Huang, C., Barnett, A. G., Xu, Z., Chu, C., Wang, X., Turner, L. R., & Tong, S. (2013). Managing the health effects of temperature in response to climate change: challenges ahead. *Environmental Health Perspectives*, *121*(4), 415–419. <https://doi.org/10.1289/ehp.1206025>

Hunt, A., Ferguson, J., Baccini, M., Watkiss, P., & Kendrovski, V. (2017) Climate and weather service provision: Economic appraisal of adaptation to health impacts. *Climate Services,* 7, 78–86. <https://doi.org/10.1016/j.cliser.2016.10.004>

Hutton, G., & Menne, B. (2014). Economic evidence on the health impacts of climate change in europe. *Environmental Health Insights*, *8*, 43–52. <https://doi.org/10.4137/EHI.S16486>

Indigenous Services Canada (ISC). (2019). *Community Voices on Climate Change and Health Adaptation in Northern Canada.* Ottawa, ON. Retrieved from <http://www.climatetelling.info/uploads/2/5/6/1/25611440/19-012-climate-change-c2-ang.pdf>

Interior Health. (2017). *@Interior Health: A publication for staff and physicians of IH.*

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, R. K. Pachauri & L. A. Meyer, Eds.). Geneva, Switzerland.

Janssen I. (2012). Health care costs of physical inactivity in Canadian adults. *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition et Metabolisme*, *37*(4), 803–806. <https://doi.org/10.1139/h2012-061>

Jarrett, J., Woodcock, J., Griffiths, U. K., Chalabi, Z., Edwards, P., Roberts, I., & Haines, A. (2012). Effect of increasing active travel in urban England and Wales on costs to the National Health Service. *Lancet (London, England)*, *379*(9832), 2198–2205. <https://doi.org/10.1016/S0140-6736(12)60766-1>

Jay, O., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R.S., Ma, W., Malik, A., Morris, N.B., Nybo, L., Seneviratne, S.I., Vanos, J., Ebi, K.L. Heat and Health 2 - Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. The Lancet. Vol 398: 709–24. <https://pubmed.ncbi.nlm.nih.gov/34419206/>

Kennedy, E., Olsen, H., Vanos, J., Vecellio, D. J., Desat, M., Richters, K., Rutledge, A., & Richardson, G. (2021). Reimagining spaces where children play: developing guidance for thermally comfortable playgrounds in Canada. *Canadian Journal of Public Health = Revue Canadienne de Sante Publique*, *112*(4), 706–713. <https://doi.org/10.17269/s41997-021-00522-7>

Kidd, S. A., Greco, S. & McKenzie, K. (2020). Global Climate Implications for Homelessness: A Scoping Review. *Journal of Urban Health*, *98,* 385-393. <https://doi.org/10.1007/s11524-020-00483-1>

Kigali Cooling Efficiency Program. (2018). *Global Climate Impact from Hospital Cooling.* Retrieved from <https://www.climateworks.org/wp-content/uploads/2018/11/kigali-ceo-global-hospital-cooling-report.pdf>

King, N., Bishop-Williams, K. E., Beauchamp, S., Ford, J. D., Berrang-Ford, L., Cunsolo, A., IHACC Research Team., & Harper, S. L. (2019). How do Canadian media report climate change impacts on health? A newspaper review. *Climatic Change, 152,* 581-596. <https://doi.org/10.1007/s10584-018-2311-2>

Knowledge Management. (2018). *Towards a pan-Canadian surveillance system for climate-related health indicators: Final report.* Kingston, ON: KFL&A Public Health.

Kodjak, A. (2017). Hurricane Damage To Manufacturers In Puerto Rico Affects Mainland Hospitals, Too. *National Public Radio*. Retrieved from <https://www.npr.org/sections/health-shots/2017/11/15/564203110/hurricane-damage-to-manufacturers-in-puerto-rico-affects-mainland-hospitals-too>

Kolnick, L. (2016). *Analysis of a decade of climate change and health research in Canada: Are researchers making progress in addressing identified knowledge gaps?*. Report prepared for Health Canada.

Kovacs, P., Guilbault, S., Darwish, L., & Comella, M. (2018). *Cities adapt to extreme weather: Celebrating local leadership. Institute for Catastrophic Loss Reduction.* Retrieved from <https://www.iclr.org/wp-content/uploads/2018/12/Cities-Adapt-Website.pdf>

Kovacs, P., Guilbault, S., Lambert, E., & Kovacs, R. (2020). *Cities adapt to extreme wildfires: Celebrating local leadership. Institute for Catastrophic Loss Reduction.* Retrieved from <https://www.iclr.org/wp-content/uploads/2020/12/Cities-Adapt-to-Extreme-WILDFIRES_Final_Dec19.pdf>

Kovats, S., Lloyd, S., Hunt, A., & Watkiss, P. (2011). *The Impacts and Economic Costs on Health in Europe and the Costs and Benefits of Adaptation.* Technical Policy Briefing Note Series. Oxford, United Kingdom: Stockholm Environment Institute.

KPMG. (2017). *May 2016 Wood Buffalo Wildfire Post-Incident Assessment Report. Report prepared for Alberta Emergency Management Agency.* Prepared for Alberta Emergency Management Agency. Retrieved from <https://www.alberta.ca/assets/documents/Wildfire-KPMG-Report.pdf>

Kuchmij, N., Berry, P., Enright, P., Schnitter, R., & Hamilton, S. (2020). *Climate and Health Vulnerability & Adaptation Assessments: A Knowledge to Action Resource Guide*. Ottawa, ON: Health Canada.

Kyselý, J., & Plavcová, E. (2012). Declining impacts of hot spells on mortality in the Czech Republic, 1986–2009: Adaptation to climate change? *Climatic Change*, *113*, 437–453.

L'Hérault, E., Michel, A., Fortier, D., Carbonneau, A-S., Doyon-Robitaille, J., Lachance, M-P., Ducharme, M-A., Larrivée, K., Grandmont, K., & Lemieux, C. (2013). *Production de cartes prédictives des caractéristiques du pergélisol afin de guider le développement de l'environnement bâti pour les communautés du Nunavik.* Rapport final. Québec, QC : Centre d'études nordiques, Université Laval.

Lambert, S. (2018). Judge approves $90M settlement for flooded Manitoba First Nations. *CBC News.* Retrieved from <https://www.cbc.ca/news/canada/manitoba/manitoba-first-nations-flooding-settlement-1.4482353>

Larrivée, C., Sinclair-Désgagné, N., Da Silva, L., Revéret, J. P., Desjarlais, C. (2015). *Évaluation des impacts des changements climatiques et de leurs coûts pour le Québec et l'État québécois. Rapport d'étude*. Montréal, QC: Ouranos. Retrieved from <https://www.environnement.gouv.qc.ca/changementsclimatiques/evatuation-impacts-cc-couts-qc-etat.pdf>

Lebel, G., Dubé, M., & Bustinza, R. (2019). Surveillance des impacts des vagues de chaleur extrême sur la santé au Québec à l'été 2018. Institut National De Santé Publique du Québec. Retrieved from <https://www.inspq.qc.ca/bise/surveillance-des-impacts-des-vagues-de-chaleur-extreme-sur-la-sante-au-quebec-l-ete-2018>

Lee, V., Zermoglio, F., Ebi, K. L., & Chemonics International Inc. (2019). *Heatwaves and Human Health: Emerging Evidence and Experience to Inform Risk Management in a Warming World.* United States Agency for International Development. Retrieved from <https://www.climatelinks.org/sites/default/files/asset/document/2019_USAID-ATLAS_Heat-Waves-and-Human-Health.pdf>

Legassic, A. (2018). Interior Health facilities filling up with wildfire evacuated patients. *Info News.* Retrieved from <https://infotel.ca/newsitem/interior-health-facilities-filling-up-with-wildfire-evacuated-patients/it44209>

Lesnikowski, A., Ford, J., Berrang-Ford, L., Paterson, J., Barrera, M., & Heymann, S. (2011). Adapting to health impacts of climate change: A study of UNFCCC Annex I parties. *Environmental Research Letters, 6*(4), 044009. doi:10.1088/1748-9326/6/4/044009

Levison, M. M., Butler, A. J., Rebellato, S., Armstrong, B., Whelan, M., & Gardner, C. (2018). Development of a Climate Change Vulnerability Assessment Using a Public Health Lens to Determine Local Health Vulnerabilities: An Ontario Health Unit Experience. *International Journal of Environmental Research and Public Health*, *15*(10), 2237. <https://doi.org/10.3390/ijerph15102237>

Limaye, V. S., Max., W., Consitible., J., & Knowlton, K. (2019). Estimating the health-related costs of 10 climate-sensitive U.S. events during 2012. *GeoHealth, 3*(9), 245-265. <https://doi.org/10.1029/2019GH000202>

Lower Mainland Facilities Management. (2020). *Moving towards climate resilient health facilities for Vancouver Coastal Health.* Retrieved from <https://bcgreencare.ca/system/files/resource-files/VCH_ClimateReport%2BAppendices_Final_181025.pdf>

Luehr, G. (2018). *Health co- 'benefits' and 'risks' in climate change mitigation technologies and policies: A review for Canada*. Report Prepared for Health Canada.

MacIntyre, E., Khanna, S., Darychuk, A., Copes, R., & Schwartz, B. (2019). Evidence synthesis - Evaluating risk communication during extreme weather and climate change: a scoping review. *Health Promotion and Chronic Disease Prevention in Canada : Research, Policy and Practice*, *39*(4), 142–156. <https://doi.org/10.24095/hpcdp.39.4.06>

Maguet, S. (2020). *Climate change and health: A research agenda for BC.* Retrieved from <https://shiftcollaborative.ca/wp-content/uploads/2020/05/Adaptation-Canada-2020-Climate-Change-and-Health-Dialogue-Report.pdf>

Maibach, E. (2019). Increasing public awareness and facilitating behavior change: Two guiding heuristics. In L. Hannah & T. Lovejoy (Eds.), *Climate Change and Biodiversity* (2nd ed.) Yale University Press.

Man, R. X., Lack, D. A., Wyatt, C. E., & Murray, V. (2018). The effect of natural disasters on cancer care: a systematic review. *The Lancet. Oncology*, *19*(9), e482–e499. <https://doi.org/10.1016/S1470-2045(18)30412-1>

Martinez, G. S., Berry, P., Balbus, J., Hodgson, T., Salazar, M. Sellers, S., & Hess, J. (2018). The adaptation health gap: A global overview. In H. Neufeldt, G. S. Martinez, A. Olhoff, C. Knudsen, & K. Dorkenoo (Eds.), *The Adaptation Gap Health Report.* Nairobi, Kenya: United Nations Environment Programme (UNEP). Retrieved from <https://www.unep.org/resources/adaptation-gap-report-2018>

Martinez, G. S., Linares, C., Ayuso, A., Kendrovski, V., Boeckmann, M., & Diaz, J. (2019). Heat-health action plans in Europe: Challenges ahead and how to tackle them. *Environmental Research*, *176*, 108548. <https://doi.org/10.1016/j.envres.2019.108548>

Matthies, F. Bickler, G., Marín, N. C., & Hales, S. (Eds.). (2008). *Heat health action plan guidance.* World Health Organization Europe. Retrieved from <http://www.euro.who.int/__data/assets/pdf_file/0006/95919/E91347.pdf?ua=1>

McGregor, G. R., Bessemoulin, P., Ebi, K., & Menne B. (Eds.). (2015). *Heatwaves and Health: Guidance on Warning-System Development.* World Meteorological Organization and World Health Organization. Retrieved from <https://www.who.int/globalchange/publications/WMO_WHO_Heat_Health_Guidance_2015.pdf?ua=1>

Mehiriz, K., & Gosselin, P. (2019). Evaluation of the Impacts of a Phone Warning and Advising System for Individuals Vulnerable to Smog. Evidence from a Randomized Controlled Trial Study in Canada. *International Journal of Environmental Research and Public Health*, *16*(10), 1817. <https://doi.org/10.3390/ijerph16101817>

Mehiriz, K., Gosselin, P., Tardif, I., & Lemieux, M. A. (2018). The Effect of an Automated Phone Warning and Health Advisory System on Adaptation to High Heat Episodes and Health Services Use in Vulnerable Groups-Evidence from a Randomized Controlled Study. *International Journal of Environmental Research and Public Health*, *15*(8), 1581. <https://doi.org/10.3390/ijerph15081581>

Michelozzi, P., De Sario, M., Accetta, G., de'Donato, F., Kirchmayer, U., D'Ovidio, M., Perucci, C. A., & HHWWS Collaborative Group (2006). Temperature and summer mortality: geographical and temporal variations in four Italian cities. *Journal of Epidemiology and Community Health*, *60*(5), 417–423. <https://doi.org/10.1136/jech.2005.040857>

Miller, F., Bytautas, J.P., & Feng, P. (2018). *Opportunities for engaging Canadian health systems in addressing the challenge of climate change.* Retrieved from <https://ssrn.com/abstract=3167088>

Missirian, A., & Schlenker, W. (2017). Asylum applications respond to temperature fluctuations. *Science (New York, N.Y.)*, *358*(6370), 1610–1614. <https://doi.org/10.1126/science.aao0432>

MNP LLP. (2013). *Review and Analysis of the Government of Alberta's Response to and Recovery from the 2013 Floods.* Report prepared for the Alberta Emergency Management Agency and the Government of Alberta. Retrieved from <https://open.alberta.ca/dataset/48bd39ee-2a5a-4846-944d-6004e0a8a498/resource/8404f003-1bde-49d9-a953-d37e0d671dac/download/2013-flood-response-report.pdf>

Morabito, M., Profili, F., Crisci, A., Francesconi, P., Gensini, G. F., & Orlandini, S. (2012). Heat-related mortality in the Florentine area (Italy) before and after the exceptional 2003 heatwave in Europe: an improved public health response?. *International journal of biometeorology*, *56*(5), 801–810. <https://doi.org/10.1007/s00484-011-0481-y>

National Academies of Sciences, Engineering, and Medicine (NASEM). (2018). *Protecting the health and well-being of communities in a changing climate: Proceedings of a workshop.* Washington, DC: The National Academies Press.

National Health Service. (2016). *NHS and health and care sector hit first target on climate change – but more testing goals are to come.* Retrieved from <https://www.england.nhs.uk/2016/01/climate-change/>

National Intelligence Council (NIC). (2016). *Implications for US National Security of Anticipated Climate Change.* Retrieved from <https://www.dni.gov/files/documents/Newsroom/Reports%20and%20Pubs/Implications_for_US_National_Security_of_Anticipated_Climate_Change.pdf>

Noble, I. R., Huq, S., Anokhin, Y. A., Carmin, J., Goudou, D., Lansigan, F. P., Osman-Elasha, B., & Villamizar, A. (2014). Adaptation needs and options. In C. B. Field, , V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Northern Health. (2018a). *2017 Cariboo Wildfires: Northern Health After Action Report*. Prince George, BC: Northern Health Emergency Management. Retrieved from <https://physicians.northernhealth.ca/sites/physicians/files/news/documents/2018/after-action-review-report-cariboo-wildfires-2017.pdf>

Northern Health. (2018b). *Stuart Lake Hospital (Fort St. James) - advance patient transfers*. Retrieved from <https://www.northernhealth.ca/newsroom/stuart-lake-hospital-fort-st-james-advance-patient-transfers>

Northern Health. (2018c). *Wildfires, heart health and hospital projects: NH Board meeting highlights.* Retrieved from <https://www.northernhealth.ca/newsroom/wildfires-heart-health-and-hospital-projects-nh-board-meeting-highlights?keys=2018%20wildfire#>

Nova Scotia. (2003). *A Report on emergency response to Hurricane Juan.* Retrieved from <https://www.halifaxexaminer.ca/wp-content/uploads/2019/09/report_on_the_emergency_response_to_hurricane_juan.pdf>

Nova Scotia Health Authority. (2019a). *PSA: Nova Scotia Health Authority responding to impacts of Hurricane Dorian.* Retrieved from <https://www.nshealth.ca/news/psa-nova-scotia-health-authority-responding-impacts-hurricane-dorian>

Nova Scotia Health Authority. (2019b). *Several NSHA facilities experiencing downed phones lines in wake of Hurricane Dorian.* Retrieved from <https://www.nshealth.ca/news/several-nsha-facilities-experiencing-downed-phones-lines-wake-hurricane-dorian>

Paavola, J. (2017). Health impacts of climate change and health and social inequalities in the UK. *Environmental Health, 16*, 113. <https://doi.org/10.1186/s12940-017-0328-z>

Panditharatne, M. (2018). *Six Months After Maria: Puerto Rico's Growing Health Crisis.* Natural Resource Defense Council. Retrieved from <https://www.nrdc.org/experts/mekela-panditharatne/six-months-after-maria-puerto-ricos-growing-health-crisis>

Paterson, J. A., Ford, J. D., Berrang-Ford, L., Lesnikowski, A., Berry, P., Henderson, J., & Heymann, J. (2012). Adaptation to climate change in the Ontario public health sector. *BMC Public Health*, *12*, 452. <https://doi.org/10.1186/1471-2458-12-452>

Paterson, J., Berry, P., Ebi, K., & Varangu, L. (2014). Health care facilities resilient to climate change impacts. *International Journal of Environmental Research and Public Health*, *11*(12), 13097–13116. <https://doi.org/10.3390/ijerph111213097>

Patz, J. A., & Thomson, M. C. (2018). Climate change and health: Moving from theory to practice. *PLoS Medicine*, *15*(7), e1002628. <https://doi.org/10.1371/journal.pmed.1002628>

Perotta, K. (Ed.). (2019). *Climate change toolkit for health professionals*. Canadian Association of Physicians for the Environment (CAPE). Retrieved from <https://cape.ca/wp-content/uploads/2019/05/Climate-Change-Toolkit-for-Health-Professionals-Updated-April-2019-2.pdf>

Philip, S. Y., Kew, S. F., van Oldenborgh, G. J., Yang, W., Vecchi, G. A., Anslow, F. S., Li, S., Seneviratne, S. I., Luu, L. N., Arrighi, J., Singh, R., van Aalst, M., Hauser, M., Schumacher, D. L., Marghidan, C. P., Ebi, K. L., Bonnet, R., Vautard, R., Tradowsky, J., … Otto, F. E. L., (2021). *Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada June 2021.* Retrieved from <https://www.ecodebate.com.br/wp-content/uploads/2021/07/20210707-rapid-attribution-analysis-of-the-extraordinary-heatwave-on-the-pacific-coast-of-the-us-and-canada-june-2021.pdf>

Pichler, P. P., Jaccard, I. S., Weisz, U., & Weisz, H. (2019). International comparison of health care carbon footprints *Environmental Research Letters, 14*(6), 064004. <https://doi.org/10.1016/S2542-5196(20)30121-2>

Poitras, A. (2018). *Extreme heatwaves in Quebec*. Retrieved from<https://climatedata.ca/case-study/extreme-heat-waves-in-quebec/>

Presse Canadienne. (2017). Quebec floods: Long wait for some patients forced out by water. *Montreal Gazette.* Retrieved from <https://montrealgazette.com/news/local-news/quebec-floods-long-wait-for-some-hospital-patients-forced-out-by-water>

Public Health Agency of Canada (PHAC). (2017). *The Chief Public Health Officer's Report on the State of Public Health in Canada 2017 – Designing Healthy Living.* Retrieved from <https://www.canada.ca/en/public-health/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living.html>

Public Infrastructure Engineering Vulnerability Committee (PIEVC). (n.d.). *The Protocol.* Retrieved from <https://pievc.ca/protocol>

Public Safety Canada (PSC). (2017). *An emergency management framework for Canada - Third Edition.* Ottawa, ON: Emergency Management Policy and Outreach Directorate. Retrieved from <https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2017-mrgnc-mngmnt-frmwrk/2017-mrgnc-mngmnt-frmwrk-en.pdf>

RDH Building Science. (2018). N*anaimo Regional General Hospital Climate Change Vulnerability Assessment Report*. Retrieved from <https://pievc.ca/sites/default/files/nrgh-pievc-climate-change-vulnerability-assessment-report-e.pdf>

Ribesse, J., & Varangu, L. (2019). *Climate Change Toolkit for Health Professionals: Module 6 – Taking Action on Climate Change at Health Facilities.* Canadian Association of Physicians for the Environment (CAPE). Retrieved from <https://cape.ca/wp-content/uploads/2019/04/Module-6-Final-Solo-April-2-2019.pdf>

Roffel, B. (2021). BC's heatwave likely contributed to 719 sudden deaths in a week, coroner says – triple the usual number. *CBC News*. Retrieved from <https://www.cbc.ca/news/canada/british-columbia/heat-wave-719-deaths-1.6088793>

Roles, A. (2013). *Southern Alberta Flood.* Presented to the Canadian Healthcare Network.

Royal Society of Canada. (1995). *Implications of global change for human health: Final report of the health issues panel of the Canadian Global Change Program*. Incidental Report. No IR95-2.

Schifano, P., Leone, M., De Sario, M., de'Donato, F., Bargagli, A. M., D'Ippoliti, D., Marino, C., & Michelozzi, P. (2012). Changes in the effects of heat on mortality among the elderly from 1998-2010: results from a multicenter time series study in Italy. *Environmental Health : A Global Access Science Source*, *11*, 58. <https://doi.org/10.1186/1476-069X-11-58>

Scott, D., Minano, A., Chakraborty, L., Henstra, D., Thistlethwaite, J., & Apajee, Y. (2020). *Flood risk analysis of Canadian health and emergency infrastructure*. Climate Risk Research Group, University of Ottawa.

Séguin. J. (Ed.). (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities*

and Adaptive Capacity. Ottawa, ON: Health Canada. Retrieved from <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Sellers, S., & Ebi, K. L. (2017). Climate change and health under the shared socioeconomic pathway framework. *International Journal of Environmental Research and Public Health*, *15*(1), 3. <https://doi.org/10.3390/ijerph15010003>

Shah, C., Ford, J., Labbe, J., & Flynn, M. (2018). Adaptation policy & practice in Nunavik. OURANOS. Retrieved from <https://www.ouranos.ca/publication-scientifique/RapportFord2018.pdf>

Shapiro, L. T., Gater, D. R., Jr, Espinel, Z., Kossin, J. P., Galea, S., & Shultz, J. M. (2020). Preparing individuals with spinal cord injury for extreme storms in the era of climate change. *EClinicalMedicine*, *18*, 100232. <https://doi.org/10.1016/j.eclinm.2019.12.002>

Sheridan, S. C., & Allen, M. J. (2018). Temporal trends in human vulnerability to excessive heat. E*nvironmental Research Letters, 13*(4), 043001. <https://doi.org/10.1088/1748-9326/aab214>

Sheridan, S. C., & Dixon, P. G. (2016). Spatiotemporal trends in human vulnerability and adaptation to heat across the United States. *Anthropocene*, *20*, 61-73. <https://doi.org/10.1016/j.ancene.2016.10.001>

Shin, Y. S., & Ha, J. (2012). Policy Directions Addressing the Public Health Impact of Climate Change in South Korea: The Climate-change Health Adaptation and Mitigation Program. *Environmental Health and Toxicology*, *27*, e2012018. <https://doi.org/10.5620/eht.2012.27.e2012018>

Shindell, D.T., Lee, Y., & Faluveg, G. (2016). Climate and health impacts of US emissions reductions consistent with 2°C. *Nature Climate Change, 6*(5), 503-507. doi:10.1038/nclimate2935, 2016.

Shindell, D. T., Faluvegi, G., Seltzer, K., & Shindell C. (2018). Quantified, localized health benefits of accelerated carbon dioxide emission reductions. *Nature Climate Change, 8*(4), 291-295. doi:10.1038/s41558-018-0108-y

Shumake-Guillemot, J., Amir, S., Anwar, N., Arrighi, J., Böse-O'Reilly, S., Brearley, M., Cross, J., Daanen, H., … Zaitchik, B. (2020). *Technical brief: Protecting health from hot weather during the COVID-19 pandemic.* Global Heat Health Information Network. Retrieved from <http://www.ghhin.org/assets/technical-brief-COVID-and-Heat-final.pdf>

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., . . . Sauerborn, R. (2014). Human health: Impacts, adaptation, and co-benefits. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 709-754). Cambridge, United Kingdom: Cambridge University Press. Retrieved from <https://www.ipcc.ch/report/ar5/wg2/>

Springmann, M., Godfray, H. C., Rayner, M., & Scarborough, P. (2016). Analysis and valuation of the health and climate change cobenefits of dietary change. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(15), 4146–4151. <https://doi.org/10.1073/pnas.1523119113>

Survey Research Centre. (2019). *Survey of health sector officials: A contribution to Health Canada's Climate Change and Health Adaptation Capacity Building Program and the National Assessment - Technical and data analysis report*. Report prepared for Health Canada. University of Waterloo.

Tan, J., Zheng, Y., Song, G., Kalkstein, L. S., Kalkstein, A. J., & Tang, X. (2007). Heatwave impacts on mortality in Shanghai, 1998 and 2003. *International Journal of Biometeorology*, *51*(3), 193–200. <https://doi.org/10.1007/s00484-006-0058-3>

Toews, E. (2018). In the face of fire. Canadian healthcare facilities. *Hospital News.* Retrieved from <https://hospitalnews.com/face-fire-taking-care-healthcare-facilities/>

Tröltzsch, J., Görlach, B., Lückge, H., Peter, M., & Sartorius, C. (2012). *Costs and benefits of climate adaptation measures.* Umweltbundesamt. Retrieved from <https://www.umweltbundesamt.de/en/topics/climate-energy/climate-change-adaptation/adaptation-tools/project-catalog/costs-benefits-of-climate-change-adaptation>

United Nations Environment Program (UNEP). (2018). *The Adaptation Gap Report 2018.* Nairobi, Kenya. Retrieved from <https://wedocs.unep.org/bitstream/handle/20.500.11822/27114/AGR_2018.pdf?sequence=3>

United Nations Framework Convention on Climate Change (UNFCCC). (2015). Paris Agreement. <https://unfccc.int/sites/default/files/english_paris_agreement.pdf>

United Nations Office for Disaster Risk Reduction (UNDRR). (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030.* Retrieved from <https://www.unisdr.org/we/inform/publications/43291>

United Nations Office for Disaster Risk Reduction (UNDRR). (2019). *Critical infrastructure including schools, health facilities, and roads threatened by the climate crisis.* Retrieved from <https://www.undrr.org/news/critical-infrastructure-including-schools-health-facilities-and-roads-threatened-climate>

United Nurses of Alberta. (2013). *UNA Calgary office closed, many health facilities affected by southern Alberta flooding.* Retrieved from <https://www.una.ab.ca/194/una-calgary-office-closed-many-health-facilities-affected-by-calgary-flooding>

University Health Network (UHN). (2021). *UNH reducing emissions with huge new wastewater energy system.* Retrieved from <https://www.uhn.ca/corporate/News/Pages/UHN_reducing_emissions_with_huge_new_wastewater_energy_system.aspx>

Valois, P., Jacob, J., Mehiriz, K., Talbot, D., Renaud, J.-S., & Caron, M. (2018). *Portrait de l'adaptation aux changements climatiques dans les organisations du secteur de la santé au Québec.* Québec, QC: Université Laval.

Valois, P., Talbot, D., Caron, M., Carrier, M.-P., Morin, A. J. S., Renaud, J.-S., Jacob, J. & Gosselin, P. (2017). Development and Validation of a Behavioural Index for Adaptation to High Summer Temperatures among Urban Dwellers. International *Journal of Environmental Research and Public Health*, *14*(7), 820. <https://doi.org/10.3390/ijerph14070820>

Vanlint, L. (2019). A Deeply Cool Year in Energy & Environment. *Talkin' Trash with UHN.* Retrieved from <https://talkintrashwithuhn.com/2019/05/03/a-deeply-cool-year-in-energy-environment/>

Vodden, K., & Cunsolo, A. (2021). Rural and Remote Communities. In F. J. Warren & N. Lulham (Eds.), *Canada in a Changing Climate: National Issues Report.* Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/national-issues/>

Waddington, K., & Varangu, L. (2016). Canadian Coalition for Green Health Care Leading the Evolution of Green. *Healthcare Quarterly (Toronto, Ont.)*, *19*(3), 23–29. <https://doi.org/10.12927/hcq.2016.24869>

Waddington, K., Varangu, L., Berry, P., & Paterson, J. (2013). Preparing for the health impacts of climate change: How ready is your health care organization? *Journal of the Canadian Healthcare Engineering Society, 1,* 34–39.

Wardekker, J. A., de Jong, A., van Bree, L., Turkenburg, W. C., & van der Sluijs, J. P. (2012). Health Risks of Climate Change: An Assessment of Uncertainties and Its Implications for

Adaptation Policies. *Environmental Health, 11*(67). <https://doi.org/10.1186/1476-069X-11-67>

Warr, S. (2016). *Northern Lights Regional Health Centre evacuation swift and successful*. Alberta Health Services. Retrieved from <https://www.albertahealthservices.ca/news/features/2016/page13156.aspx>

Watkiss, P. (2015) *A review of the economics of adaptation and climate-resilient development*. Centre for Climate Change Economics and Policy and Grantham Research institute on Climate Change and the Environment. Retrieved from <https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2015/09/Working-Paper-205-Watkiss.pdf>

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P. M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., Hamilton, I., … Costello, A. (2015). Health and climate change: policy responses to protect public health. *Lancet (London, England)*, *386*(10006), 1861–1914. <https://doi.org/10.1016/S0140-6736(15)60854-6>

Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Beagley, J., Belesova, K., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Coleman, S., Dalin, C., Daly, M., Dasandi, N., Dasgupta, S., Davies, M., Di Napoli, C., Dominguez-Salas, P., … Costello, A. (2021). The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. *Lancet (London, England)*, *397*(10269), 129–170. <https://doi.org/10.1016/S0140-6736(20)32290-X>

Watts, N., Amann, M., Ayeb-Karlsson, S., Belesova, K., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J., Cox, P. M., Daly, M., Dasandi, N., Davies, M., Depledge, M., Depoux, A., Dominguez-Salas, P., Drummond, P., Ekins, P., Flahault, A., … Costello, A. (2018). The Lancet Countdown on health and climate change: from 25 years of inaction to a global transformation for public health. *Lancet (London, England)*, *391*(10120), 581–630. <https://doi.org/10.1016/S0140-6736(17)32464-9>

Watts, T. (2014). *Alberta Health Services: Southern Alberta Floods 2013*. Presented at the Hospital Emergency Preparedness Conference of Ottawa. Retrieved from <https://www.drieottawa.org/presentations/20141017/20141017_tom_watts.pdf>

Weinberger, K. R., Zanobetti, A., Schwartz, J., & Wellenius, G. A. (2018). Effectiveness of National Weather Service heat alerts in preventing mortality in 20 US cities. *Environment international*, *116*, 30–38. <https://doi.org/10.1016/j.envint.2018.03.028>

Weisskopf, M. G., Anderson, H. A., Foldy, S., Hanrahan, L. P., Blair, K., Török, T. J., & Rumm, P. D. (2002). Heatwave morbidity and mortality, Milwaukee, Wis, 1999 vs 1995: an improved response?. *American Journal of Public Health*, *92*(5), 830–833. <https://doi.org/10.2105/ajph.92.5.830>

Wheeler, N., Watts, N. (2018). Climate Change: From Science to Policy. *Curr Envir Health Rpt* 5, 170–178 (2018). <https://doi.org/10.1007/s40572-018-0187-y>

Wondmagegn, B. Y., Xiang, J., Williams, S., Pisaniello, D., & Bi, P. (2019). What do we know about the healthcare costs of extreme heat exposure? A comprehensive literature review. *The Science of the Total Environment*, *657*, 608–618. <https://doi.org/10.1016/j.scitotenv.2018.11.479>

Woodcock, J., Abbas, A., Ullrich, A., Tainio, M., Lovelace, R., Sá, T. H., Westgate, K., & Goodman, A. (2018). Development of the Impacts of Cycling Tool (ICT): A modelling study and web tool for evaluating health and environmental impacts of cycling uptake. *PLoS Medicine*, *15*(7), e1002622. <https://doi.org/10.1371/journal.pmed.1002622>

World Bank. (2017). *Climate-smart health care: Low-carbon and resilience strategies for the health sector*. Washington, DC. Retrieved from <https://documents1.worldbank.org/curated/en/322251495434571418/pdf/113572-WP-PUBLIC-FINAL-WBG-Climate-smart-Healthcare-002.pdf>

World Health Organization (WHO). (2009). *Protecting health from climate change: Global research priorities.* Geneva, Switzerland. Retrieved from <https://www.afro.who.int/publications/protecting-health-climate-change-global-research-priorities>

World Health Organization (WHO). (2010). *Protecting health in an environment challenged by climate change: European Regional Framework for Action.* Copenhagen, Denmark. Retrieved from <https://www.euro.who.int/__data/assets/pdf_file/0005/95882/Parma_EH_Conf_edoc06rev1.pdf>

World Health Organization (WHO). (2013). *Protecting Health from Climate Change: Vulnerability and Adaptation Assessment.* Retrieved from <http://www.who.int/iris/handle/10665/104200>

World Health Organization (WHO). (2015). *Operational Framework for Building Climate Resilient Health Systems.* Geneva, Switzerland. Retrieved form <http://apps.who.int/iris/bitstream/10665/189951/1/9789241565073_eng.pdf?ua=1>

World Health Organization (WHO). (2018a). *WHO UNFCCC Climate Health Country Profile Project—Monitoring Health Impacts of Climate Change and Progress in Building Climate Resilient Health Systems*.

World Health Organization (WHO). (2018b). *Factsheet: Climate change and health*. Retrieved from <https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health#:~:text=Climate%20change%20affects%20the%20social,malaria%2C%20diarrhoea%20and%20heat%20stress>

World Health Organization (WHO). (2018c). *COP24 Special Report: Health and Climate Change*. Retrieved from <https://apps.who.int/iris/bitstream/handle/10665/276405/9789241514972-eng.pdf>

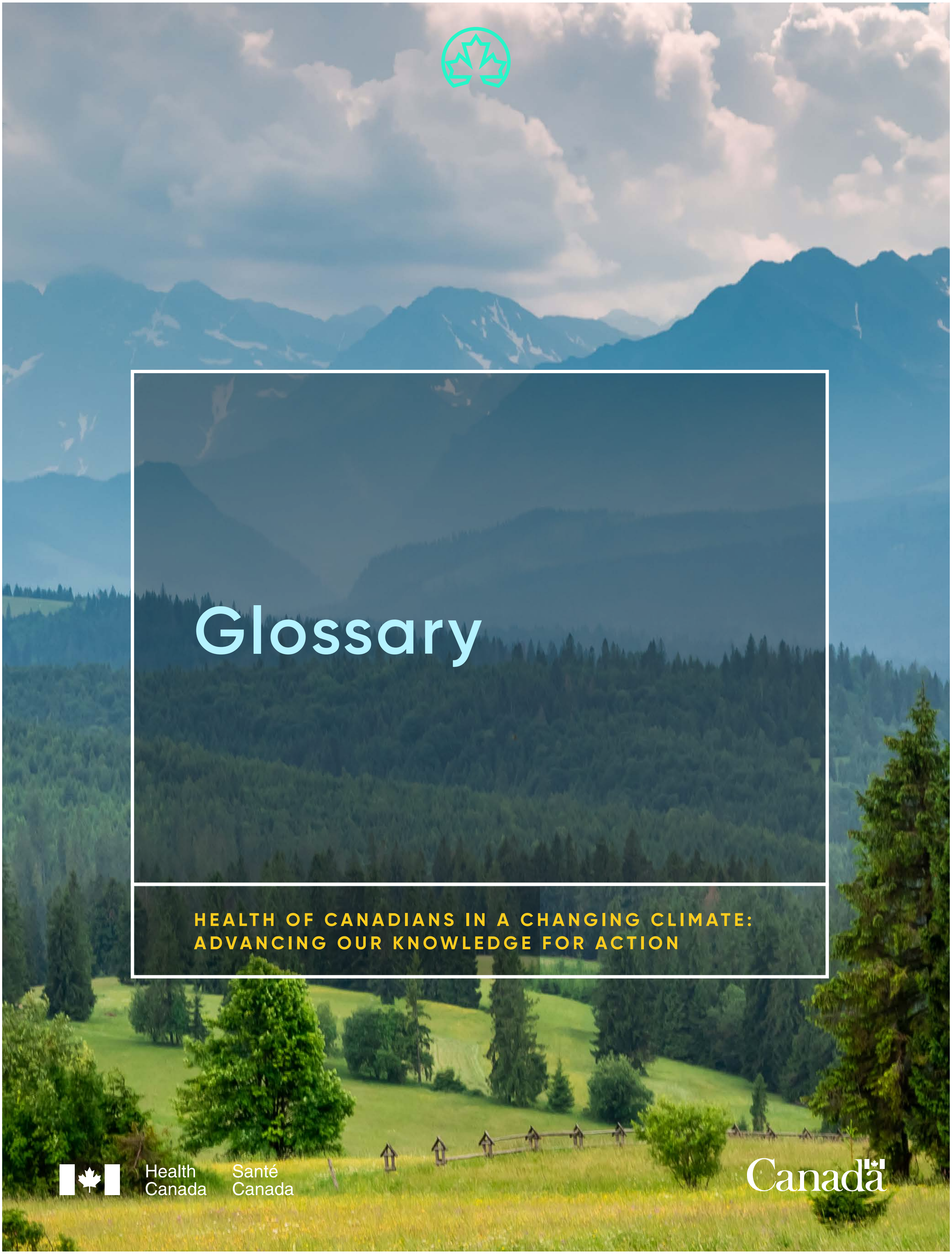
World Health Organization (WHO). (2019). *2018 WHO health and climate change survey report: Tracking global progress*. Retrieved from <https://apps.who.int/iris/handle/10665/329972>

World Health Organization (WHO). (2020). *WHO guidance for climate-resilient and environmentally sustainable health care facilities*. Geneva, Switzerland. Retrieved from <https://www.who.int/publications/i/item/9789240012226>

World Health Organization (WHO). (2021). *Quality criteria for health national adaptation plans*. Geneva, Switzerland. Retrieved from <https://www.who.int/publications/i/item/quality-criteria-health-national-adaptation-plans>

World Health Organization (WHO), & World Bank. (2018). *Methodological guidance: Climate change and health diagnostic. Country-based approach for assessing risks and investing in climate-smart health systems.* Retrieved from <https://documents.worldbank.org/en/publication/documents-reports/documentdetail/552631515568426482/a-country-based-approach-for-assessing-risks-and-investing-in-climate-smart-health-systems>

Zhang, X., Flato, G., Kirchmeier-Young, M., Vincent, L., Wan, H., Wang, X., Rong, R., Fyfe, J., Li, G., & Kharin, V. V. (2019). Changes in temperature and precipitation across Canada. In E. Bush & D.S. Lemmen (Eds.), *Canada's Changing Climate Report.* Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019>



Glossary

HEALTH OF CANADIANS IN A CHANGING CLIMATE:
ADVANCING OUR KNOWLEDGE FOR ACTION

Health Canada Santé Canada

Canada

Acute – Occurring over a short period of time (as opposed to *chronic*).

Adaptation – The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or to exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014).

Adaptation mainstreaming – Integrating climate change adaptation considerations and information into policies, programs, and operations at all levels of decision making rather than creating new policies or policy instruments. The goal is to make the adaptation process an essential component of existing decision making and planning frameworks (adapted from UNDP, 2005).

Adaptive capacity – The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2014).

Aerosols – A collection of airborne solid or liquid particles with a typical size of 0.01 to 10 mm that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in two ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds (IPCC, 2001).

Air Quality Benefits Assessment Tool (AQBAT) – A computer application designed by Health Canada that provides economic valuation estimates of health impacts of air quality, considering the potential social, economic, and public welfare consequences of the health outcomes, including medical costs, reduced workplace productivity, pain and suffering, and increased mortality risk (Government of Canada, 2020).

Albedo – The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the surface albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's planetary albedo varies mainly through differences in cloudiness, snow, ice, leaf area and land cover changes (IPCC, 2007).

Anomaly – Departure from the average over a reference period (Bush & Lemmen, 2019).

Anthropogenic – Resulting from human activities or produced by human beings (IPCC, 2007).

Atmosphere – The gaseous envelope surrounding the Earth. The atmosphere consists almost entirely of nitrogen and oxygen, together with a number of trace gases such as argon and helium, and greenhouse gases such as carbon dioxide and ozone. In addition, the atmosphere contains water vapour, clouds, and aerosols (WHO, 2003).

Attribution (science) – Identifying the causes of an observed change or event in terms of the relative contributions of multiple causal factors (Bush & Lemmen, 2019).

Autochthonous – Formed or originating in the place where it is found.

Baseline – The baseline (or reference) is the state against which change is measured. A baseline period is the period relative to which anomalies are computed (IPCC, 2014).

Black carbon – Commonly known as *soot*. An aerosol that is emitted as a result of the incomplete combustion of carbon-based fuels. Black carbon absorbs solar radiation and has a warming effect. It is termed a short-lived climate pollutant given it remains in the atmosphere only for days or weeks (IPCC, 2018).

Burden of disease – The burden of disease can be thought of as the measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability (UNEP, 2018).

Carbon dioxide (CO_2) – A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas, and coal, of burning biomass, of land use changes, and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1 (IPCC, 2014).

Chronic – Occurring over a long period of time (as opposed to *acute*).

Climate –The average or expected weather and related atmospheric, land, and marine conditions for a particular location over a given period. The usual period for averaging weather variables is 30 years, as defined by the World Meteorological Organization. The relevant variables are usually temperature, precipitation, and wind (IPCC, 2007).

Climate anxiety – See Ecoanxiety

Climate change – A persistent, long-term change in the state of the climate, measured by changes in the mean state and/or its variability. Climate change may be due to natural internal processes, natural external forcings such as volcanic eruptions and modulations of the solar cycle, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014).

Climate change scenario – See Climate scenario

Climate model – A computer-based 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 some of the climate system's known properties. Climate models are used as a research tool, to study and simulate the climate, and for operational purposes, to make monthly, seasonal, and year-over-year climate projections (IPCC, 2007).

Climate penalty – The impact of climate change alone on air quality based on constant, present-day emissions (Wu et al., 2008).

Climate projection – A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative-forcing scenario used, which is in turn based on assumptions concerning, for example, future socio-economic and technological developments that may or may not be realized (IPCC, 2014).

Climate-resilient health systems – Systems that can anticipate, respond to, cope with, recover from, and adapt to climate-related shocks and stresses, to make sustained improvements to population health, despite an unstable climate (WHO, 2015).

Climate scenario – A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as the observed current climate (IPCC, 2014).

Climate variability (or internal climate variability) – Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all space and time scales beyond individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2007).

Co-benefits – The positive effects that a policy or measure aimed at one objective might have on other objectives, regardless of its net effect on overall social welfare. Co-benefits (or *ancillary* benefits) are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors (IPCC, 2014).

Cryosphere – Places on (and beneath the surface of) the Earth where water is frozen, including snow, sea ice, ice shelves, land ice (glaciers and ice caps), freshwater ice (lake and river ice), permafrost, and seasonally frozen ground.

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 adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

Disaster risk reduction – Denotes both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience (IPCC, 2014).

Dose–response – Association between dose and the incidence of a defined effect in an exposed population. Dose–response relationships are used to determine the probability of a specific outcome or disease, or risk of a disease, by extrapolating from high doses to low doses and from laboratory animals to humans, and using mathematical models that define risk as a function of exposure dose (WHO, 2003).

Drought – A period of abnormally dry weather long enough to cause a serious hydrological (water) imbalance. Drought is a relative term, referring to a particular precipitation-related activity. For example, a shortage of precipitation during the growing season impinges on crop production or ecosystem function in general (*soil-moisture drought* or *agricultural drought*) and during the runoff and percolation season primarily affects water supplies (*hydrological drought*). Storage changes in soil moisture and groundwater are also affected by increases in evapotranspiration in addition to reductions in precipitation. A period with an abnormal precipitation deficit is defined as a *meteorological drought*. A *megadrought* is a very lengthy and pervasive drought, lasting much longer than normal, usually a decade or more (IPCC, 2014).

Early warning system – A system to generate and disseminate timely and meaningful warning information to enable individuals, communities, and organizations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss (IPCC, 2014).

Ecoanxiety (climate anxiety) –The anxiety people experience as a result of awareness of ecological threats facing the planet due to climate change (Albrecht, 2011; Albrecht, 2012).

Ecological grief (ecogrief) – Distress related to ecological loss or anticipated losses related to climate change. These losses may relate to land, species, culture, or lost sense of place and/or of cultural identity and ways of knowing. Ecogrief can include loss and trauma related to specific hazards, such as climate-related flooding or wildfires, or to slow-onset climate change impacts, such as rising global temperatures, drought, melting permafrost, and sea-level rise (Cunsolo & Ellis, 2018).

Ecoparalysis – Ecoparalysis refers to the complex feelings of being unable to do anything grand enough to mitigate or stop climate change (Koger et al., 2011).

Ecosystem – The interactive system formed by all living organisms and their abiotic (physical and chemical) environment within a given area. Ecosystems can cover a range of scales: from the entire globe, to communities of plants and animals living in specific environmental conditions at the continental scale, to small systems such as a pond (IPCC, 2007).

Emergency response – Actions taken before, during, and immediately after an emergency to ensure that its effects are minimized and that people affected are given immediate relief and support (Canadian Red Cross et al., n.d.).

Emissions scenario – A plausible representation of the future development of emissions of substances that may affect radiative forcing (e.g., greenhouse gases, aerosols). These scenarios are based on a set of assumptions about driving forces (such as demographic and socio-economic development, technological change, and energy and land use) and their key relationships. There are several sets of emissions scenarios being used as the basis of climate projections (IPCC, 2014). See also Representative Concentration Pathways (RCPs) and Special Report on Emissions Scenarios (SRES).

Exposure – Contact between a person and/or community and one or more biological, psychological, chemical, or physical stressors, including stressors affected by climate change.

Extreme weather event – Weather that is rare at a particular place and time of year. Definitions of *rare* vary, but such an event would normally be in the 10th or 90th percentile of probability based on previous observations. Extreme weather may vary from place to place. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme *climate* event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season) (IPCC, 2014).

Flood – The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, rainfall-related (pluvial) floods, sewer floods, coastal floods, and glacial lake outburst floods (IPCC, 2014).

Food-borne diseases (food-borne illnesses) – Diseases that are infectious, parasitic, or toxic in nature and that are acquired through the ingestion of contaminated food (CDC, 2020).

Food security – A state that prevails when people have secure access to sufficient amounts of safe and nutritious food for normal growth, development, and an active and healthy life (IPCC, 2014).

Greenhouse gas – Gases in the atmosphere, both natural and anthropogenic, that absorb and emit radiation, warming Earth's surface and the lower atmosphere. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. There are also a number of entirely human-made greenhouse gases in the atmosphere, such as halocarbons and other chlorine- and bromine-containing substances (IPCC, 2014).

Ground-level ozone (O_3) – Ground-level (tropospheric) ozone (O_3) is a colourless and highly irritating gas that forms just above the earth's surface when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react in sunlight and stagnant air. Exposure to O_3 has been linked to premature mortality and a range of morbidity health end points, such as hospital admissions and asthma symptoms, as well as negative impacts on vegetation and synthetic materials (Environment Canada, 2016). See also Ozone.

Hazard – The potential occurrence of a natural or human-induced physical event, trend or its impact that may cause loss of life, injury, or other health impacts. Hazards may also cause damage and loss of property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, hazard usually refers to climate-related physical events or trends or their physical impacts (IPCC, 2014).

Health equity – The absence of unfair systems and policies that cause health inequalities. The reduction of inequalities and increase in access to opportunities and conditions conducive to health for all (Government of Canada, 2019).

Health inequity – Health differences that are unfair or unjust and modifiable. For example, Canadians who live in remote or northern regions do not have the same access to nutritious foods such as fruits and vegetables as other Canadians (Government of Canada, 2019).

Health system – All of the activities whose primary purpose is to promote, restore, and/or maintain health. The people, institutions, and resources to improve the health of the population they serve, while responding to people's legitimate expectations and protecting them against the cost of ill health through a variety of activities whose primary intent is to improve health.

Heat island effect – The effect whereby a smaller area (neighbourhood or zone) within a larger urban area is characterized by ambient temperatures higher than those of the surrounding area because solar energy is absorbed by materials such as asphalt, shade is lacking, etc. (IPCC, 2001).

Heavy precipitation (rainfall and snowfall) – Heavy rainfall is defined as rainfall greater than the annual 90th percentile from all rainfall events greater than 1 mm/day. Similarly, heavy snowfall is defined as snowfall greater than the annual 90th percentile from all events greater than 1 mm/day (Bush & Lemmen, 2019).

Impact – A change in, for example, a health outcome. Impact is used instead of effect to characterize the often-complex interrelationships between changes in weather variables (including extreme weather and climate events), other factors that determine the magnitude and pattern of a health outcome, and the health outcome. For example, changing weather patterns mean that the ticks that can carry Lyme disease are increasing their geographic range in southern Ontario. This change in range, along with outdoor activities putting people into contact with ticks, increased forestation in some urban areas, and other factors can affect the distribution and incidence of the disease. Impacts can refer not only to effects on health, but also to effects on ecosystems, economic status, social and cultural assets, infrastructure, and geophysical systems, including floods and droughts.

Indigenous knowledge – There is no single definition of Indigenous knowledge. For our purposes, we understand Indigenous knowledge as a set of complex knowledge systems based on the worldviews of Indigenous Peoples. Indigenous knowledge reflects the unique cultures, languages, governance systems, and histories of Indigenous Peoples from a particular location. Indigenous knowledge is dynamic and evolves over time. It builds on the experiences of earlier generations and adapts to present conditions. First Nations, Inuit, and Métis each have a distinct way of describing their knowledge. Knowledge-holders are the only people who can truly define Indigenous knowledge for their communities (Government of Canada, 2021).

Indigenous Peoples – The term Indigenous is used in this report to refer collectively to the original inhabitants of Canada and their descendants, including First Nations, Inuit, and Métis peoples, as defined under Section 35 of the *Constitution Act, 1982*. Wherever possible, clear distinctions are made between these three distinct, constitutionally recognized groups.

Infectious diseases – Any disease that can be transmitted from one person to another. Transmission may occur by direct physical contact, by common handling of an object that has picked up infective organisms, through a disease carrier, or by spread of infected droplets coughed or exhaled into the air (IPCC, 2001).

Maladaptation – Any deliberate adjustments in natural or human systems that inadvertently increase vulnerability to climatic stimuli; an adaptation that does not succeed in reducing vulnerability but increases it instead (IPCC, 2001).

Mental health – A state of well-being in which every individual realizes his or her own potential, can cope with the normal stresses of life, work productively and fruitfully, and make a contribution to her or his community (WHO, 2018). Mental health can be demonstrated by the range of thoughts, feelings, and behaviours that people experience in their lifetimes. This conceptualization of mental health goes beyond diagnostic categories to encompass broader definitions of mental health across cultures and contexts. Mental health, like physical health, exists on a spectrum and includes states of mental wellness, mental challenges, and mental illness, each of which can influence functioning across life domains (MHCC, 2018).

Methane – A hydrocarbon and greenhouse gas produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, coal production, and incomplete fossil fuel combustion (WHO, 2003).

Mitigation (of climate change) – A human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014).

Morbidity – Rate of occurrence of disease or other health disorder within a population, taking account of the age-specific morbidity rates. Health outcomes include chronic disease incidence/prevalence, rates of hospitalization, primary care consultations, disability-days (i.e. days when absent from work) and prevalence of symptoms (IPCC, 2001).

Mortality – Rate of occurrence of death within a population within a specified time period. Calculation of mortality takes into account age-specific death rates and can thus yield measures of life expectancy and the extent of premature death (IPCC, 2001). See also Premature (early) mortality or death.

Nitrous oxide (N_2O) – A powerful greenhouse gas emitted through soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning (WHO, 2003).

Ozone (O_3) – Ozone, the triatomic form of oxygen, is a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photochemical reactions involving gases resulting from human activities (photochemical smog). In high concentrations, tropospheric ozone can be harmful to a wide range of living organisms. Tropospheric ozone acts as a greenhouse gas. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen. Stratospheric ozone plays a decisive role in the stratospheric radiative balance. Depletion of the stratospheric ozone, due to chemical reactions that may be enhanced by climate change, results in an increased ground-level flux of ultraviolet (UV) B radiation (IPCC, 2001). See also Ground-level ozone.

Particulate matter (PM) – Very small solid exhaust particles emitted during the combustion of fossil and biomass fuels. Particulates may consist of a wide variety of substances. Of greatest concern for health are particulates of 2.5 μm in diameter or less, usually designated $PM_{2.5}$ (IPCC, 2001).

Parts per million (ppm) – Unit of concentration often used when measuring levels of pollutants in air, water, body fluids, etc. One ppm is one part in one million by volume (WHO, 2003).

Paris Agreement – At the 2015 United Nations Climate Change Conference in Paris, France, representatives of 196 state parties negotiated and adopted an agreement on mitigating greenhouse gas emissions and adapting to climate change. The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) calls for zero net greenhouse gas emissions during the second half of the 21st century. Canada ratified the Paris Agreement in 2016 (Bush & Lemmen, 2019).

Pathogen – An agent that causes disease, such as bacteria, viruses, algae, fungi, and protozoa (Health Canada, 2007).

Premature (early) mortality or death – Death that occurs before the average age of death in a certain population (NCI, n.d.).

Preparedness – Developing and readying response and recovery actions to increase a community's ability to respond to future impacts (adapted from the F/P/T Network on Emergency Preparedness and Response, 2004).

Psychosocial adaptation – Developing or enhancing existing coping behaviours, practices, tools, or interventions to protect mental health and social well-being in a changing climate (Séguin, 2008; Brown & Westaway, 2011).

Psychosocial health – The interplay between social well-being, which arises from relationships with others and one's context and culture, and psychological well-being, including thoughts, feelings, and behaviours (Berry et al., 2014).

Psychoterratic syndromes – Earth-related mental health phenomena such as ecoanxiety, ecoparalysis, and solastalgia (Albrecht, 2011).

Representative Concentration Pathways (RCPs) – A set of emission scenarios (see Emission scenarios) that include time series of emissions and concentrations of greenhouse gases, aerosols, and chemically active gases, as well as land use/land cover. *Representative* signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. *Pathway* emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome (IPCC, 2014).

Resilience – The capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation (IPCC, 2014).

Risk –The uncertainty of future events and outcomes; the likelihood of a future event occurring as well as its potential to influence the achievement of an organization's objectives (Health Canada, 2005).

Sea-level rise – An increase in the mean level of the ocean (IPCC, 2007).

Sensitivity – The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damage caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC, 2007).

Social capital – Combined actual or potential resources that can be mobilized through social relationships and membership in social networks (Nahapiet & Ghoshal, 1998, as cited in Resilience Alliance, 2007).

Social cost of carbon – The social cost of carbon is a monetary measure of the global damage expected from climate change from one additional tonne of CO_2 emissions in a given year (Government of Canada, 2012).

Solastalgia – The distress of bearing witness to ecological changes in one's home environment due to climate change, conceptualized as feeling homesick when a person is still in their home environment (Albrecht, 2011; Albrecht, 2012).

Special Report on Emissions Scenarios (SRES) – A set of *storylines* and *scenarios* based on population, gross domestic product, and emissions associated with the Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000). The SRES scenarios (A1, A2, B1 and B2) represent different futures depending on differences in two dimensions: economic versus environmental concerns and global versus regional development patterns (IPCC, 2007).

Stakeholder – A person or an organization that has a legitimate interest in a project or entity or would be affected by a particular decision (IPCC, 2007).

Storm surge – A temporary increase, at a particular locality, in the height of the sea due to extreme weather conditions (low atmospheric pressure and/or strong winds). Storm surge is the excess height above the level expected from the tidal variation alone at that time and place (IPCC, 2007).

Surveillance – The collection, analysis, interpretation, and dissemination of health data (USGCRP, 2016).

Threshold – The level at which sudden or rapid change occurs. In an ecological, economic, or other system, it is also a point or level at which new properties emerge, so that predictions that apply at lower levels are no longer valid (IPCC, 2007).

Tipping point – The level at which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated. For the climate system, it refers to a critical threshold when global or regional climate changes from one stable state to another stable state. A tipping point event may be irreversible (IPCC, 2014).

Tools (for adaptation) – Methods, guidelines, and simplified processes that enable stakeholders to assess the implications of climate change impacts and adaptation options in the context of their operating environment. Tools come in a variety of formats and have diverse applications — from cross-cutting or multidisciplinary (e.g., climate models, scenario-building methods, stakeholder analysis, decision-support tools, decision-analytical tools) to specific sectoral applications (e.g., crop or vegetation models, methods for coastal zone vulnerability assessment) (adapted from UNFCCC, n.d.).

Ultraviolet radiation – Solar radiation with certain wavelengths between the frequencies of visible light and X-rays, depending on the type of radiation (UV A, B, or C) (WHO, 2003).

Urban heat island effect – See Heat island effect

Vector – An organism, such as an insect, that transmits a pathogen (virus, bacterium, or parasite) from one host to another (IPCC, 2001).

Vector-borne disease – A disease that is transmitted between hosts by a vector organism such as a mosquito or tick (e.g., malaria, dengue fever, leishmaniasis) (IPCC, 2007).

Vulnerability – The propensity or predisposition to be adversely affected. Vulnerability can be due to individual susceptibility, geographic location, socio-economic factors, and a wide range of other factors that determine an individual or community's susceptibility to harm and ability to cope with an event. For example, certain individuals can be vulnerable to extreme heat events because of where they live (parts of cities that warm more than others) and characteristics of their dwelling (such as whether there is cross-ventilation) (IPCC, 2014).

Water-borne diseases (water-borne illnesses) – Diseases that result from exposure to disease-causing microorganisms or chemicals in drinking water or recreational water. Contaminated water most often enters the body by ingestion, but contaminants in water can also be inhaled, adsorbed, or enter the body through contact with open sores or wounds (Environment Canada, 2001).

Water security – The capacity of a population to safeguard sustainable access to adequate quantities of acceptable-quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems (United Nations, 2013).

Zoonosis – An infectious disease of vertebrate animals, such as rabies, which can be transmitted to humans (WHO, 2003).

References

Albrecht, G. (2011). Chronic environmental change: Emerging "psychoterratic" syndromes. In I. Weissbecker (Ed.), *Climate Change and Human Well-being* (pp. 43-56). New York, NY: Springer.

Albrecht, G. (2012). Psychoterratic conditions in a scientific and technological world. In P. Kahn, & P. Hasbach (Eds.), *Ecopsychology: Science, Totems, and the Technological Species* (pp. 241-264). MIT Press.

Berry, P., Clarke, K.-L., Fleury, M. D., & Parker, S. (2014). Human Health. In F. J. Warren, & D. S. Lemmen (Eds.), *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation* (pp. 19–22). Ottawa, ON: Natural Resources Canada.

Brown, K., & Westaway, E. (2011). Agency, capacity, and resilience to environmental change: Lessons from human development, well-being, and disasters. *Annual Review of Environment and Resources, 36*, 321–342. <https://doi.org/10.1146/annurev-environ-052610-092905>

Bush, E., & Lemmen, D. S. (Eds.). (2019). *Canada's Changing Climate Report*. Ottawa, ON: Government of Canada. Retrieved from <https://changingclimate.ca/CCCR2019>

Canadian Red Cross, Salvation Army, & St. John Ambulance. (n.d.). *Voluntary sector framework for health emergencies* (2nd ed.). Retrieved from <https://ccednet-rcdec.ca/sites/ccednet-rcdec.ca/files/voluntary_sector_framework_for_health_emergencies.pdf>

Centers for Disease Control and Prevention (CDC). (2020). *Foodborne germs and illnesses*. Retrieved from https://www.cdc.gov/foodsafety/foodborne-germs.html>

Cunsolo, A., & Ellis, N. R. (2018). Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change, 8*(4), 275-281. <https://doi.org/10.1038/s41558-018-0092-2>

Environment Canada. (2001). *Threats to sources of drinking water and aquatic ecosystem health in Canada*. NWRI Scientific Assessment Report Series No. 1. Burlington, ON: National Water Research Institute. Retrieved from <https://www.southsaskriverstewards.ca/wp-content/uploads/2019/09/Threats-EnvironmentCanada.pdf>

Environment Canada. (2016). Common Air Pollutants: Ground-level Ozone. Retrieved from <https://www.canada.ca/en/environment-climate-change/services/air-pollution/pollutants/common-contaminants/ground-level-ozone.html>

Federal/Provincial/Territorial (F/P/T) Network on Emergency Preparedness and Response. (2004). *National framework for health emergency management: Guideline for program development*. Prepared for the Conference of F/P/T Ministers of Health.

Government of Canada. (2012). Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations (SOR/2012-167). Canada Gazette Part II, 146(19). Retrieved from <http://www.gazette.gc.ca/rp-pr/p2/2012/2012-09-12/html/sor-dors167-eng.html>

Government of Canada. (2019). *Social determinants of health and health inequalities*. Retrieved from <https://www.canada.ca/en/public-health/services/health-promotion/population-health/what-determines-health.html>

Government of Canada. (2020). *Air Quality Benefits Assessment Tool (AQBAT)*. Retrieved from <https://science.gc.ca/eic/site/063.nsf/eng/h_97170.html>

Government of Canada. (2021). *Indigenous Knowledge*. Retrieved from <https://www.canada.ca/en/impact-assessment-agency/programs/aboriginal-consultation-federal-environmental-assessment/indigenous-knowledge-policy-framework-initiative/indigenous-knowledge.html>

Health Canada. (2005). *A Strategy to Implement an Integrated Risk Management Framework in Health Canada*. Retrieved from <https://publications.gc.ca/collections/Collection/H21-232-2004E.pdf>

Health Canada. (2007). *Glossary*. Retrieved from <http://www.hc-sc.gc.ca/sr-sr/biotech/about-apropos/gloss_e.html#p>

Intergovernmental Panel on Climate Change (IPCC). (2001). *Climate change 2001: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (J.J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Dokken, & K. S. White, Eds.). Cambridge, United Kingdom: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2007). Summary for Policymakers. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C.E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 7-22). Cambridge, United Kingdom: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L.White (Eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2018). Annex I: Glossary (J.B.R. Matthews, Ed.). In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Retrieved from <https://www.ipcc.ch/sr15/chapter/glossary/>

Koger, S. M., Leslie, K. E., & Hayes, E. D. (2011). Climate Change: Psychological Solutions and Strategies for Change. *Ecopsychology, 3*(4), 227–235. <https://doi.org/10.1089/eco.2011.0041>

Mental Health Commission of Canada (MHCC). (2018). *The Working Mind: Continuum Self Check*. Retrieved from <https://theworkingmind.ca/continuum-self-check>

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Griibler, A., Jung, T. Y., Kram, T., Lebre La Rovere, E., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H.-H … Dadi, Z. (2000). *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press.

National Cancer Institute (NCI). (n.d.). *Dictionary of Cancer Terms*. Retrieved from <https://www.cancer.gov/publications/dictionaries/cancer-terms/def/premature-death>

Resilience Alliance. (2007). *Glossary*. Retrieved from <https://www.resalliance.org/glossary>

Séguin, J. (Ed.). (2008). *Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity.* Ottawa, ON: Health Canada. Retrieved from <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

United Nations. (2013). *Water Security and the Global Water Agenda: A UN-Water Analytical Brief.* Hamilton, ON: United Nations, Institute for Water, Environment & Health. Retrieved from <https://www.unwater.org/publications/water-security-global-water-agenda/>

United Nations Development Programme (UNDP). (2005). *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures* (B. Lim, & E. Spanger-Siegfried, Eds.). Cambridge, United Kingdom: Cambridge University Press

United Nations Environment Programme (UNEP). (2018). *The Adaptation Gap Report 2018*. Nairobi, Kenya: United Nations Environment Programme.

United Nations Framework Convention on Climate Change (UNFCCC). (n.d). *Methodologies and Tools to Evaluate Climate Change Impacts and Adaptation*. Retrieved from <https://unfccc.int/methodologies-and-tools-to-evaluate-climate-change-impacts-and-adaptation>

U.S. Global Change Research Program (USGCRP). (2016). *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment* (A. Crimmins, J. Balbus, J. L. Gamble, C. B. Beard, J. E. Bell, D. Dodgen, R. J. Eisen, N. Fann, M. D. Hawkins, S. C. Herring, L. Jantarasami, D. M. Mills, S. Saha, M. C. Sarofim, J. Trtanj, & L. Ziska, Eds.). Washington, DC: U.S. Global Change Research Program. <http://dx.doi.org/10.7930/J0R49NQX>

World Health Organization (WHO). (2003). *Climate Change and Human Health: Risks and Responses* (A. J. McMichael, D. H. Campbell-Lendrum, C. F. Corvalán, K. L. Ebi, A. K. Githeko, J. D. Scheraga, & A. Woodward, Eds.). Geneva, Switzerland. Retrieved from <https://www.who.int/globalchange/publications/climchange.pdf>

World Health Organization (WHO). (2015). Operational Framework for Building Climate Resilient Health Systems. Geneva, Switzerland. Retrieved form <http://apps.who.int/iris/bitstream/10665/189951/1/9789241565073_eng.pdf?ua=1>

World Health Organization (WHO). (2018). *Mental Health: Strengthening our Response.* Retrieved from <https://www.who.int/news-room/fact-sheets/detail/mental-health-strengthening-our-response>

Wu, S., Mickley, L. J., Leibensperger, E. M., Jacob, D. J., Rind, D., & Streets, D. G. (2008). Effects of 2000-2050 change on ozone air quality in the United States. *Journal of Geophysical Research: Atmospheres, 113*(D6), D06302. <https://doi.org/10.1029/2007JD008917>