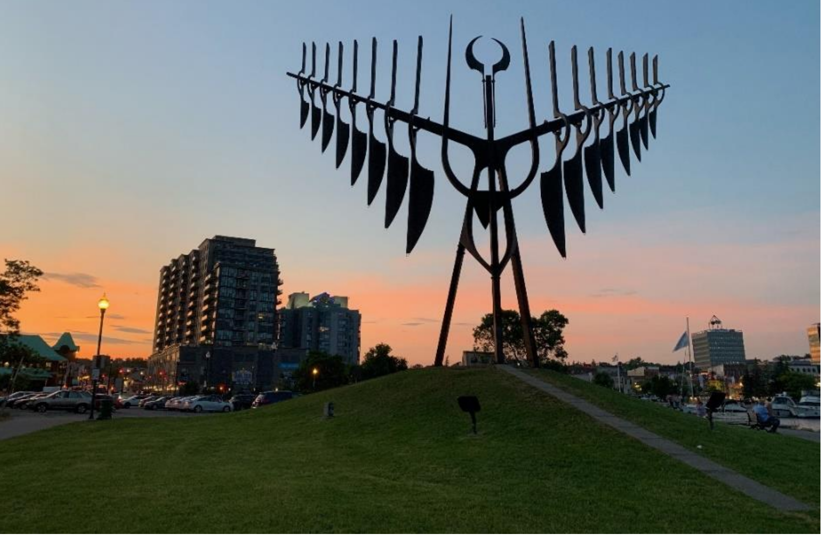

Ontario Provincial Climate Change Impact Assessment

Technical Report

January 2023

This report was prepared for the Ontario Ministry of the Environment, Conservation and Parks by the Climate Risk Institute in collaboration with Dillon Consulting Limited.

Project Team: Climate Risk Institute (CRI), Dillion Consulting Limited, ESSA Technologies Limited, Kennedy Consulting, and VIRIDI Global.

Acknowledgements

We gratefully acknowledge the Ontario Ministry of the Environment, Conservation and Parks (MECP), the Impact Assessment Inter-Ministry Committee (IAIC), and the Peer Review Panel for the guidance, support, and input throughout the project.

The following ministries comprised the IAIC:

Ontario Ministry of Agriculture, Food and Rural Affairs

Ontario Ministry of Citizenship and Multiculturalism

Ontario Ministry of Economic Development, Job Creation and Trade

Ontario Ministry of Energy

Ontario Ministry of Environment, Conservation and Parks

Ontario Ministry of Finance

Ontario Ministry of Health

Ontario Ministry of Infrastructure

Ontario Ministry of Labour, Immigration, Training and Skills Development

Ontario Ministry of Mines

Ontario Ministry of Municipal Affairs and Housing

Ontario Ministry of Natural Resources and Forestry

Ontario Ministry of Northern Development

Ontario Ministry of Public and Business Service Delivery

Ontario Ministry of Solicitor General

Ontario Ministry of Tourism, Culture and Sport

Ontario Ministry of Transportation

Ontario Ministry of Treasury Board Secretariat

Infrastructure Ontario

This report could not have been possible without the input of the following individuals serving as part of the Peer Review Panel:

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Executive Summary

Climate change is one of the greatest challenges of our time. Rising atmospheric concentrations of greenhouse gases are altering the earth's climate, driving increases in global average temperatures and variability and extremes of weather. These changes are causing unprecedented impacts, transforming ecosystem structure and function, damaging infrastructure, disrupting business operations, and imposing harm to human health and well-being. Physical climate impacts and risks to human, natural and built systems in Ontario are driven by average annual warming temperature and extreme heat, drought, changes to intensity and frequency of precipitation and other climate variables. Avoiding or reducing the worst impacts of human-induced climate change requires action on parallel fronts: rapid and deep reductions in greenhouse gas emissions and proactive and planned measures to adapt to current and imminent future changes. While there are adaptation efforts underway to address these impacts, the rapid pace of climate change requires large scale, accelerated action in all facets of our society and economy.

The Ontario Provincial Climate Change Impact Assessment (PCCIA) provides an overview of impacts, including risks and opportunities, that stem from a changing climate. This report presents results of the comprehensive and multi-sectoral assessment of potential climate change-related impacts that underscore the understanding of how and where climate change may affect Ontario's economy, infrastructure, communities, public health and safety, and ecosystems, and provides the impetus for adaptation planning and resilience action across the province. The PCCIA establishes a foundation of impacts against which future assessments can be compared and provides a methodological model for future province-wide studies. Methods used in the PCCIA can also inform derivative assessments of climate change impacts at, for example, regional, watershed, sectoral scales. The PCCIA and its related products can be considered one of many sources of information to inform adaptation decisions and priorities across Ontario sectors and sub-regions.

The assessment was designed to utilize known best current practice for climate change risk assessment with methods grounded in International Standards (ISO 31000 and 14090). The assessment employed a diversity of knowledge, research and skills in areas that include climatology, thematic subject-matter, risk assessment, engagement and communications, socio-economics and geospatial expertise. The process included targeted and broad engagement and sought validation from an Impact Assessment Inter-Ministerial Advisory Committee (IAIC) and external stakeholders. There was also a dedicated initiative to engage with Indigenous organizations across Ontario. In total, more than 250 partners and subject-matter experts were actively engaged over the course of the PCCIA.

The impact assessment was conducted across five Areas of Focus and in six regions that cover the entire province (Far North, Northeast, Northwest, Eastern, Central and Southwest). The five Areas of Focus for the PCCIA include:

Sub-themes for each Area of Focus were developed to enable assessment at finer levels of granularity as noted by Level 1 and 2 categories. Direct impacts were assessed for frequency, consequence and likelihood, and indirect impacts were qualitatively identified and characterized, within Level 1 and 2 categories.

The PCCIA process and results are reported as main sections of this report. Section 1.0 provides a summary of the project context and goals of the impact assessment. An overview of the approaches used to assess climate change impacts and capacity, as well as limitations associated with the PCCIA is included in Section 2.0. A characterization of Ontario's historical and future climate conditions, including the climate information used to inform the assessment of impacts is summarized in Section 3.0. Socio-economic modeling and projections used to support the impact assessment can be found in Section 4.0.

The findings for each Area of Focus are included under the following sections:

- Section 5.0 – Food and Agriculture
- Section 6.0 – Infrastructure
- Section 7.0 – Natural Environment
- Section 8.0 – People and Communities
- Section 9.0 – Business and Economy

The characterization of current and future climate change impacts that stretch across and between Areas of Focus are labeled as 'cross-sectoral' and is provided in Section 10.0. Finally, Section 11.0 summarizes recommended next steps for Ontario to advance adaptation and build capacity to respond to the identified impacts.

What are the key findings of the PCCIA?

More than 3,400 risk scenarios were developed and analyzed as part of the PCCIA. Risk scores were calculated in levels or layers through a step-wise process, then totaled and rolled up into the relevant Level 1 and 2 categories.

Risk scores were assigned for current, mid-century (2050s) and end of century (2080s) time periods. When evaluating the consequences of an impact, ratings of 'very low', 'low', 'medium', 'high', and 'very high' were used. Depending on the Area of Focus, different categories were used to assess consequences in relation to a single risk scenario. Consequences were assessed based on consideration of one or more of the following categories:

- Impacts to Human Health and Safety
- Environmental Damage
- Disruption of Services
- Financial Loss

Based on the consequence of impact, likelihood of occurrence, and frequency of the associated climate variable, risk scores were determined for categories assessed for every Area of Focus and applicable region of Ontario. A summary of risk scores for Level 1 categories is provided below in Table 1.0.

Climate conditions and events driving the highest climate risks differ depending on the timeframe, Area of Focus, and region of the province being assessed. Overall, extreme heat, extreme precipitation and seasonal temperature-related impacts are the drivers of highest risks across Ontario. However, wildfire, drought conditions and seasonal precipitation were also found to be particularly impactful for future time periods in certain regions and Areas of Focus. A summary of key takeaways for each Area of Focus is provided below.

Food and Agriculture

While changes in particular climate conditions (e.g. low temperature) may present stable or even declining risk scores for specific commodities and regions, any potential opportunities are likely to be offset by negative impacts, resulting in declining productivity, crop failure, and livestock fatalities. Several commodities, particularly in the southern regions of the province, are expected to face 'very high' climate risks by the end of the century.

Infrastructure

Existing infrastructure condition pressures combined with a changing climate will drive mid- to long-term challenges in managing Ontario's infrastructure. Not a single asset included in this assessment is considered to have a risk profile less than 'medium' under current climate conditions. Across most regions and asset types, this risk is expected to rise in the future by mid-century (2050s). Risks may be amplified by existing interdependencies between infrastructure types, triggering cascading impacts across systems.

Natural Environment

Climate change is already causing significant changes to Ontario's natural environment, and risks to species, habitats, and ecosystems, will continue to rise into the future. The impact assessment finds that risk profiles across almost all natural systems and species assessed are rising to 'high' by mid-century. By the end of century, one quarter of these are expected to be 'very high'. Regional differences are important to recognize, with human development enhancing risks in regions further south, and an accelerated rate of climatic changes driving risks in northern regions of Ontario.

People and Communities

The PCCIA finds that climate risks are highest among Ontario's most vulnerable populations and will continue to amplify existing disparities and inequities. Climate risks to Indigenous Communities and associated systems are found to be significant based on additional layers of sensitivity and exposure.

Business and Economy

Climate impacts, and the associated economic shocks will not be uniform across Ontario. The impact assessment finds that most Ontario businesses will face increased risks due to climate change, with the largest increases in risk expected for businesses dependent on natural resource systems and where historical infrastructure deficits exist.

Cross-Sectoral Themes

To represent the inherent connectedness and complex interactions between Areas of Focus, cross-sectoral analyses were conducted and summarized in Section 10.0. The cross-sectoral evaluation centered around human populations and impacts were viewed through an equity lens which highlighted unique factors or populations that may be disproportionately impacted. The cross-sectoral impacts are qualitatively characterized under five broad themes:

- Food security
- Water security
- Energy security
- Human health, safety, and well-being
- Community function

Identifying Adaptation Priorities

Climate change adaptation enabling factors, noted as Adaptive Capacity, were also included in the PCCIA. The categories of Adaptive Capacity included technology, resource availability, sector complexity, equity, and governance. Based on the risk scores derived from this impact assessment and identified levels of capacity, adaptation priorities are identified for each Area of Focus (Sections 5.0 – 9.0), in regions and sectors where risks are highest, and capacity is lowest.

Moving Forward

The PCCIA has produced a number of products aimed at improving knowledge and capacity and stimulating adaptation action across Ontario. This report and each of the accompanying PCCIA products are complimentary to one another and are founded in the findings presented in this report. The external products are identified and referenced in the following section.

The information gained from the PCCIA is not meant to be an endpoint, and it is important to recognize how these findings can be used to spur action to protect residents, ecosystems, businesses and communities across Ontario. As such, key findings should be aligned and used to inform policies, programs, research, and investment decisions moving forward. A next step in this process could be to evaluate specifically how risk results can be used to accelerate adaptation at various scales and in various sectors and systems across Ontario.

Table 1.0: Current and Future Climate Risk Summary for PCCIA Areas of Focus (RCP8.5)

Risk Table Legend			
Risk		**Most at Risk Regions Abbreviations[1]**	
Low		FN	Far North
Medium		NE	Northeast
High		NW	Northwest
Very High		E	Eastern
		C	Central
		SW	Southwest

[1] 'Most at risk regions' are those that display highest risk scores operating under RCP8.5 (high emissions scenario). For more details on regional risk breakdown by Level 1 category, see Appendix 9.

Food and Agriculture Area of Focus				
Level 1 Categories	Risk			Most at Risk Regions
	Current	2050s	2080s	
Field Crops				C, E, SW
Fruits and Vegetables				C, E, SW
Livestock				C, E, SW
Infrastructure Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Buildings				SW, FN
Pipeline Transportation				All
Stormwater Management				All
Transportation				C, E, SW, NE, NW
Utilities				All
Waste Management				C, E, SW, NE, NW
Natural Environment Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Fauna				C, SW
Flora				SW
Aquatic Ecosystems				C, NE, NW, FN
Terrestrial Ecosystems				All
Regulating Services				C, NE, FN
Provisioning Services				C, SW, E
Ecosystem Cultural Services				NE, NW
People and Communities Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Population				C, E, SW
Health Care				SW
Social Assistance and Public Admin				E
Indigenous Communities				All

Business and Economy Area of Focus				
Level 1 Categories	Risk			Most at Risk Regions
	Current	2050s	2080s	
Accommodation and Food Services				All
Arts, Entertainment and Recreation				C
Construction				C, E, SW, NE, NW
Financial and Insurance				All
Forestry, Fishing and Hunting Economies				All
Information and Cultural Industries				All
Manufacturing				All
Mining, Quarrying and Oil/Gas Extraction				All
Retail Trade				C, E, SW, NE, NW
Transportation Economy				C, E, SW, NE, NW
Utility Services				FN

External PCCIA Products

The following products, in full, are available in separate and distinct documents:

External Resource – 1: PCCIA Methodology Framework

External Resource – 2: PCCIA Adaptation Best Practices (ABP) Report

External Resource – 3: PCCIA Decision-making Supports (DMS)

External Resource – 4: PCCIA Summary Reports

Key Terms and Definitions

Adaptation: Process of adjustment to actual or expected climate events and their effects.

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.

Area of Focus: The five Areas of Focus defined by the Ontario Ministry of the Environment, Conservation and Parks for the PCCIA. These include: Food and Agriculture; Infrastructure; Natural Environment; People and Communities and Business and Economy.

Cascading Impacts: A climate-related event or trend that triggers a chain of impacts across different Areas of Focus. Cascading impacts are often associated with interdependencies between systems where components may be intrinsically dependent, or rely upon, one another to provide a function. (e.g. critical infrastructure failures can cause cascading impacts across several different sectors).

Climate Change: Refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.

Climate Resilience: The ability of systems and structures to absorb the shocks of climate change related events and impacts and return to normal functioning without major delays.

Climate Variable: A measurable aspect of weather that contributes to the characterization of weather conditions in a given area.

Climate Variable Group: Climate variable(s) grouped together based on commonalities such as temperature or precipitation and representing changes in climate (physical events or stressors) that have the potential to cause harm, damage, or losses.

Consequence Criteria: Criteria used to assess the level of impact (or damage) to human health and safety, environmental damage, disruption to services, and financial loss. Consequence of impacts are rated from ‘very low’ to ‘very high’ based on the given criteria.

Consequences: Negative impact that arises when a climate variable interacts with an Area of Focus.

Cross-Sectoral Impacts: Climate change impacts that span multiple Areas of Focus. For the purposes of Ontario's PCCIA, cross-sectoral impacts are characterized across five themes: 1) food security, 2) water security, 3) energy security, 4) human health, safety and well-being, and 5) community function. More details can be found in Section 10.0.

Direct Impact: Effects of changes in climate that in and of themselves cause an impact. Also referred to as primary effects of climate change. In the context of Ontario's PCCIA, direct impacts are those resulting from climate interactions within each Area of Focus and have been quantitatively assessed following the PCCIA methodology and given risk scores.

Equity Lens: Within the context of the PCCIA, this is a term specifically used within the cross-sectoral analysis (Section 10.0). An equity lens has been applied to every cross-sectoral theme, which identifies unique factors or populations that may be disproportionately impacted associated with the cross-sectoral theme.

Event: Occurrence or change of a particular set of circumstances.

Expert [evidence, experience]**:** Refers to assessment-related subject matter knowledge, expertise and experience that was represented by the assessment consulting team. This also refers to external expertise derived from those who participated in the engagement process, providing input to risk characterization and assessment.

Exposure: An interaction, either actual or expected, between the climate variable and the presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economy. Exposure was not explicitly assessed as a discrete element of vulnerability under the PCCIA methodology.

Frequency: The number of occurrences of a repeating climate variable per unit of time (e.g. a flood event that is reasonably expected to occur 1 time in a 100-year time span has a frequency = 1/100 years or is sometimes called "Annual Frequency"). Using this example, "1 time in a 100-year time span" is expressed as 1:100 year, which is called a "Return Period". Frequency is also referred to as 'likelihood' within the report.

Impact: The effect of climate change variables on natural, built and human systems.

Impact Assessment: Process used to identify, analyze, and evaluate impacts, inclusive of risks and opportunities.

Indirect impacts: For the PCCIA, indirect impacts are secondary effects of changes in climate and are directly tied to (stem from) a primary impact within an Area of Focus. Indirect impacts were excluded from the quantitative assessment but are characterized qualitatively.

Individual Risk Score: The quantification of each interaction between a climate variable and area of impact as noted by a Level 1 or 2 category within each Area of Focus and region (e.g. interaction between extreme precipitation event (short-term) and rail infrastructure in Central Ontario).

Interaction: The combination of a region and asset/service/operation with a climate variable that has the potential to impact the asset/service/operation in the given region.

Interconnected linkages: A term used to represent the inherent connectedness between Areas of Focus as part of cross-sectoral analyses in Section 10.0. Interconnected linkages are defined as complex interactions among system components that are dependent, or rely upon, one another to provide a function.

Likelihood: In the context of the PCCIA, likelihood is a measurement of the probability of consequence associated with an impact occurrence. Likelihood scales are characterized by the percent chance of an impact occurring, categorized as 'improbable', 'remote', 'occasional', 'probable', and 'frequent' levels of occurrence.

Most Probable Worst-Case Event: The Most Probable Worst-Case Event (MPWCE), otherwise referenced as a 'risk scenario' and represents the most severe possible outcome that can reasonably be expected to occur based on a specific interaction between the climate variable, Level 1 or 2 category and region. The MPWCE is a conservative risk estimate in order to provide latitude for adaptation planning purposes to reduce risk.

Normals: In reference to the climate, Normals are averages over a period of time (usually 30 years) that are used to summarize or describe the average climatic conditions of a particular location.

Opportunities: Opportunities are cases where risk scores decrease over time or are described qualitatively where evidence suggests that a changing climate may lead to favourable effects under each Area of Focus.

Probability: Percentage chance of the occurrence of an event.

Risk: Risk is measured as the combination of the probability of an event, with its likelihood of impact and severity of consequences.

Risk Analysis: Process of understanding the nature of risk and its characteristics including likelihood and consequence.

Risk Evaluation: Process of comparing the risk results with the risk tolerance criteria to determine the degree to which action is required.

Risk Identification: Process of finding, recognizing, and describing risks.

Risk Scenario: Derived from the Most Probable Worst-Case Event (MPWCE), a PCCIA risk scenario describes the interaction between a select climate variable, a Level 1 or 2 category and within an applicable region. For example, the risk scenario developed for extreme heat days (climate variable) and corn crops (Level 2 category) in Southwest Ontario (region) reads as: 'An extreme heat event (+32° C during day/+20°C at night) occurs during later reproductive phases (blister and maturity) of corn development, reduces crop productivity by impacting the grain fill period, lowering kernel weight, and resulting in yield losses of between 20 to 40%'.

Sensitivity: The degree to which a system is adversely or beneficially affected by the climate variable to which it is exposed. Sensitivity was not explicitly assessed as a discrete element of vulnerability under the PCCIA methodology.

Severity: The degree of impact of an event and related to consequence.

Threshold: Context-specific, a point beyond which a system is deemed to be no longer effective or efficiently functioning (economically, technologically, or environmentally). Thresholds define inflection points at which time declines in function occur. Threshold is also "The level of risk exposure above which risks are addressed and below which risks may be accepted." A threshold level is a level beyond which an organization does not want to tolerate the risk.

Vector-borne Diseases: Human illnesses caused by parasites, viruses, and bacteria that are transmitted by mosquitoes, sandflies, triatomine bugs, blackflies, ticks, tsetse flies, mites, snails, and lice.

Vulnerability: The extent to which a system or component is susceptible to damage from climate change. This is calculated based on the potential impact (exposure and sensitivity) and the Adaptive Capacity of the system or component. It is important to note that Ontario's PCCIA is an assessment of climate impacts, including risks and opportunities as a function of likelihood and consequence, and does not explicitly assess vulnerability.

Acronyms and Abbreviations

AC: Adaptive Capacity

CDD: Cooling Degree Days

CICES: Common International Classification for Ecosystem Services

COP21: 21stConference of the Parties

°C: Degree Celsius

DD: Degree Days

EbA: Ecosystem-based Adaptation

EbM: Ecosystem-based Management

FWI: Fire Weather Index

GDD: Growing Degree Days

GDP: Gross Domestic Product

GHG: Greenhouse Gas

Ha: Hectares

ICI: Industrial, Commercial, and Institutional

ICT: Information, Communication, and Technology

IPCC: Intergovernmental Panel on Climate Change

ISO: International Organization for Standardization

LID: Low Impact Development

MPWCE: Most Probable Worst-Case Event

NAICS: North American Industrial Classification System

NbS: Nature-based Solutions

OLCC: Ontario Land Cover Compilation

PCCIA: Provincial Climate Change Impact Assessment

R&D: Research and Development

SFM: Sustainable Forest Management

SMEs: Small and Medium-Sized Enterprises

TSS: Total Suspended Solids

Yr: Year

1.0 Introduction

The Sixth Assessment of the Intergovernmental Panel on Climate Change (IPCC) (AR6) concluded with certainty that human influence has been the main cause of recently observed global temperature increases and that if greenhouse gas (GHG) emissions are not significantly reduced, warming trends will continue into the latter half of this century, leading to an increase in more devastating and frequent extreme weather. Binding agreements forged at the international Conference of the Parties meeting in 2015 (COP21) - the Paris Agreement – established a goal to limit global warming to well below 2˚C above pre-industrial levels by 2050, and to pursue efforts to limit the temperature increase to 1.5˚C. The IPCC has emphasized that in addition to the need for deep reductions in GHG emissions, adaptation is critical as continued warming over the coming decades is no longer reversible even with mitigation efforts.

Domestically, the Council of Canadian Academies established the Expert Panel on Climate Change Risks and Adaptation Potential who published *Canada's Top Climate Change Risks* which outlines 12 major areas of climate change risk for Canada which have the potential to impose significant loses, damages or disruptions over the next 20 years. The Panel noted that the top six areas of concern are physical infrastructure, coastal communities, northern communities, human health and wellness and ecosystems and fisheries. In addition to the risk findings, the report notes the importance of more detailed assessments for, and with, Indigenous Communities, as well as better coordination of adaptation between levels of government (Council of Canadian Academies, 2019). Jurisdictions within Canada including British Columbia, Nova Scotia, and Yukon, have conducted assessments of climate change risks looking both at the impacts to the function of government and business and services, as well as whole-of-region risk assessments. In both cases, results improve knowledge of the priority climate risks and provide the impetus for adaptation action along with supportive policies and programs.

Ontario's mean annual temperature has increased by 1.3°C between 1948 and 2016, with mean annual precipitation increasing by 9.7% over the same period (Bush and Lemmen, 2019). Climate model projections indicate that these changes will continue, highlighting that the risks currently presented by climate change will become even greater in the future. Gradual changes in average climate conditions combined with increased variability and changes in the frequency, intensity and duration of extreme weather events, drive impacts that are having, and will continue to have, predominantly negative effects across the province (Cohen et al., 2020; Zhang et al., 2019). Ontario has already been affected by climate change as evidenced by recent events such as flooding, heat waves, and unusually high climate variability or extremes. The impacts of climate change have the potential to affect built and natural systems through water shortages, forest fires, power outages, outbreaks of diseases, and more. These changes in climate translate into risks to economic sectors, ecosystems, communities, and people. Ontario, in general, has high institutional, technical, human and financial levels of capacity to support adaptation actions, however, this capacity has not yet been mobilized widely despite the imperative (Environmental Commissioner of Ontario, 2018).

Incorporating climate change resilience into decision-making requires the right information, tools, resources and most importantly, willingness. Mainstreaming climate change adaptation into existing frameworks and processes will ease the seeming burden and more fully engrain climate considerations which serve to protect the environment, public health and safety, infrastructure, economies and communities. While it is responsible and cost-effective to integrate considerations of future climate change into decision-making processes, current infrastructure investment, community planning and business operations often don't, and subscribe to the assumptions of predictable climatic conditions (Boyd and Markandya, 2021). Climate change has created the need for data and information that includes projections at its core to provide decision-makers with the information in support of more resilient outcomes.

While some local-scale climate change risk assessment and adaptation planning has occurred in Ontario, notably by provincial ministries, municipalities, Indigenous Communities, and non-governmental organizations, the PCCIA is the first province-wide assessment. An identification and assessment of climate change impacts and key climate change risks and opportunities at this scope and scale is unique amongst Canadian jurisdictions and will help set the context for broader Ontario-wide climate change adaptation and resilience policy development, as well as advance the capacity of jurisdictions to respond to climate change events as they occur. Regional and municipal climate change risk assessments such as those for Barrie, Thunder Bay, Windsor, Oakville, Sudbury, Durham, Peel, York and Waterloo have led to plans and action to build climate resilience. Conservation Authorities in Ontario have been leaders in incorporating climate change into their stewardship and other activities. Ontario has also conducted climate change assessments at various scales such as by Eco-region (e.g. 3E-1), watershed (Lake Simcoe) and sector- or theme-based (e.g. Public Health Units).

As changes in Ontario's climate are expected to continue at unprecedented rates, it is critical for governments and regulatory agencies to support and enhance adaptation by developing enabling policies and programs. Climate resilience is strengthening the ability of social, economic and natural systems to withstand climate change including hazardous and catastrophic events or shifting trends in ways that these systems can maintain their essential functions or structures, as well as the capacity to respond to future changes. The PCCIA outputs promote improved general preparedness for governments whose role is to serve civil society with adequate structure and function. Emergency preparedness in times of extreme weather is crucial for society to respond to, and recover from, the impacts of extreme weather. The findings of the assessment can also support policy development at provincial and other scales.

Inherent momentum in the climate system will continue to drive hazards and impacts for many years and thus advancements in the regulatory environment will ensure that impacts are being adequately managed to limit damage and liability. The PCCIA results also highlight the need for policy consistency and alignment between levels of government, not only to improve climate resiliency, but also to avoid maladaptation.

By assessing climate change impacts and the associated risks and opportunities across Ontario, this assessment provides important information on the urgency required for action and priority areas for adaptation planning and decision-making. The findings from this assessment can inform a strategic approach to adaptation prioritization and serve as a foundation for developing or updating appropriate climate change risk management processes by a wide range of decision-makers. By identifying, understanding and communicating the existing and potential future climate impacts across Ontario, the provincial government, municipalities, Indigenous Communities and other local decision-makers will be further supported in making informed and timely choices that can help keep communities and people healthy and safe, protect the natural environment and infrastructure, support a strong economy.

Information from the PCCIA can inform climate-smart investment in capital and other areas of business development. Awareness of the physical impacts of climate change can empower businesses and the public sector to manage the transition to more climate-sensitive business operations and perform climate risk due diligence through various regulatory reporting processes. The pervasive nature of climate change also invokes interacting and compounding effects on other important societal issues such as biodiversity loss, food and water insecurity, inequity and conflict. Ontario’s actions to manage risks in these areas should recognize climate change impacts identified throughout the PCCIA.

Perhaps most importantly, outputs from the PCCIA help to establish a baseline level of climate risk against which continued and new risks can be evaluated. Knowledge of the baseline for climate risk helps determine the degree to which adaptation measures have been implemented and their effectiveness. The PCCIA also forms a mechanism for future assessment where new science and new or unique methods can be applied to re-evaluate based on continued climate change. A climate risk baseline can also be used to establish targets for climate risk reduction in the context of an adequate monitoring and measurement system.

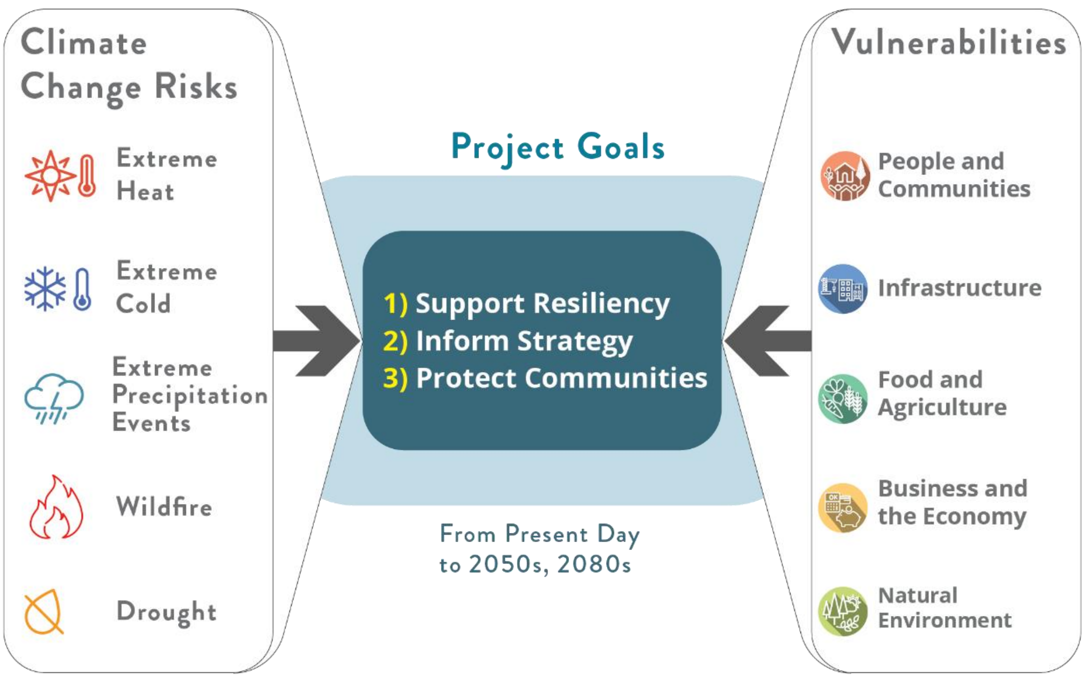
1.1 PCCIA Objectives and Outputs

The objectives of the Ontario PCCIA include the following:

- To allow for future decisions to be more resilient to climate impacts
- To inform a more strategic approach to adaptation by governments, businesses, and communities
- To help protect livelihoods, public health, and investments
- To provide a methodology that can be scaled for smaller scale application
- To provide a foundation from which future assessments can be measured

Figure 1.1 provides the vision of the PCCIA, capturing the overall goals and general scope of the assessment.

Figure 1.1: Vision and Goals for Ontario's PCCIA



Adapting to climate change is a shared responsibility. Awareness of impacts and priority risks and implementation of spatially appropriate adaptation measures is a shared responsibility across levels of government, institutions, and individuals. As such, the PCCIA has produced a series of information products that will support a wide range of decisions and be helpful to a similarly wide range of audiences and decision-makers (see Table 1.1).

Table 1.1: An Overview of Products Developed through Ontario's PCCIA

PCCIA Product	Brief Overview	Intended Audience Type
Technical Report	A full report that synthesizes all components of the PCCIA. The report is geared towards technical staff at provincial and local governments, and other organizations.	Technical decision-makers and policymakers across Government of Ontario Ministries, local governments and other government organizations.
Adaptation Best Practices (ABP) Report	A compendium of adaptation measures and practices associated with each Area of Focus and using a cross-sectoral lens to consider, including identifying possible implementation details.	Technical decision-makers and policymakers across Government of Ontario Ministries, local governments, and other government organizations.
Decision-Making Supports (DMS)	Scoped, tailored, and targeted information briefs that support different audiences to understand and interpret how they could use PCCIA information in their roles and how PCCIA methods could be scaled for future assessments.	Non-Technical staff internal to the Government of Ontario and externally across local governments, government organizations, industry associations, and non-profit organizations.
Summary Reports	Synthesis reports that are tailored for each Area of Focus. The Summary Reports convey key results and are accessible to a wide range of audiences. These plain language summaries can be used to improve knowledge of climate change impacts and adaptation across Ontario's regions and sectors. The reports also include a concise summary of the approach to undertaking the PCCIA that is designed to inform future assessment opportunities.	Non-Technical staff internal to the Government of Ontario and externally across local governments, government organizations, industry associations, and non-profit organizations.

2.0 The PCCIA Approach

The province-wide climate change impact assessment was enabled by a detailed method that supported an accounting of the scale and breadth. The PCCIA methodology was designed to be systematic, structured, transparent, and to align outputs with adaptation planning and decision making. Applying the methodology across the chosen sectors and systems (Areas of Focus), enabled consistency where possible and provided a scalable approach for future province-wide assessments as well as those of smaller scale in regions and sectors. In the following section, a summary of the methods used to characterize impacts is provided and includes the high-level assessment of Adaptive Capacity. A more fulsome description of the methods is provided in the PCCIA Methodology Framework (External Resource – 1).

2.1 Overview of Methodology

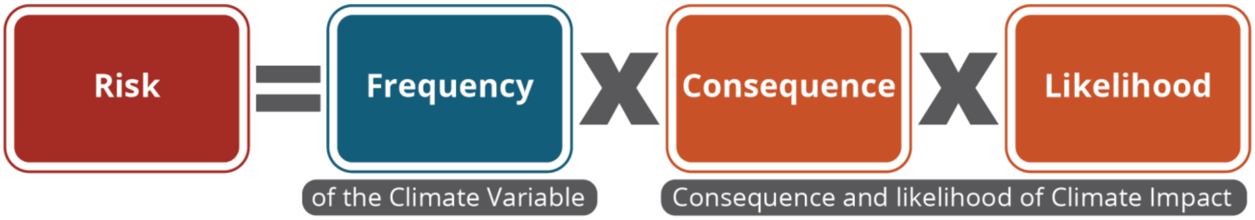
Climate change impact assessment requires a scientifically robust approach that enables systematic characterization of climatological, biophysical, and human factors that create impacts and drive risks. An international review of approaches and frameworks used to assess impacts informed the PCCIA approach, including guidance from the Intergovernmental Panel on Climate Change (IPCC) and the International Organization for Standardization (ISO). A standard published in 2019: ISO 14090, provides two options in undertaking climate change impact assessment:

1. **Option One:** The consideration of vulnerabilities, exposure, and climate change hazards.
2. **Option Two:** The consideration of likelihood and consequences.

For the purposes of the PCCIA, **risk** is measured as the combination of the **frequency of a climate event,** the **severity of consequences** and its **likelihood of impact.**

Other standardized approaches to risk assessment, such as in ISO 31000, were consulted. The scale of the PCCIA and accompanying top-down nature of the design led to the selection of **Option Two**. Thus, climate risk reported through the PCCIA can be interpreted as a "function of the frequency of a climate variable occurring now and/or in the future, the consequence(s) of its impact on the Area of Focus component, and the likelihood of it leading to the identified impact" (see Figure 2.1). These three building blocks of risk (frequency, consequence, and likelihood) are referenced throughout this report.

Figure 2.1: PCCIA Climate Risk Formula



The Methodology Framework was applied across the entire province using the sub-division based on 1) Geographic Regions and 2) Areas of Focus. Further details on the structure of the Methodology Framework by geographic region and Areas of Focus are provided in the respective subsections below.

2.2 Geographic Regions

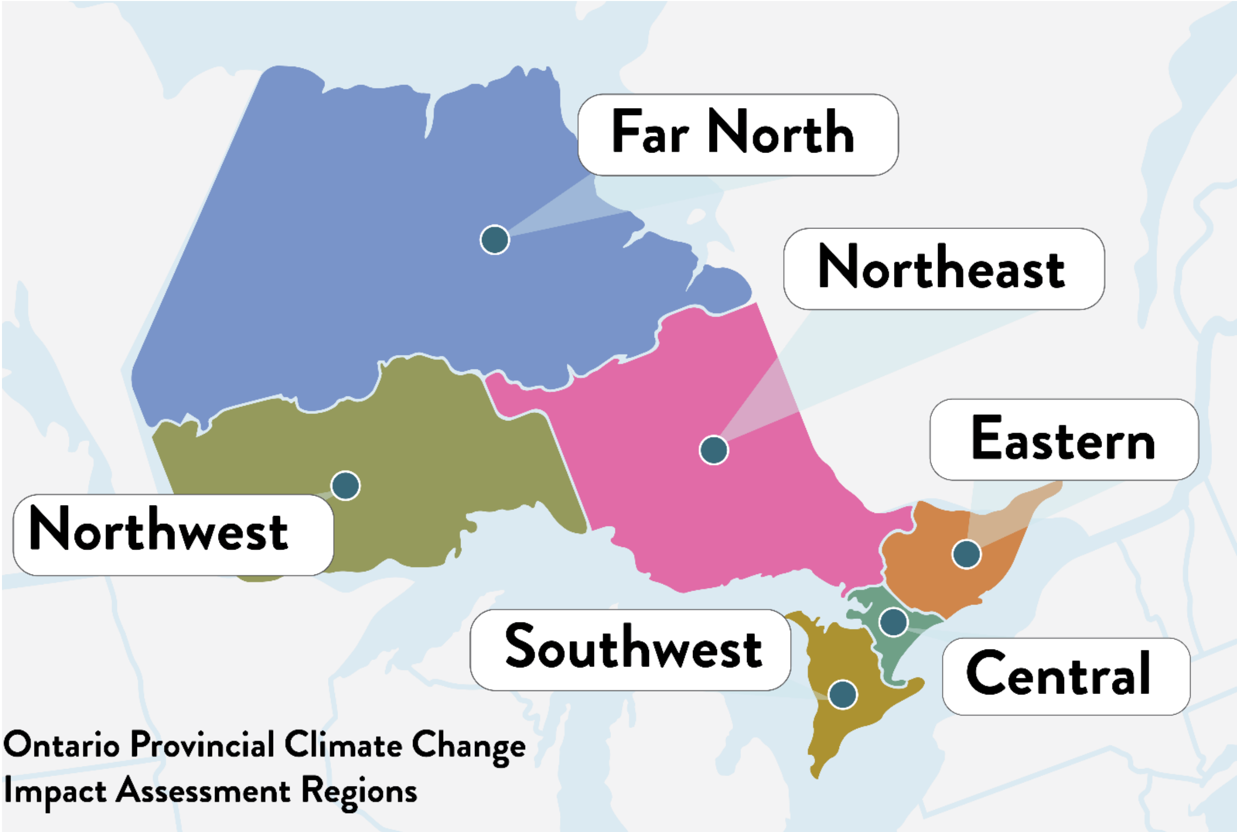
For the purposes of the PCCIA, the Province was divided into six Geographic Regions (see Figure 2.2):

- Southwest
- Central
- Eastern
- Northeast
- Northwest
- Far North

The boundaries are derived from Census Canada Divisions with the exception of the Far North region which used the Far North boundary line. As a result, certain areas of Kenora, Cochrane and Thunder Bay appear in two distinct geographic regions.

Each of these regions were explicitly considered and characterized within the PCCIA, with regional differences, gaps in data available and/or variations being documented. This regional approach was used in literature review search terms, for the development of risk scenarios, and to identify relevant data sets that informed mapping and qualitative characterization of risk.

Figure 2.2: Geographic Regions Defined in Ontario's PCCIA



Southwest Region

Southwest Ontario is defined as all areas between Essex County in the west to Grey and Bruce Counties in the north to Niagara in the south. Southwest Ontario excludes Hamilton, Halton and Peel Region, but does include Haldimand-Norfolk, Brant and Wellington Counties.

Central Region

Central Ontario is defined as the areas that lie between Georgian Bay and the eastern end of Lake Ontario. The region includes the Greater Toronto Area, including Hamilton, Halton, Peel, York, Simcoe, Durham, Kitchener-Waterloo, and Toronto. Notably, Central Ontario excludes Niagara Region, which is included in Southwest Ontario.

Eastern Region

The Eastern Ontario is defined as all areas east of Central Ontario, from Kawartha Lakes to Prescott and Russel. Renfrew and Haliburton are the two counties further north included in this region of the province.

Northeast Region

The Northeast Ontario includes all areas north of Central and Eastern Ontario between Muskoka and Nipissing in the south, up to Algoma and parts of Cochrane in the north.

Northwest Region

For the purposes of the PCCIA, Northwest Ontario is comprised of almost all of Thunder Bay, all of Rainy River, and portions of Kenora. Small areas in the far north of Thunder Bay are included in the Far North region of Ontario, along with vast areas of Kenora.

The Far North Region

Far North Ontario was defined for the PCCIA based on the Ontario Ministry of Natural Resources and Forestry Far North Boundary Line. This region includes significant areas of Kenora, northern areas of Cochrane and the farthest north areas of Thunder Bay.

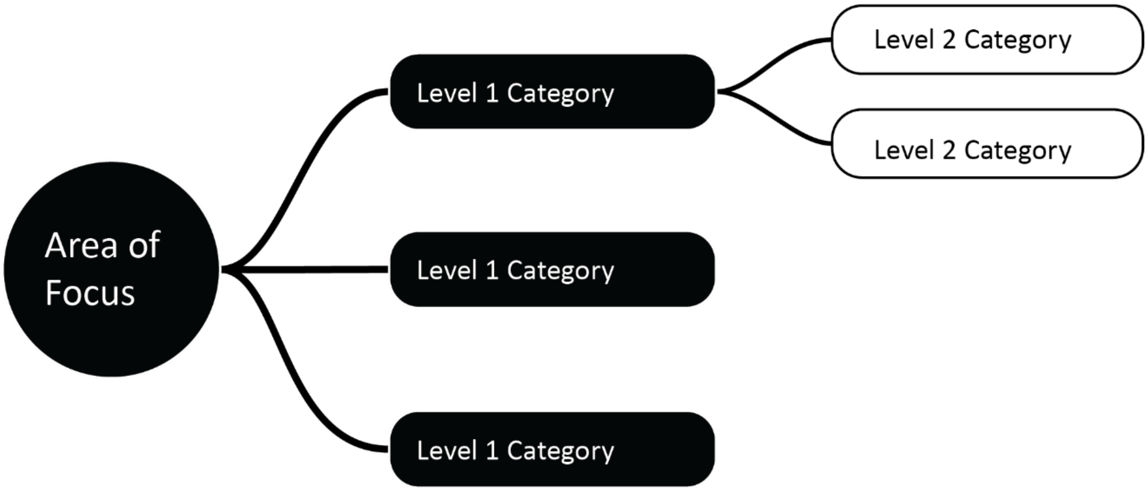
2.3 Areas of Focus

Climate change impacts were assessed within five broad thematic areas. These areas, defined as Areas of Focus, constitute the broad diversity of ecological, social, and economic systems in Ontario. The Areas of Focus include:

- Food and Agriculture
- Infrastructure
- Natural Environment
- People and Communities
- Business and Economy

Each Area of Focus was sub-divided to inform impact assessment in greater detail. A simple hierarchical classification system, 'Level 1 and Level 2' categories, was developed to label further thematic detail. Level 1 categories refer to a primary branch of an Area of Focus, similar to how a "sector" is defined under the North American Industrial Classification System (NAICS). Level 2 categories provide additional speciation based on each Area of Focus component or criteria, similar to how subsectors and/or industry groups are identified in NAICS. Figure 2.3 identifies the conceptual speciation of an Area of Focus, illustrating how some of these categories are further delineated to include sub-categories, labeled as Level 1 and 2 categories.

Figure 2.3: Structural Breakdown for Each Area of Focus



Areas of Focus were divided and categorized differently where NAICS classifications were not as applicable or appropriate. For example, the Natural Environment Area of Focus employed criteria informed by the International Union for Conservation of Nature (IUCN) principles for species conservation alongside additional international classification of ecosystem services. As a result, Natural Environment Level 1 categories include themes such as species, regulating services, among others. Focal, or representative species, were then defined via literature and in consultation with the Government of Ontario to inform Level 2 categories.

A summary of the Level 1 categories for each Area of Focus is provided in Table 2.1. Defining the Level 1 and Level 2 categories was an iterative process, based on a suite of criteria for each Area of Focus as well as discussions with government staff (IAIC members) to ensure relevance. General criteria used to identify categories for Areas of Focus included considerations of:

- Alignment with relevant North American Industrial Classification System (NAICS) codes
- Data availability for each Level 1 and 2 category
- Regional differences and commonalities across Ontario
- Societal and economic importance and contribution
- Sensitivity and exposure to climate-related impacts

Table 2.1: Summary of PCCIA Areas of Focus Categories

Area of Focus	Level 1 Categories
Food and Agriculture	Field Crops
	Fruits and Vegetables
	Livestock
Business and Economy	Accommodation and Food Services
	Arts, Entertainment and Recreation
	Construction
	Financial and Insurance
	Forestry, Fishing and Hunting Economies
	Information and Cultural Industries
	Manufacturing
	Mining, Quarrying and Oil/Gas Extraction
	Retail Trade
	Transportation Economy
	Utility Services
Infrastructure	Buildings
	Pipeline Transportation
	Stormwater Management
	Transportation
	Utilities
	Waste Management
Natural Environment	Aquatic Ecosystems
	Ecosystem Cultural Services
	Fauna
	Flora
	Provisioning Services
	Regulating Services
	Terrestrial Ecosystems
People and Communities	Health Care
	Indigenous Communities
	Population
	Social Assistance and Public Administration

2.4 Approach to Characterizing Impacts and Adaptive Capacity

Following the identification of Level 1 and 2 categories for each Area of Focus, extensive literature review was undertaken to a) identify possible impacts to each Level 1 and 2 category, now and in the future, b) identify risk scenario (using the 'Most Probable Worst-Case Event') and the consequences associated with that scenario, c) determine any assumptions or uncertainties in information based on literature, and d) document indirect and cross-sectoral considerations for qualitative characterization.

The **Most Probable Worst-Case Event**, otherwise referenced as a '**risk scenario**', considers the most severe possible outcome that can reasonably be expected to occur based on a specific interaction between the climate variable and Level 1 or 2 category. This process provides a precautionary approach for assessing climate change impacts on different Areas of Focus and Geographic Regions.

Information sources used for the PCCIA included qualitative and quantitative sources. Figure 2.4 shows the types of input which were sought and applied at different stages of the assessment. The illustration is not representative of the balance of qualitative and quantitative inputs.

Figure 2.4: Types of Information Used in the PCCIA

A systematic search and input process was developed for the literature review to ensure standardization and replicability, and to produce a transparent and defensible process. Literature focusing on both current and future climate conditions and impacts was collected simultaneously as some reports included information under current, 2050s and the 2080s time periods. Similarly, region-specific literature was also collected concurrently, as many study areas cover more than one PCCIA sub-region. The strength of evidence was evaluated to indicate the availability of sources of information and the extent to which information has high quality data to inform risk scoring. Table 2.2 summarizes the criteria used in this evaluation.

Table 2.2: Criteria used in Evaluating the Strength of Evidence in Impact Assessment

Strength of Evidence	Definition
High	- Multiple sources of information with widespread agreement between the studies and/or experts - Based on robust methodology and high-quality data - Published relatively recently (within 2 years)
Medium	- Several sources of information with general agreement between the studies and/or experts - Based on robust methodology and high-quality data - Published relatively recently (within 5 years)
Low	- No or very few sources of information and/or little agreement between the studies and/or experts - Poor methodology or quality of data - Published a long time ago (over 5 years ago)

2.4.1 Climate Variables and Frequency

Climate variables used in the PCCIA refer to individual and distinctly separate aspects of weather and climate that are a) going to change from current to future (2050s or 2080s), and b) going to have the most impact on an Area of Focus. Consideration and selection of individual climate variables was iterative with consideration given to scale and scope of the PCCIA. Input was received from the Impact Assessment Inter-Ministerial Committee (IAIC) on variables most relevant to the specified thematic area and led to a list of 15 climate variables. Climate variables were ultimately selected based on data availability and the extent to which they represent the greatest number of impacts across the different Areas of Focus and regions of the province.

In some cases, climate variables can interact with each other in the form of combined or cumulative events. The complexity is further compounded when indirect impacts are considered. As a result, only single and discrete, slow-onset or extreme climate variables were used in the PCCIA. Table 2.3 provides a high-level summary of the 15 climate variables, organized into eight groups which were used to inform the frequency analyses. The rationale and additional details associated with these variables are provided in Section 3.0 of this report.

Table 2.3: Climate Variables Analyzed for use in the PCCIA

Climate Grouping	Climate Variable	Brief Description
High and Extreme Temperature	Extreme Hot Days (> 30°C)	A count of the average number of days per year where the maximum temperature exceeds 30°C.
	Cooling Degree Days (18°C)	The annual accumulation of mean temperature over 18°C as an indication of cooling demand.
Low Temperature	Degree Days < 0°C	The annual accumulation of cold conditions in a year where the daily mean temperature is less than zero.
	Cold Days < -25°C	A count of the average number of days per year where the minimum temperature is less than -25°C.
Temperature	Growing degree Days (5°C)	The seasonal accumulation of heat where the mean temperature is greater than 5°C.
	Growing Season Length	The length of the growing season in days is determined by spring temperature and autumn temperature thresholds.
Precipitation	Spring Precipitation	Total spring precipitation (rain and snow).
	Summer Precipitation	Total summer precipitation (rain and snow).
	Autumn Precipitation	Total autumn precipitation (rain and snow).
Winter Precipitation	Winter Rain Percentage (Rain:Snow Ratio)	The proportion of winter precipitation falling as snow using a daily mean temperature threshold of less than 0°C.
	Winter Precipitation	Total winter precipitation (rain and snow).
Extreme Precipitation Events	Extreme Precipitation (Short Duration)	The average annual maximum one day precipitation amount. Projections for this variable were not directly obtained from model output and will be described in more detail in the projections section.
	Extreme Precipitation (Long Duration)	The average annual maximum three-day accumulated precipitation amount.

Climate Grouping	Climate Variable	Brief Description
Drought	Moisture Deficit	The difference between annual precipitation and annual evapotranspiration.
Wildfire	Wildfire Index	The average return period of wildfire in years determined by climate and burnable material. Wildfire return period is the average time between fire events. The values for this variable and its methodology were obtained directly from the Canadian Forestry Service (CFS) and provided with permission from CFS.

2.4.2 Current and Future Risks

Climate risks were evaluated as a function of the frequency of the climate variable (within a grouping), the consequences of an impact, and the likelihood of that impact occurring. The frequency scales were characterized by the amount of change from baseline conditions, with the direction of change indicating potential for increased risk or opportunity.

Consequences, that form part of the risk equation, were classed in the following themes:

- Impacts on Human Health and Safety
- Environmental Damage
- Disruption of Services
- Financial Loss

Consequence rating or ranking were done using a five-point scale and were qualitatively defined as 'very low', 'low', 'medium', 'high', and 'very high'. The likelihood of an impact was characterized as the probability or percent chance of an impact occurring, categorized as 'improbable', 'remote', 'occasional', 'probable', and 'frequent' levels of occurrence. All consequence and likelihood criteria (scales) are included in Appendix 2. Additionally, details on consequence evaluation are provided for each Area of Focus in Sections 5.0 to 9.0.

Risks were scored using a four-point scale, which is referenced throughout this report and is shown in Table 2.4.

Table 2.4: Climate Risk Scoring Scale

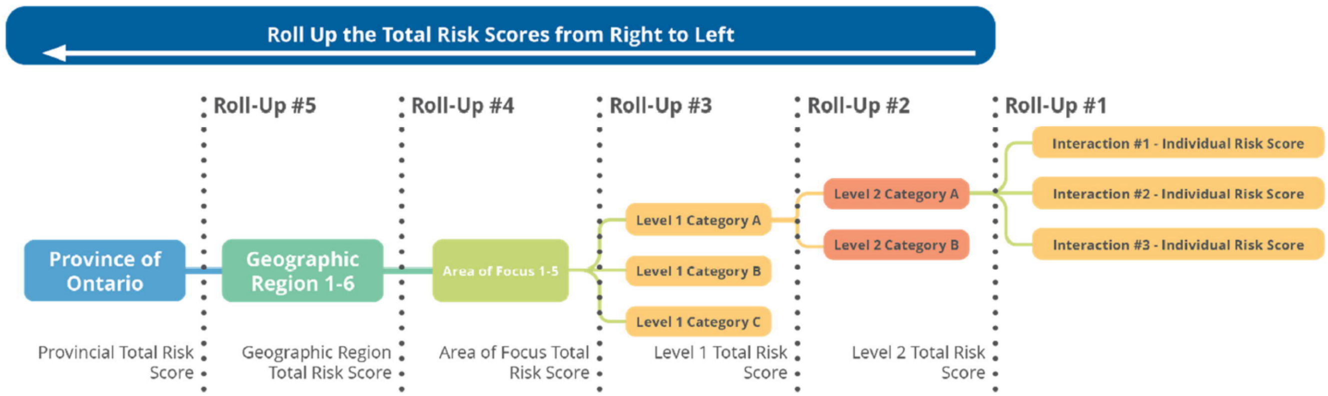
How to Read Risk Scores				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Risks were evaluated in all Level 1 and 2 categories for each Area of Focus. The evaluation included the 15 climate variables, with consideration given to specific agricultural commodities, infrastructure, ecosystems, populations and services, and economic sectors, present in different regions, according to available data and literature. Consequences were identified and scored under current, mid-century (2050s) and end of century (2080s) time periods.

As a result, risk scores were produced for each unique interaction (e.g. one climate variable and its associated risk scenario for a particular Level 2 category and provincial region). Every risk score was then compared, evaluated, normalized and added, or 'rolled-up', to produce a representative risk profile for a Level 2 category, then a Level 1 category, then an entire Area of Focus, and finally across an entire geographic region.

The approach of normalization applies to all levels of roll-up, as shown in Figure 2.5 that illustrates the conceptual roll-up of risk scoring. It is this roll-up process that enables significant scalability in results for future assessments, where local decision-makers can leverage, build upon or dive deeper into a particular theme, sector or system that is strategically important for their context. Additional details on the scoring process and application of the methodology are available in Section 2.5.

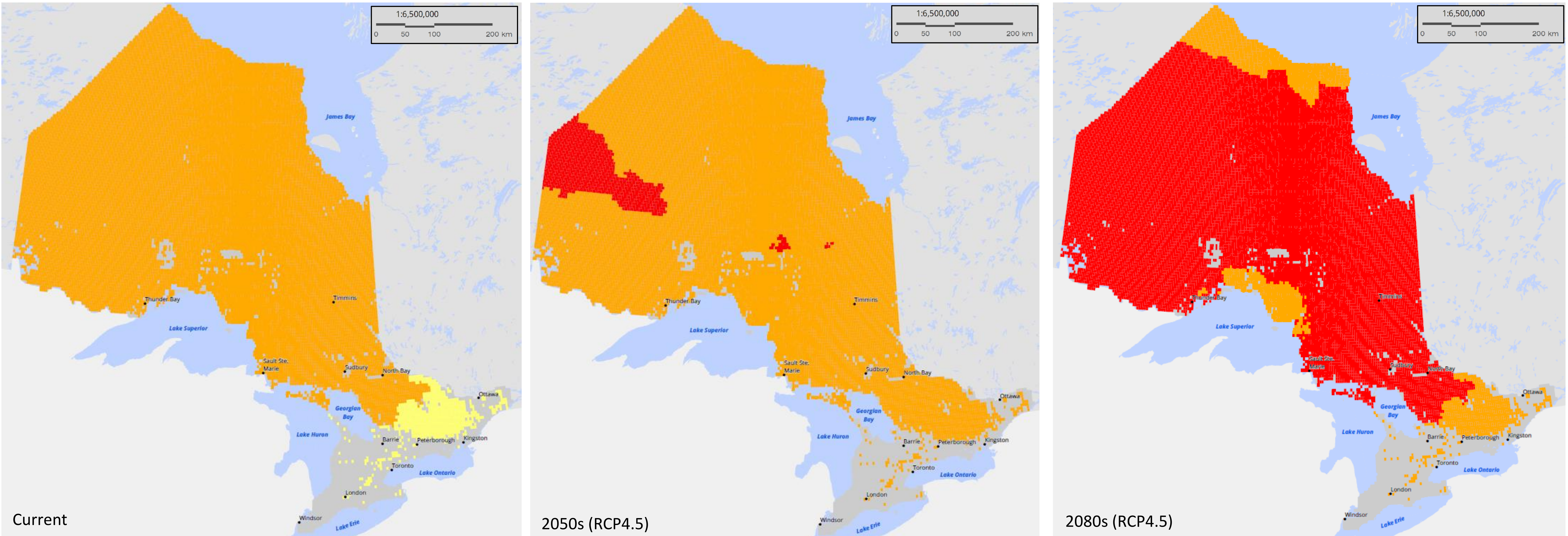
Figure 2.5: Visual Risk Roll-Up Approach



The various levels of roll-up avoided prejudice across the Level 1 and 2 categories, since some of the categories may be broken down to less or more degrees of granularity (e.g. more branches). The process involved normalizing the specific risk scores as they are summed during a roll-up, so that a category with more branches does not get a higher score than categories with fewer branches. As an example, if there are three individual risk scores for soybeans and six individual risk scores for rail, simply summing the risk scores will result in rail having a higher total risk score than soybeans.

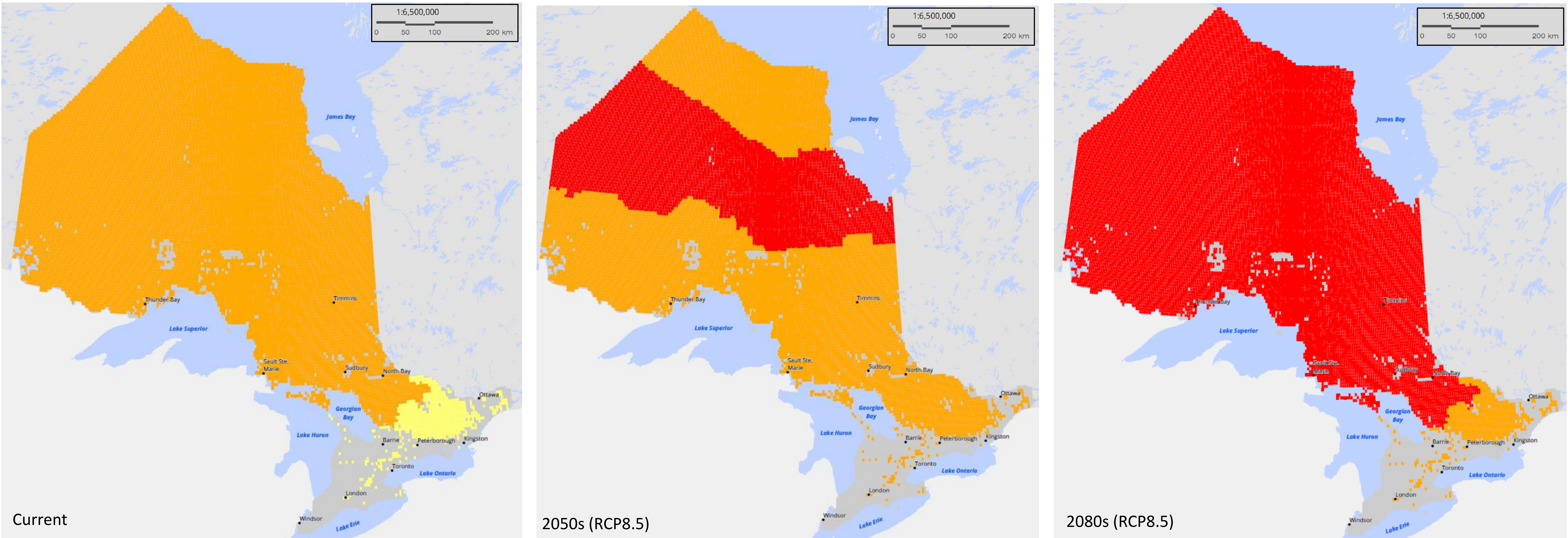
Figure 2.6 and 2.7 provide an example (Natural Environment Level 2 category – Bogs) that demonstrates the second finest level of risk scores calculated as part of the assessment, corresponding to roll-up #2 as shown in Figure 2.5. The example below illustrates risk scores for bogs with a spatial resolution of 10 km x 10 km grid cells for RCP4.5 and RCP8.5 scenarios, respectively. The graphics reveal the level of detail available for climate variables and projections assessed across Ontario (see Section 3.0). The results can then be rolled up to different spatial (regional and provincial) and methodological (Level 1 category and Area of Focus) scales representing the scalability of the assessment.

Figure 2.6: Scaling the PCCIA Methodology: An Illustrative Example of Climate Risks to Bogs across Ontario (Evaluated based on 10 x 10 km grids). Future climate risks are illustrated for RCP4.5.



No Value (e.g. Bogs not assessed in region)	Medium Risk (4)	High Risk (8)	Very High Risk (16)

Figure 2.7: Scaling the PCCIA Methodology: An Illustrative Example of Climate Risks to Bogs across Ontario (Evaluated based on 10 x 10 km grids). Future climate risks are illustrated for RCP8.5.



No Value (e.g. Bogs not assessed in region)	Medium Risk (4)	High Risk (8)	Very High Risk (16)

2.4.3 Climate Change Opportunities

The PCCIA defined opportunities as a decrease in risk score over time. Each Area of Focus has been reviewed for interactions that have reductions in risk over time, to identify potential opportunities. In select cases, risk scenario interactions exhibited a declining risk score (current to 2050s or current to 2080s), indicating a reduction in risk that may pose opportunities for the future. However, the assessment found that there are very few specific interactions or Level 2 categories that meet this criterion. The interactions that did decline in risk overtime were mainly linked to risks driven by low temperature. For example, declining frequency of Extreme Cold Days resulted in reduced risk scores for select animal and plant species (e.g. certain reptile species) assessed under the Natural Environment Area of Focus, as opportunities may exist for species to shift and expand their ranges. In addition, certain field crop and fruit and vegetable commodity interactions assessed under the Food and Agriculture Area of Focus saw declining risk scores based on declining risk associated with low temperatures. It is important to note that while there may be some opportunities associated with specific interactions, risks to overall Level 1 categories were mainly found to outweigh the potential opportunities across the Areas of Focus. Opportunities and appropriate adaptation action to limit the identified risks and help materialize potential opportunities are discussed throughout Sections 5.0 to 9.0.

2.4.4 Adaptive Capacity

Adaptive Capacity is a measure of the facets of a system, organization, or industry that can be used or applied to support climate change adaptation. Adaptive Capacity was qualitatively characterized based on literature review, engagement and expert experience. The components were scored on a three-point scale from 'low' to 'high'. Two Adaptive Capacity rankings were generated:

- Level 1 Category Adaptive Capacity within each Area of Focus
- Regional Adaptive Capacity for each Geographic Region

Note that Adaptive Capacity was assessed at the Level 1 instead of Level 2, based on available information and evidence to support the rankings. Although not exhaustive, the PCCIA used the following categories to evaluate Adaptive Capacity:

- Technology
- Resource Availability
- Equity
- Governance
- Sector Complexity

For the purposes of the PCCIA, **Adaptive Capacity** is defined as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (ISO 14090).

Technology refers to machinery, equipment or knowledge that can support the resilience of a system. Technology can include both hard technologies (e.g. field irrigation systems, real-time, road weather monitoring systems, etc.), and practices and planning (e.g. climate change-related best practices) as they relate to expertise in the field, lessons learned databases, best practices implementation, and capacity to innovate. Technology was included in the Adaptive Capacity assessment for all Areas of Focus and Geographic Regions.

Resource Availability relates to financial, human and natural resources that are available to an organization, industry, or system. Resources can be applied and/or redistributed to support resilience. This component was applied to all Areas of Focus and Geographic Regions.

Equity refers to the presence of equally distributed opportunities such as access to healthcare, employment opportunities, distribution of income, and social cohesion. This component was applied only to the People and Communities Area of Focus.

Governance notes the level of political or administrative presence and its organization and function to support resilience within an organization/industry. It addresses how an organization/industry is prepared to adapt for, and respond to, climate change hazards and shocks, including implemented policies, programs, and recognition of climate change. This component was applied to all Areas of Focus.

Complexity relates to the number of stakeholders or decision-makers present in a sector or at a regional level. The capacity to make decisions and change course at the sector or regional level can be inversely correlated to the number of decision-makers/stakeholders. This component was applied to all Areas of Focus and Geographic Regions.

The full characterization of Adaptive Capacity for each Area of Focus is provided in Sections 5.0 to 9.0 of this report. Full details on Adaptive Capacity for each Area of Focus and Region are available in Appendices 10 and 11. The characterization involved evaluating one or more of the five Adaptive Capacity themes, assigning a score of Low, Medium, or High based on literature and expert judgment for each Level 1 categories. Adaptive Capacity ratings were derived from a weighted average of the components, with complexity weighted higher than technology, resource availability or governance (or equity, for People and Communities). Full details on Adaptive Capacity scoring steps, including assigning scores to each Adaptive Capacity component for every Level 1 category and regions a, are available in the PCCIA Methodological Framework document (External Resource – 1).

2.4.5 Climate Adaptation Priorities

Climate change adaptation priorities were also identified as part of the impact assessment. An adaptation priority is defined as any Level 1 or Level 2 category in a given region that has relatively lower Adaptive Capacity rating and a relatively higher risk score. More specifically, if a Level 1 or 2 category and associated region receives an Adaptive Capacity rating of 'medium' or lower and exhibits a risk score of 'high' or 'very high', it is labelled as an adaptation priority. In general, these represent sectors and regions of Ontario that may have lesser capacity to adapt and exhibit a relatively high risk to climate change impacts. Current and emerging priorities were identified for Level 1 and Level 2 categories and regions within each Area of Focus (Sections 5.0 to 9.0). General adaptation options are identified for each Area of Focus to address priority areas. The adaptation options are drawn from the PCCIA Adaptation Best Practices Report (External Resource – 2), which provides more specific adaptation options and supporting details for each Area of Focus and Cross-Sectoral Theme.

2.5 Application of the PCCIA Methodology

The PCCIA methodology has been developed in a manner that is scalable to local contexts, scopes, and needs. Single risk scores for the PCCIA have been rolled up for each Level 1 and Level 2 category across applicable regions of Ontario. Regional averages have been used in characterizing the climate variable frequency – based upon the scale and scope of this top-down process across the province. The PCCIA Methodology Framework (External Resources – 1) establishes a top-down approach, beginning with climate modeling, tailoring those projections to assess impacts, evaluating risks and Adaptive Capacity, and ultimately recommending best practices for adaptation. A bottom-up risk assessment on the other hand, begins with characterizing in greater detail localized datasets, sensitivities, and exposures. This local characterization then informs thresholds and indicators to drive climate model projections and whether systems exceed those thresholds and are at higher risk or have lower capacity to respond. In the context of the PCCIA Methodology Framework, there may be instances in the future where bottom-up, localized impact assessments (e.g. those undertaken across a specific jurisdiction or sector) that have more detailed and local information to be incorporated, can bolster the granularity of results that align with geographic-specific policies and priorities.

A top-down impact assessment approach begins with climate modeling, tailoring those projections to estimate impacts and risks.

A bottom-up impact assessment begins with characterizing in greater detail localized datasets, sensitivities, and exposures.

The PCCIA Methodology Framework (External Resource – 1) has been fully detailed and can be scaled or applicable in a variety of ways:

- Area of Focus structures (Level 1 and 2 categories) can be adopted and built upon to be more locally specific and therefore increase resolution in what systems are being assessed across Ontario (e.g. transportation could examine freeways, regional roads, collector roads, local roads at a finer scale for an infrastructure climate change risk assessment).
- The risk criteria (e.g. defining scores and consequence categories) can be adopted and applied to different themes of climate change impact assessment.
- Risk and Adaptive Capacity scores can be assessed and employed at various scales, ranging from characterizing one particular climate variable for a given Level 2 category in one geographic region of Ontario, all the way up to examining an entire sector or system across Ontario as a whole. Subsequent local climate change impact assessments could leverage this information at the scale that aligns with their scope and scale, and dive into further depth and/or explore further indirect impacts or consequences that align with their mandate.
- The resources and literature being compiled and synthesized to inform risk and Adaptive Capacity scoring can be a springboard for future assessments at the local level, particularly where sectors and systems have not yet been assessed or where resources are challenging to find.

2.6 Limitations of the PCCIA

Achieving great depth and detail in a climate change impact assessment for Ontario's broad geography and complex built, social and natural systems proves challenging. Necessarily, and by design, the assessment is at coarse scales and is informed by representative scenarios of climate risk. The scale of risk reporting is at regional and Area of Focus levels and is founded on a variety of knowledge sources (e.g. datasets, literature, consultation, professional judgement etc.). Finer scales of climate change impact assessment and accompanying adaptation response could be conducted independently following on methods used by the PCCIA. The following limitations constitute general challenges that accompany broad scale climate change impact assessments and specifically those encountered as part of the overall PCCIA process. In addition, limiting factors specific to Areas of Focus are listed throughout Sections 5.0 to 9.0.

Open Access to Relevant Data

The PCCIA methodology was structured based on an underlying assumption of publicly available and accessible data sources. Data on losses, damage, declines in function and changes to structure help establish trends and projections of change which are fundamental to climate change impact assessments. Datasets sought for the PCCIA lacked comparability and consistency (e.g. time scales and length), and in some cases ideal data were not captured or freely available. In many cases, datasets were available in a subset of jurisdictions or upon request from specific organizations, however, data availability constrained desired assessment in some regions and sub-sectors. Data also play an important role in the development of geospatial analysis of climate impacts and risk which are powerful communication tools. Future assessments may have greater access to improved or longer datasets which can be incorporated into climate risk identification, analysis and evaluation.

Uncertainty in Climate Change and Socio-Economic Projections

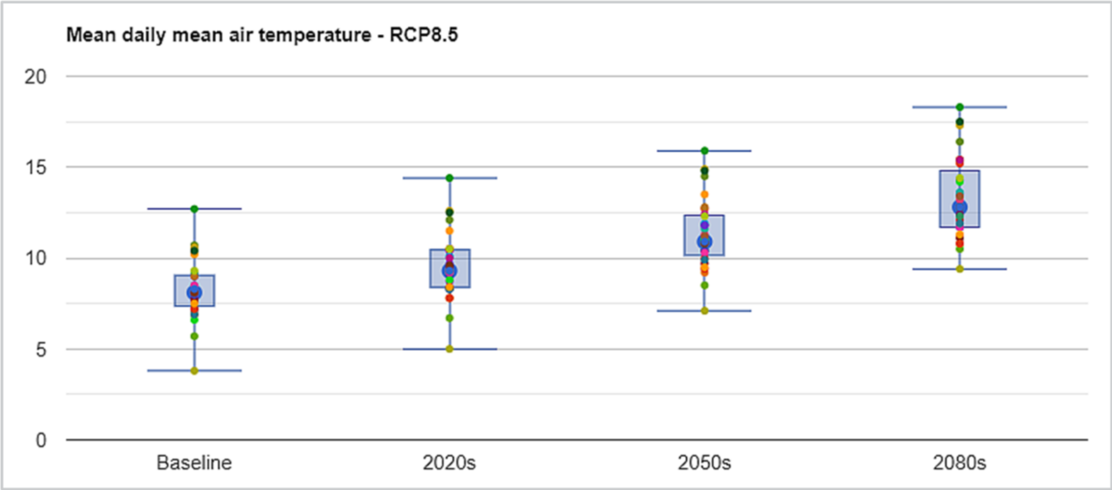
Climate model output and projections of socio- economic change are foundational to characterizing potential future risks in any climate change impact assessment. These inputs paint a picture of the bounds of future conditions that directly or indirectly influence climate risk. There are various inputs to both climate change and socio-economic projections that have inherent uncertainties in determining future conditions. All are plausible and require clear communication around their boundaries and limitations.

With relation to socio-economic data specifically, there are many possible developments that are not accounted for in projections. Therefore, the socio-economic scenarios should not be classed as ‘predictive’ but rather be used to provide a plausible and consistent reference case from which to assess different climate risk scenarios and consider the relative scale and importance of anticipated impacts. In other words, we use a single scenario to identify plausible changes in socio-economic factors that are related to climate change alone and not differing pathways of socio-economic change. In addition, population forecasts have been updated since this analysis was conducted in 2021, and therefore the socio-economic scenarios applied in the PCCIA are no longer based on the most recent projections (Ontario Ministry of Finance, 2022).

For climate change projections, some variables or indices are difficult to model, most notably those associated with extreme weather (e.g. high winds or extreme sub-daily precipitation). Regardless of the source of these data, an explanation about degrees of confidence is important for the reader to appreciate the full range of plausible future states. Uncertainties are inherent within climate downscaling including the statistical processes associated with defining future climate variables (see Box 1). The top-down approach to the PCCIA means that climate variables were scaled to 10 km x 10 km grid cells covering the entire province and were then averaged or “fitted” to the regions defined by the Ontario Ministry of Environment, Conservation and Parks. The fitting of climate variables within geopolitical boundaries introduced additional uncertainty into the assessment process, as did evaluating climate risk across entire regions (where significant variability may exist within one region of Ontario).

Box 1: Uncertainty Associated with Climate Models

When using any ensemble of regional or global models, a distribution of outcomes is determined primarily by the individual model formulations. In most cases the models tend to produce a near-Gaussian distribution with a cluster of model estimates near the mean or median and smaller tails to the distribution. The mean of the ensemble is the implied convergence of estimates from the cloud of outcomes. This is not a consensus, but a 'best estimate', illustrated below, in a sample box and whisker plot of mean annual temperature projections. In the plot below, coloured dots represent individual model values with the larger blue circle representing the model ensemble average. The top of each box represents the 75th percentile value and the bottom of each box the 25th percentile value of all the models. The top and bottom horizontal lines represent the highest and lowest model values, respectively.



From the boxplot it is evident there is uncertainty in projections from the range of possible model outcomes. This is accepted in any climate change impact assessment and explains why the PCCIA applies the model ensemble average (the value of the blue circles) as the projected value.

Selection of Climate Variables

A suite of 15 different climate variables were selected for the PCCIA based on their prominence in literature, application to the Areas of Focus, and through consultation with provincial departments associated with the PCCIA. Some climate variables of interest were not included in the assessment because they could not be downscaled with acceptable accuracy. Specifically, freezing rain and high winds were excluded from the analysis, as these variables cannot be readily projected due to data gaps, poor data quality or data insufficiency. The climate variables that were used, expressed as indices, have been designed to be multi-purpose and to meet the needs of each Area of Focus, but as technology and data processing improves, additional or expanded climate variables could be used in subsequent impact assessments.

Scale of Risk Assessment

As noted above, the assessment of climate change impacts occurred across six Geographic Regions of Ontario and assumed average conditions across each region. Finer scale assessments would help to develop information at more granular and localized scales to better inform decision-makers in communities and organizations, and ensure information is usable and pertinent to their jurisdictions, members and networks. The PCCIA includes a suite tailored and targeted Decision-Making Supports (DMS) (External Resources – 3) to provide different audiences with understanding of the scalability of the PCCIA process and assistance with interpreting how they could use PCCIA information in their respective roles.

Additionally, the PCCIA was constrained to impacts inside of provincial boundaries. Numerous participants throughout engagement noted strong external influence on systems, processes and communities within Ontario. Climate impacts occurring outside of Ontario that could cascade through to, or impact Ontario (e.g. widespread brownouts) were not assessed under the PCCIA and could be considered in future assessments.

Due to the scale and scope of the PCCIA and the complexity that can appear, indirect and cascading impacts were not quantitatively scored. The scope of the assessment would exponentially increase if those interactions were to have been accounted for through risk scoring. In many cases, the indirect and cascading impacts are jurisdictional or context-dependent and would not scale well within a province-wide assessment. Such impacts have in most cases been qualitatively characterized within each Area of Focus (Sections 5.0 to 9.0).

Evaluating the Consequence of Climate Change Impacts

Commensurate with the scale of the impact assessment and the breadth of data and information applied, a single consequence criterion was typically used to quantify each risk scenario, dependent on relevance to each Area of Focus. Using a single category to assess consequence has limitations, as it not only reduces the inputs into the impact assessment, but also does not allow for inclusion of a more holistic picture of consequence. If the PCCIA Methodology Framework were to be reproduced or replicated at finer spatial scales, multiple or additional criteria (such as legal/regulatory risk and reputational risk) could be used to represent a variety of consequence types across each Area of Focus.

Cost of Impacts and Inaction

While it is well-documented that climate change impacts have and will continue to have economic consequences for public and private sectors, a cost analysis of impacts or inaction (absence of adaptation) was not included within the PCCIA. The costs associated with climate change related risks and adaptation could be an area of future study.

Engagement Constraints

Original plans for PCCIA engagement included in-person workshops in the regions of the province. The COVID-19 pandemic altered the engagement approach to full-virtual. While technology enabled comprehensive input from groups across the province, the virtual delivery constrained discussion depth and the natural 'building' or 'playing off' that occurs when discussions are in-person. By the time virtual engagement sessions were underway, there had been a (perceived) degree of virtual fatigue and resulted in lower-than-expected participation.

Indigenous Engagement Limitations

Indigenous culture and traditional ways of life in Ontario are a key area of risk under a changing climate, particularly in northern and remote regions of the province. While a unique engagement process took place for Indigenous engagement, the nature of the Area of Focus categories along with time and budget availability were such that the required, more fulsome engagement of Indigenous Peoples and Communities was not possible. Through engagement activities and interviews with Indigenous organizations, it was emphasized that inclusion of Indigenous Peoples and respectful use of Indigenous Knowledge is fundamental to an Ontario-wide climate change impact assessment and must been recognized a fundamental limitation of this assessment.

3.0 Ontario's Changing Climate

3.1 Approach to Characterizing Climate Change

3.1.1 Defining Climate Variables used in the PCCIA

Historical and projected climate data were a fundamental component of the PCCIA. In consultation among all Area of Focus leads and with select provincial departments (Ministry of Environment, Conservation and Parks and other IAIC members), climate variables were selected and vetted for their utility in the assessment. Each variable was rationalized based upon a) the degree to which the variable led to impacts within an Areas of Focus, b) the level of uncertainty associated with future projections, and c) the scope of the PCCIA. Ultimately, 15 climate variables were selected for the PCCIA. The selected variables are defined in Table 2.3, with a brief rationale for their inclusion outlined in Table 3.1. Climate variables that were excluded from the PCCIA are listed in Table 3.2, with supporting rationale for their exclusion.

Table 3.1: A Summary of the PCCIA Climate Variables and Rationales for Inclusion

Climate Variable	Rationale for Inclusion
Extreme Hot Days (> 30°C)	Extreme Hot Days were selected as they impact all Areas of Focus. This variable has a variety of applications, including human health impacts on vulnerable populations, livestock stress, limits to outdoor recreational activities, algae or water quality impairments on water bodies, electricity infrastructure impacts, and road pavement deterioration, among others.
Degree Days < 0°C	Degree Days < 0°C represent the accumulated cold days below zero throughout the year and can act as a proxy for a warming climate/region, which may be especially important in the North. Applications can include seasonal lake, ice formation, winter roads capacity or maintenance impacts, impacts to roadbeds and pavement, deterioration of assets or foundations, construction practice restrictions or costs, snow and ice accumulation, among others.
Cold Days < -25°C	Cold Days represent winter extremes and can vary between regions (e.g. Far North thresholds of cold temperatures are different from those of Southwest Ontario). Impacts include human health, infrastructure limitations, potential for discontinuous permafrost, and viability of pests and invasive species, among many others.
Cooling Degree Days (18°C)	This variable is used to design cooling and ventilation systems and can be used as a measure for summer energy use. It can also be used as a proxy for overall change in average annual temperature. Specific applications include infrastructure HVAC impacts, heat stress or human health consequences, and shifts in cooling needs or electricity demand in the summer.
Growing Degree Days (5°C)	Growing Degree Days is an important variable for Food and Agriculture and Natural Environment Areas of Focus, indicating potential changes in

Climate Variable	Rationale for Inclusion
	growth patterns over time. Applications of this variable include agricultural conditions for crops, new varieties, seasonality of pests, management, or possible impacts to forestry, and shifts in wildlife populations, among others.
Growing Season Length	Growing Season Length is an important variable for Areas of Focus that include (or rely upon) the natural environment and can help to refine the limitations for agricultural decisions and vegetation types. This variable could be applied to Food and Agriculture, Natural Environment, People and Communities (especially Indigenous Communities Level 1 category), and Business and Economy Areas of Focus.
Spring Precipitation	Spring Precipitation can be used to inform and characterize the frequency of spring flood potential, pre-growing season precipitation for crop germination and productivity, water supplies and nutrient disturbance regimes for ecosystems, soil erosion, pavement deterioration, among others.
Summer Precipitation	Summer Precipitation is relevant in characterizing tourism and recreational activity limitations, forest productivity and/or wildfire risks, water levels, water supply or sources and streamflow conditions in the natural environment, among other applications.
Autumn Precipitation	Autumn Precipitation variable can be useful to evaluate reservoir or water storage capacity and operations, some crops (e.g. forages or spring wheat) germination, forest health and habitats for fall-spawning fish species.
Winter Precipitation	Winter Precipitation variable includes snow and rainfall occurring within the winter months; changes in the variable can impact infrastructure and communities across Ontario. Applications could include flood risks and timing, winter sports potential and season length, impacts to soil moisture and lake levels, tree survival, underground infrastructure, and disruptions to supply chains or industry from storms, among numerous others.
Winter Rain Percentage (Rain:Snow Ratio)	The Winter Rain:Snow Ratio allows for the detection of changes in precipitation regimes in the wintertime, which can impact all Areas of Focus. This variable can be used to characterize flood impacts in winter and spring, impacts to spring soil moisture or water storage and recharge, water levels, soil erosion or runoff, perennial and forage crop productivity, winter road maintenance, and de-icing needs for transportation such as at airports, among others.
Extreme Precipitation (Short Duration)	Short Duration Extreme Precipitation events can impact all regions and all Areas of Focus. Applications include risks associated with damage to buried and ground level infrastructure, crop damage or timing of losses, flooding and health risks and supply chain or industry disruptions.

Climate Variable	Rationale for Inclusion
Extreme Precipitation (Long Duration)	Long Duration Extreme Precipitation events tend to have a longer lasting impact on natural systems, and possibly on the built environment as well. Applications for this variable include examining soil erosion, crop pests or diseases timing, reservoirs or streamflow levels, and flooding risks, among others.
Moisture Deficit/Drought	Moisture Deficit/Drought variable represents a function of precipitation and evaporation (based on temperature), so it does not fit in either the temperature or the precipitation groupings. The impacts of drought can be wide-ranging and affect agricultural production, water storage and supply, streams and lake levels, and wildfires.
Wildfire Index	Fire return period is estimated using multiple climate variables. It is identified in this study as a standalone climate grouping. The consequences of wildfire can be severe, and impact natural systems, the communities that rely on them, and the communities in the way of the fires. This variable can be used to characterize wildfire risks, community health risks from wildfires and smoke, forest management, emergency response, and infrastructure losses or disruptions.

Table 3.2: A Summary of Climate Variables Excluded from the PCCIA and Rationales for Exclusion

Excluded Climate Variable	Rationale for Exclusion
Heatwave	The impact from a heatwave can be captured by the more multi-purpose variable of Extreme Hot Days (>30°C), which is applicable to all Areas of Focus and not just human health and/or electricity demand/stress.
Mean Maximum Summer Temperature	This is better captured by the Extreme Hot Days variable, which is more multi-purpose.
Mean Winter Temperature	There are not many applications for this variable since Low Temperature variables (Degree Days <0°C and Cold Days <-25°C) already capture winter cold or accumulated colder days.
Mean Spring Temperature	There are not many applications for this variable since spring temperatures are captured by Growing Degree Days and Growing Season Length variables.
Mean Summer Temperature	This is captured by High and Extreme Temperature and Temperature variables (Extreme Hot Days, Cooling Degree Days, Growing Degree Days, Growing Season Length); there are not as many applications for this variable.
Mean Annual Precipitation	The variable is redundant as it can be calculated from seasonal precipitation totals.

Excluded Climate Variable	Rationale for Exclusion
Freeze-Thaw Cycles	Daily freeze-thaw cycles are usually rated as low consequence in risk assessments, relative to other impacts. Other ground frost variables such as Degree Days <0°C are more important and can be used as proxy.
Freezing Rain/Ice Storm	Freezing rain and ice precipitation cannot be reliably projected and are difficult to estimate for current conditions due to climate data insufficiency.
Cold Season Length	This is captured for more applications by Cold Days <-25°C.
Cold Snap	This is captured for more applications by Cold Days <-25°C.
High Winds	This variable cannot be reliably projected and is difficult to estimate for current conditions due to declining quality of the climate data. High winds and their projections are particularly challenging since they tend to be very site-specific due to fetch, land surface type, and model formulation.

3.1.2 Historical and Future Data Methods

Current climate impacts were assessed using Environment and Climate Change Canada's latest official Climate Normals released for the period of 1981 to 2010 (Environment and Climate Change Canada, 2022a). Then, using climate projections the same impacts were assessed in the future time horizons of the 2050s (representing the period from 2041 to 2070) and the 2080s (representing the period from 2071 to 2100). The changes from current conditions inform the quantified degree of expected future climate conditions.

Historical Data

A high resolution (10 km by 10 km) dataset of temperature and precipitation observations covering the entire province was used for the assessment (Environment and Climate Change Canada, 2016a; Natural Resources Canada, 2020a) and has been used widely within Canada for other climate research (e.g. for developing wildfire indices by the Canadian Forestry Service) (McKenney et al., 2011; Hopkinson and McKenney, 2011; Hutchinson et al., 2009). In general, the dataset used for this study represents climate conditions very well, but because it is based upon observational data there is a larger potential error in data-sparse parts of Canada's North.

Daily observed minimum and maximum temperatures and precipitation (including rain and snow) were used for the development of the gridded historical dataset (Natural Resources Canada, 2020a; Mckenney et al., 2011). As outlined, interpolation of station data uses a smoothing-spline technique to interpolate data between stations to produce a continuous climate surface. Stations with data records of more than five years were included. No additional corrections or interpolations were necessary because the dataset provides daily data at a 10 km by 10 km resolution and amounts to slightly over 18,000 data points across Ontario.

Future Projections

Projections are the possible future changes in climate conditions under different GHG emissions scenarios and socio-economic factors (e.g. use of technology, governance, land-use change etc.). Climate scientists develop projections of future climate conditions using results from different climate models. These projections are created through a standard set of computer-run experiments with mathematical models that simulate a coupled atmosphere-ice-ocean-land system. To calculate projected changes in climatic conditions, models compare future climate projections against a historical baseline period to determine expected changes. Average climate conditions are typically represented by 30-year time periods. For example, the 2071-2100 time period is typically used to represent the end of the 21st century and 1981-2010 is used to represent historical baseline climate. Climate models simulate the future climate using prescribed emissions scenarios or pathways.

In the PCCIA, 32 Global Climate Models (GCMs) were used in the RCP4.5 ensemble, while 33 models were used in the RCP8.5 ensemble to calculate projections of future conditions. Maximum, minimum, and mean temperature are standard output variables from these GCMs, as is precipitation. The suite of models used in AR5 is from the Fifth Coupled Model Intercomparison Project (CMIP5), coordinated by the World Climate Research Program (IPCC, 2013). The newest assessment (AR6) was released after completion of the climate projections for PCCIA and was not considered.

The use of multiple models to generate a best estimate of climate change is preferred over a single model outcome. Research has indicated that the use of multi-model ensembles is preferable to the selection of a single or few individual models since each model can contain inherent biases and weaknesses (IPCC-TGICA, 2007; Tebaldi and Knutti, 2007).

Representative Concentration Pathways (RCPs) refer to a set of emission standards used primarily by climate modelers to explore plausible future emissions options and their implications for climate responses. Expressed as watts per square meter, they refer to consistent prescribed pathways by 2100 for GHG and aerosol concentrations, together with land use change. Each RCP (2.6 to 8.5) is the resulting level of “forcing” in the atmosphere that would result from the scenario being realized. For the PCCIA, an ensemble of GCM projections was utilized for future projected climate conditions based on two future GHG emission pathways: RCP4.5 (moderate emission pathway) and RCP8.5 (high emission pathway).

In this assessment, the approach used to derive downscaled climate change projections is the Delta Approach, which is one of several methods for obtaining downscaled and bias-corrected projections of future climate. This approach is perhaps the simplest, the easiest to understand, and has been widely used for impacts and adaptation studies. It has also been shown to compare well with other more complicated downscaling approaches. When this method is coupled with the use of many models to generate projections, it generally provides more useful information than when a single or small set of models are used, regardless of their spatial or temporal resolution.

The approach used to downscale GCM projections to develop regional scale projections is only reasonable for a provincial scale assessment of this nature. This approach and resulting climate projections would not be technically reasonable for local scale risk assessments as more sophisticated approaches are currently available, such as the use of Regional Climate Models (RCMs) that better account for Ontario's unique geophysical features (e.g. Great Lakes, Niagara Escarpment, Hudson Bay) and their influence on local climate and weather, particularly extreme weather events. These downscaling approaches and associated climate projection data should be used for local scale assessments. A full description of the methods used to derive future projections is provided in Appendix 4.

3.1.3 Addressing Uncertainty

Inherent in any climate change projection are uncertainties in future conditions. The level of uncertainty (see Box 2) can vary by variable assessed, by future time period (longer time in the future is more uncertain), by region, and by the spatial scale of the assessment. Projections included in the PCCIA somewhat address the uncertainties associated with the last factor by averaging data points found within larger regions of Ontario, however they should not be used for specific guidance for individual locations. Local projections can be influenced by highly site-specific conditions and processes and should be developed using more sophisticated downscaling methodologies.

Box 2: IPCC Sixth Assessment Report and Uncertainty

Since this PCCIA was started, new climate change projections have become available with the IPCC Sixth Assessment report (AR6). These new projections do not negate the utility of the currently assessed AR5 projections.

In the IPCC guidance documents broad uncertainty statements are made about overall climate variables assessed with the understanding that some can be more definitively projected than others. In the IPCC documents more quantitative levels of confidence are applied and outlined below (Mastrandrea et al., 2011).

- Virtually certain (99 to 100% probability)
- Extremely likely (95 to 100% probability)
- Very likely (90 to 100% probability)
- Likely (66 to 100% probability)
- About as likely as not (33 to 66% probability)
- Unlikely (0 to 33% probability)
- Very unlikely (0 to 10% probability)
- Extremely unlikely (0 to 5% probability)
- Exceptionally unlikely (0 to 1% probability)

A recent document released by Environment and Climate Change Canada (Environment and Climate Change Canada, 2020) summarizes the levels of certainty according to qualitative descriptors such as 'very high', 'high', 'medium', 'low' and 'very low' confidence. Overall, the confidence in thermal (temperature related) variables is high since the relationship between GHG increase in the atmosphere and its thermal effect is well captured by climate models. Confidence in precipitation variables is lower, followed by others such as wind and snowfall. Accordingly, the variables assessed in PCCIA can be classified into the qualitative categories outlined in Table 3.3.

Table 3.3: Levels of Confidence Applied to PCCIA Climate Variables

Climate Variable	Confidence Level
Cooling Degree Days	Very High
Degree Days < 0°C	Very High
Extreme Cold Days	High
Extreme Hot Days	High
Extreme Long Duration Precipitation	Medium
Extreme Short Duration Precipitation	Medium
Growing Season Length	High
Mean Autumn, Winter, Spring, Summer Precipitation	Medium

Climate Variable	Confidence Level
Moisture Deficit	Medium
Rain:Snow Ratio	Medium

Model Uncertainty

There are several sources of uncertainty involved in climate change projections. The main sources are the assumption of the GHG forcing pathway (e.g. RCP4.5 (lower emission pathway) versus RCP8.5 (high emission pathway)), and the climate models themselves. Climate models are mathematical representations of the physics of the atmosphere and so are approximations of reality, where some features are well known, and some are not and require 'parameterization'. Parameterization is the process whereby some processes are simplified as indicated empirically by experiment.

In addition, some natural variability processes such as 'El Nino' are not ideally captured within climate models. Long period averages are, therefore, much more reliable than any estimate of a single year or shorter than a 30-year average value. For the PCCIA, as for IPCC assessments, an ensemble of many models tends to add to the strength of the projections because multiple estimates are combined to produce an ensemble average. This reduces the potential errors or limitations of any individual model in the final projection value. Additionally, the process used in PCCIA only considers the difference (delta) between the model average baseline historical condition and the future period condition – or the model climate change signal. The actual accuracy of the model in representing the baseline condition, which may be biased, is not considered. This means the model specific uncertainty is reduced by both the use of the ensemble and the delta process upon an identical baseline observed climate used in this PCCIA assessment. Nevertheless, the gridded dataset itself based upon point measures at Environment and Climate Change Canada observation stations, introduces some uncertainty in locations where few stations are situated (e.g. Ontario's Far North).

Methodology Uncertainty

Uncertainty is also introduced and acknowledged with the use of the delta methodology within the PCCIA. Specifically, the model ensemble delta 'signal' from the GCMs is generated at a 250 x 250 km resolution over Ontario which is then overlaid upon the higher resolution 10 km x 10 km baseline period average. This mismatch in resolutions can result in some artificial boundaries between the larger grid resolution cells over the province. This anomaly effect is visible in some variables for the projected periods (as an example, the 'Extreme Cold Days' projection map near Hudson Bay and James Bay). This effect however would not influence the regional average climate conditions used for evaluation purposes since cells across both sides of the boundary would be averaged together (e.g. spatially weighted by their number falling within the region considered).

Several points are to be considered regarding the use of GCMs in PCCIA versus more spatially discrete RCMs. Firstly, there are far more GCM estimates of climate change than that of RCMs for Ontario. A larger ensemble average is preferable over fewer higher resolution models for a provincial-scale assessment considered here. For site-specific locations going forward the use of an RCM may be a better option. Secondly, all RCMs require their linkage to a specific GCM which helps to set their 'boundary conditions' at the edge of the RCM area being considered. This GCM highly influences any outcome of the RCM, meaning if the GCM used is warmly biased, so too will be the RCM output.

Looking at the benefits, such RCMs may include better parameterizations than that found within a GCM. This would theoretically improve the projection of higher resolution effects associated with variables such as extreme precipitation where convection is important since convection can be explicitly modeled and not parameterized. Environment and Climate Change Canada adds that 'Such convection-permitting models, however, remain largely experimental because of their very high computational cost' (Environment and Climate Change Canada, 2020). Such experimental outcomes from ensembles of RCMs still find however, that there is no 'convergence' of model projections with this higher resolution – models still show a spread of projected values. Even with a high-resolution output there is still model projection uncertainty – it is not eliminated or even necessarily reduced due to different model formulations of RCMs.

Uncertainty in Climate Variables

Short Duration Precipitation

Additional discussion regarding uncertainty for the projection of short duration precipitation is also warranted. It is acknowledged that both the historical observation of extreme short duration precipitation events (such as thunderstorms) and projections of such events are ill-suited to climate models. Novel attempts to improve both these estimates were utilized within PCCIA – firstly, to improve the baseline estimates of potential extreme event gridded values by the adjustment of the gridded values based upon station specific extremes and, secondly, the use of the Clausius-Clapeyron temperature-related effect upon extreme precipitation projections. Both attempts introduce potential uncertainty themselves, but it is also understood that these procedures improve the final outcomes by incorporating observed and measured daily extremes for the historical condition as well as scientifically published and recommended methodology for the projections. It is recognized that a gridded historical precipitation value even at 10 km x 10 km resolution is often beyond the spatial scale of a single intense thunderstorm and the gridded value average would therefore be less than an extreme event value which was experienced. This was the intention of the use of 70 observation station extremes to determine the 'adjustment factor' to apply to the gridded values for such an extreme. Across all regions an adjustment of on average 38.5% increase was found, with little variation among the regions assessed. This gives some confidence in the fact that the factor determined was related to the 'grid scaling effect' versus any specific regional effect which one might expect to be very different region to region. As such, the historical gridded one-day rainfall maximum was increased by 38.5% from the original value (Environment and Climate Change Canada, 2016a). This brought the 'observed' historical values closer to the actual station observed extreme daily totals.

When considering future precipitation daily extremes, models produce such an output directly, but based upon the literature and recent recommendations of Environment and Climate Change Canada for the projections of extreme precipitation, the Clausius-Clapeyron methodology was used (Environment and Climate Change Canada, 2020). Changes in temperature are much more certain than precipitation, therefore, a thermal adjustment based upon the theoretical association between temperature increase and increased moisture holding capacity of seven percent was applied. This method should be considered the 'default' going forward for the projection of short-duration precipitation up to one day due to model limitations at such high spatial and temporal scales – including even RCMs. Quoting Environment and Climate Change Canada, 'Given that more confidence can be placed on regional temperature projections, the use of temperature scaling factors – expressing the relative change in precipitation extremes as a function of warming – is recommended' (Environment and Climate Change Canada, 2020). This methodology was applied in the PCCIA.

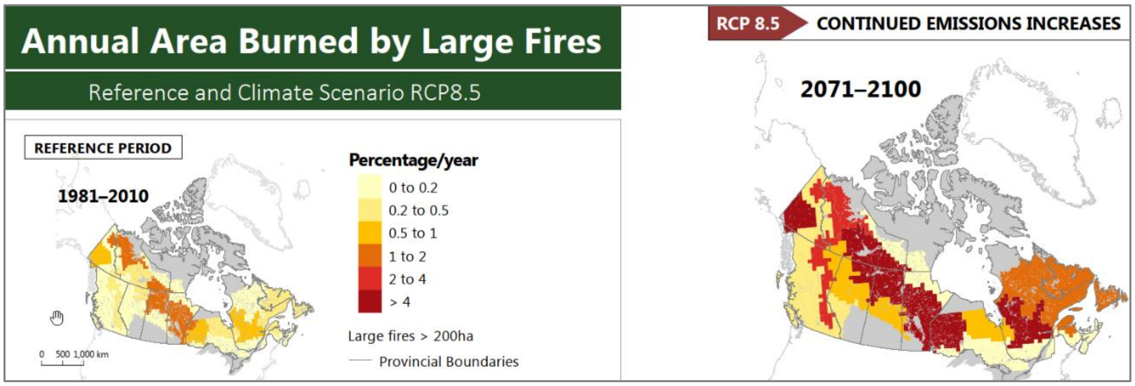
Wildfire Index

The wildfire variable provided by the Canadian Forestry Service (CFS) can be used for long-term guidance of future fire occurrence, specifically the 'fire return period'. It can range from several years where fire is most frequently expected to occur, to thousands of years where the burn rate is less frequent. Fire return interval (e.g. the average time between fire events, determined by climate and burnable material) in this case is exactly the inverse of the burn rate. The methodology of scoring this fire index by using the standard deviation (SD) of the historical range of frequencies results in a time range which is much larger than other variables since it can span between a few to thousands of years. For this reason, it did not properly reflect the potential wildland fire occurrence expected in Ontario and therefore the variable has not been included in this report. When all data points within a single region are statistically considered, standard deviations are very large. Using the same consistent standard deviation categories used for all other variables (+/- 1.5) and then (+/- 2.5), we find that applying the future projections very often generates a future value which falls within the +1.5 SD of historical datapoints. This would mean that a cell would retain the current period score of '4' which incorrectly implies there is no additional fire risk. The nature of this variable (because of its very large ‘natural variability’) makes it difficult to capture the predicted increases in fire occurrence as it means a future change in return period must be quite large to move categories even though all points through the province show shortening return fire period, in other words, increased fire occurrence.

To supplement the wildfire, return period index used for scoring within this report, two additional fire variables are provided here for additional information which are not scored. These are the ‘Annual Area Burned’ and ‘Number of Fires’, also produced by CFS for all of Canada using the CanESM2 and for the same baseline and future period under the RCP8.5 scenario as provided for other variable maps (adapted from Boulanger et al., 2014). Both Ontario-based maps indicate in other ways the importance of wildfire in a future climate and indicate both an increase in the annual area burned and an increase in number of large fires (classified as being greater than 200 ha).

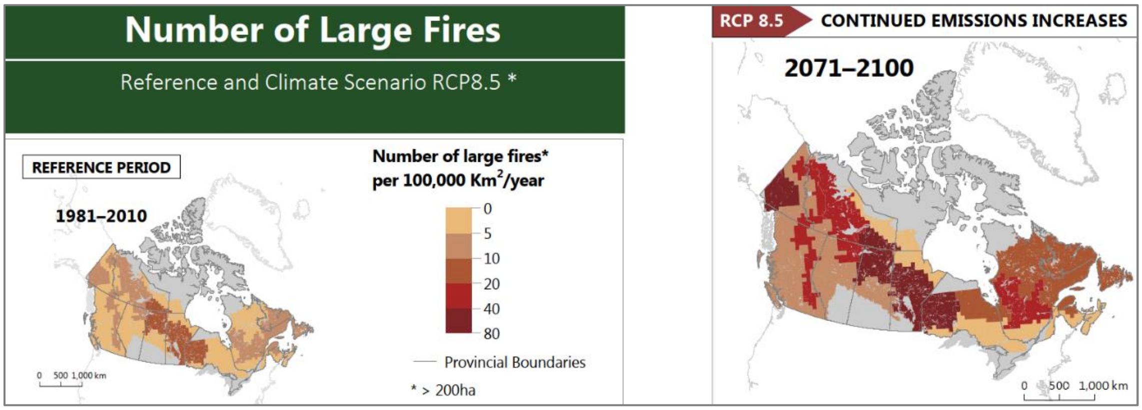
The annual area burned is shown in northern Ontario (particularly in the Northwest Region) to increase by over four points of percentage (which represent more than a four-fold increase) from the baseline reference period by the 2070s, (Figure 3.1), while the number of fires also more than doubles in this area from 10 to 20 to between 40 to 80 fires of over 200 ha – a four times increase (Figure 3.2). Together these two additional maps imply that the scoring from PCCIA using ‘Fire Return Period’ scoring **underestimates the increased risk from fire under future climate change conditions** using the standard deviation categories used for all other variables. This additional information is intended to highlight this limitation of the PCCIA index and its standard deviation categorical scoring.

Figure 3.1: Percent Annual Area Burned by Large Fires Under Current and Future 2070s Timeframes (RCP8.5)



Source: Boulanger et al., 2014

Figure 3.2: Number of Large Fires (> 200 ha) Under Current and Future 2070s Timeframes (RCP8.5)



Source: Boulanger et al., 2014

3.2 Historical Climate Trends and Future Projections

While a detailed region-by-region climatological characterization of Ontario was not part of the assessment scope, historic (current) climate conditions and future projections are foundational to understanding where and how climate risks may be changing. Prior to examining changes from current conditions into future time periods within the context of the PCCIA, a brief historical characterization is provided.

Ontario's average annual air temperatures increased between 1 to 1.5°C between 1948 and 2012, with northern regions experiencing slightly larger increases than areas further south (Vincent et al., 2015). Seasonally, the rate of increase is most accelerated in the winter season and associated with minimum air temperatures (Woudsma and Towns, 2017)

Warming air temperature has already led to declining ice cover in the Great Lakes Basin, with maximum ice cover decreasing by five percent per decade, on average. While annual variability is large, long term historical trends indicate declines since the 1970s with the greatest declines occurring in Lakes Superior, Huron, St. Clair, and Erie (Wand et al., 2020; Yang et al., 2020).

Precipitation across Ontario increased between 1948 and 2012, with more notable changes occurring in the northern regions of the province. Rain, as a proportion of total precipitation, has been increasing in the winter season while snowfall has decreased across all regions (Vincent et al., 2015). In Ontario, there has been a 9.7% increase in normalized total precipitation between 1948 and 2012. This translates to a 5.2% observed increase in winter, a 12.5% increase in spring, a 17.8% increase in autumn and an 8.6% increase in the summer season (Zhang et al., 2019).

Water levels on the Great Lakes are continuously monitored by U.S. and Canadian federal agencies (National Oceanic and Atmospheric Administration, 2022) using a network of water level monitoring stations in the region. Over the 100-year period (1918 to 2020), lake levels have had a two-metre range between the recorded maximum monthly average and minimum monthly average. In the past three decades, a greater degree of fluctuation has been observed relative to this two-metre range. For the period 1999 to 2014, average annual lake levels were at near-record low levels across all Great Lakes; however, since that period lake levels have been near record highs.

Concise characterizations for each climate grouping used in the assessment are provided below. Sections 3.2.1 through 3.2.7 describe data associated with current (1981 to 2010), mid-century (2041 to 2070) and the end of century (2071 to 2100). Section 3.3 describes how all climate data were translated into frequency scores to inform risk evaluation.

3.2.1 High and Extreme Temperatures

High and extreme temperatures used in the PCCIA are represented by Extreme Hot Days and by Cooling Degree Days. Extreme Hot Days, or the average number of days where mean air temperatures exceed 30°C, are expected to rise significantly across Ontario. The extent of this increase is particularly pronounced in Southwest, Central and Eastern Ontario and by the end of the century (2080s). Regionally, Extreme Hot Days are already prevalent in Southwest, Central and Eastern Ontario (all averaging around 8.6 to 9.1 days per year). In Northeast Ontario, between 1981 and 2010, 4.1 Extreme Hot Days occurred per year, and in Northwest, that number is 3.8. The Far North region only had on average 2.4 Extreme Hot Days per year within the baseline condition. By the end of the century, Southwest, Central and Eastern Ontario are projected (under RCP8.5) to experience an average of over 60 Extreme Hot Days per year. Northeast and Northwest Ontario are both anticipated to see rises from 3.8 and 4.1 days now, respectively, to over 35 days per year, on average. Importantly, the impacts of rising temperatures may be felt stronger in the Far North, Northwest and Northeast regions of Ontario, despite the absolute temperature numbers being lower, compared to Southwest, Central and Eastern regions. There may be an increase in the number heat warnings in the northern regions (issued at lower thresholds compared to the southern regions) to account for region-specific heat-health relationships linked to acclimatization (Environment and Climate Change Canada, 2016b).

Figure 3.3 visualizes Extreme Hot Days geographically, illustrating current and 2080s conditions (under RCP8.5) and regional averages used to inform the PCCIA. It is critical to note that Figure 3.3 illustrates absolute conditions of this climate variable. For the purposes of the PCCIA, change in condition relative to the baseline was used to assess the frequency of climate variables (see Section 3.3).

Cooling Degree Days indicate a very similar trend to Extreme Hot Days. In all regions, Cooling Degree Days are projected to increase in number and frequency scores (see Section 3.3) reflect this rise. This indicates an increased energy demand for cooling and ventilation in summertime, and amplifies the importance of a reliable energy system. Regionally, Southwest, Central and Eastern Ontario are shown to have the highest increases in Cooling Degree Days, followed by Northeast and then Northwest Ontario (see Figure 3.4).

Figure 3.3: Average Annual Number of Extreme Hot Days (>30°C). The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

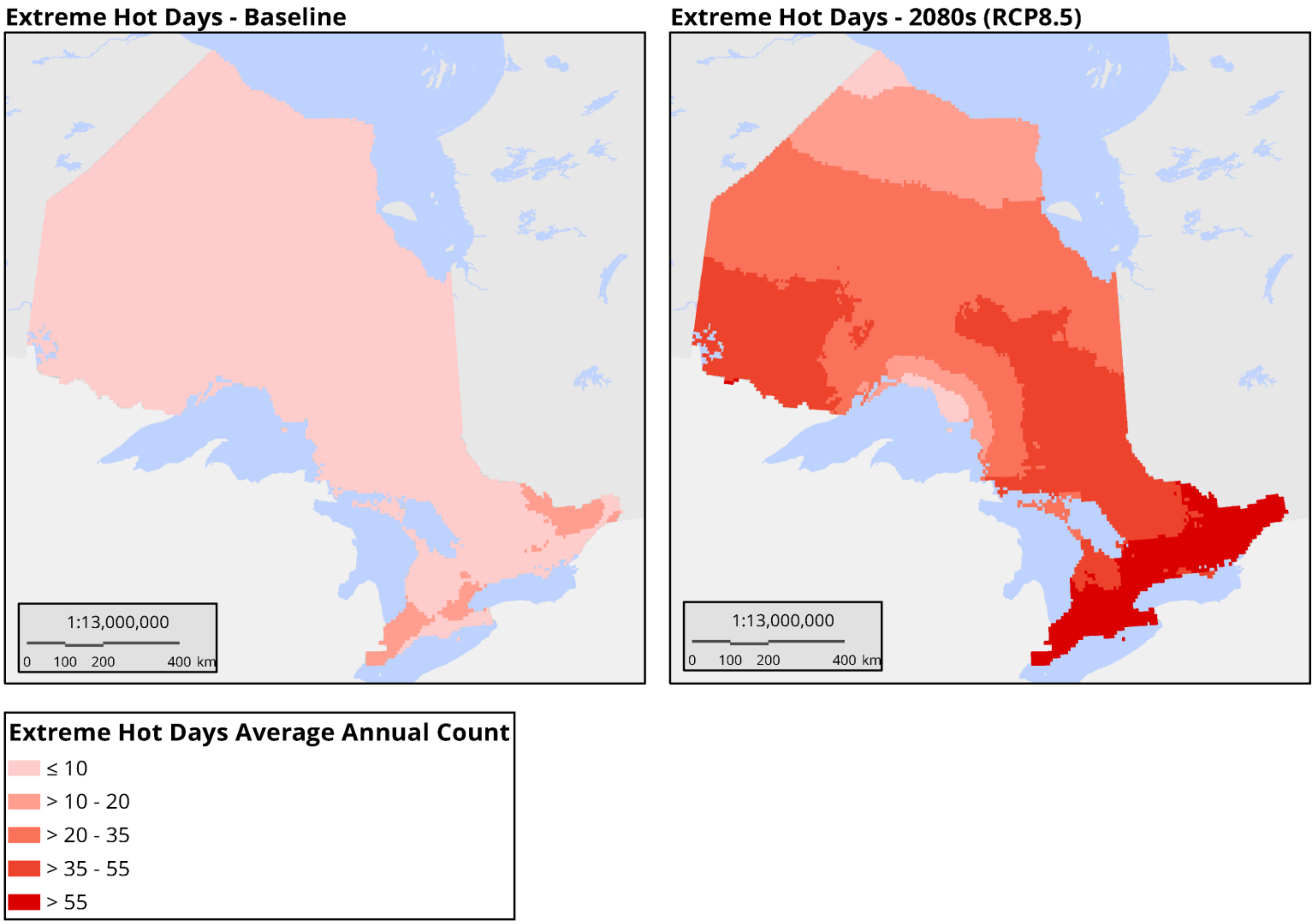
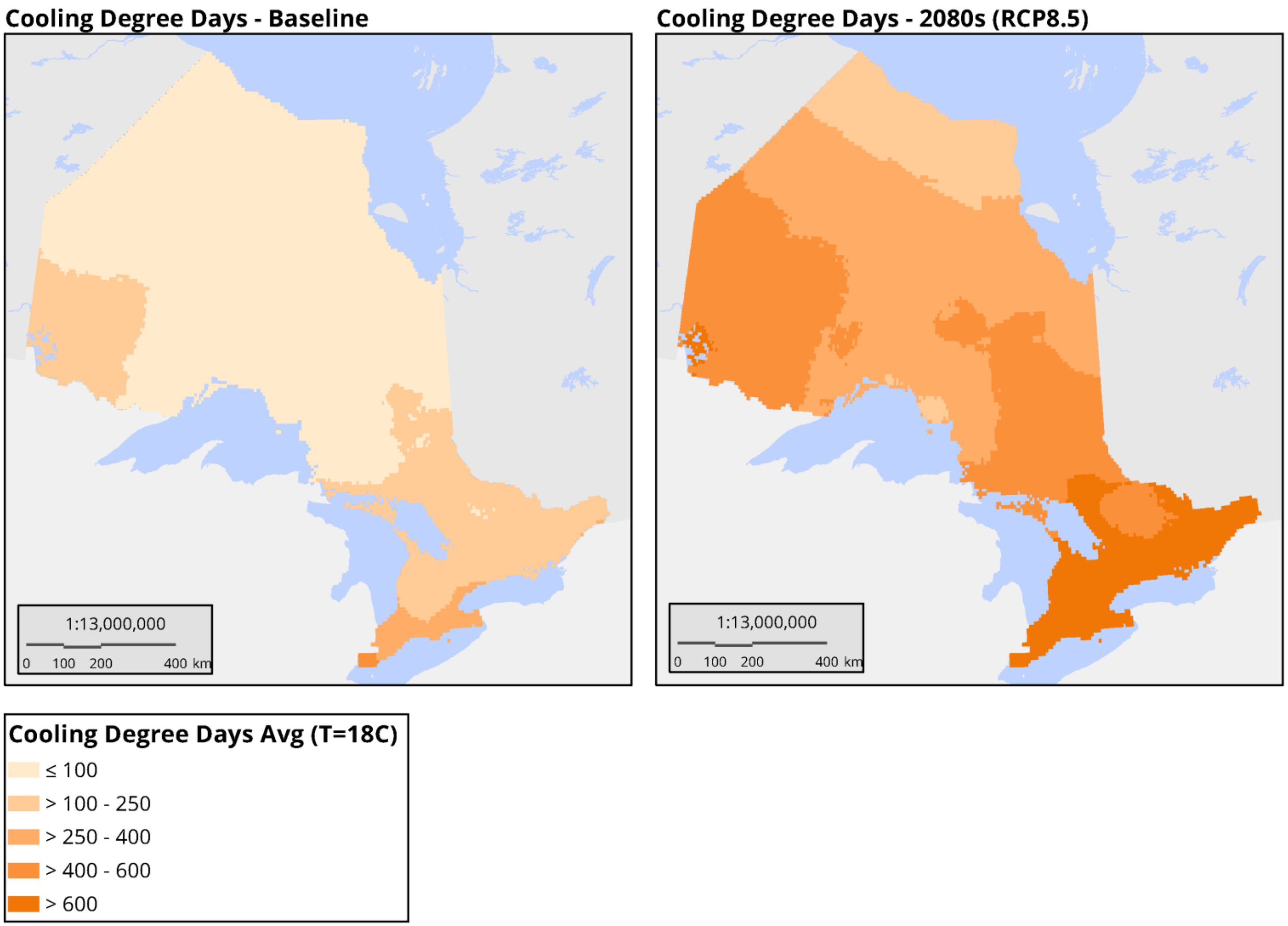


Figure 3.4: Cooling Degree Days (18°C). The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.



3.2.2 Low Temperatures

The PCCIA used two climate variables to characterize possible impacts associated with low temperatures: Extreme Cold Days where mean air temperature drops below -25°C and Degree Days Below 0°C. The latter represents accumulated cold days below zero throughout the year and can act as a proxy for a warming climate and region. Both climate variables show decreasing trends across all regions of Ontario, for all time periods analyzed (2050s and 2080s). These trends are decreasing regardless of how quickly greenhouse gas emissions are reduced (e.g. a high emissions RCP8.5 scenario or a moderate emissions RCP4.5 scenario).

Considering Extreme Cold Days, all regions show declines, with the Far North expected to feel impacts the most significantly. The Far North region currently experiences on average over 55 Extreme Cold Days per year. By the end of century, that region is expected to only experience around 12 Extreme Cold Days per year. Northeast and Northwest Ontario exhibit a similar trend, experiencing an average of 27 and 33.5 Extreme Cold Days per year now and projected to drop to 6 and 8 Extreme Cold Days per year by the 2050s and 2080s, respectively. In Southwest, Central and Eastern Ontario virtually no Extreme Cold Days are anticipated (on average) by the end of the century under RCP8.5.

Figure 3.5 illustrates Extreme Cold Days across Ontario and how this condition is expected to change by the 2080s. Notably, Degree Days Below 0°C indicate consistent trends, with northern regions of the province showing more significant declines in colder conditions by both mid and end of century (see Figure 3.6).

Figure 3.5: Average Annual Number of Extreme Cold Days (<-25°C). The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

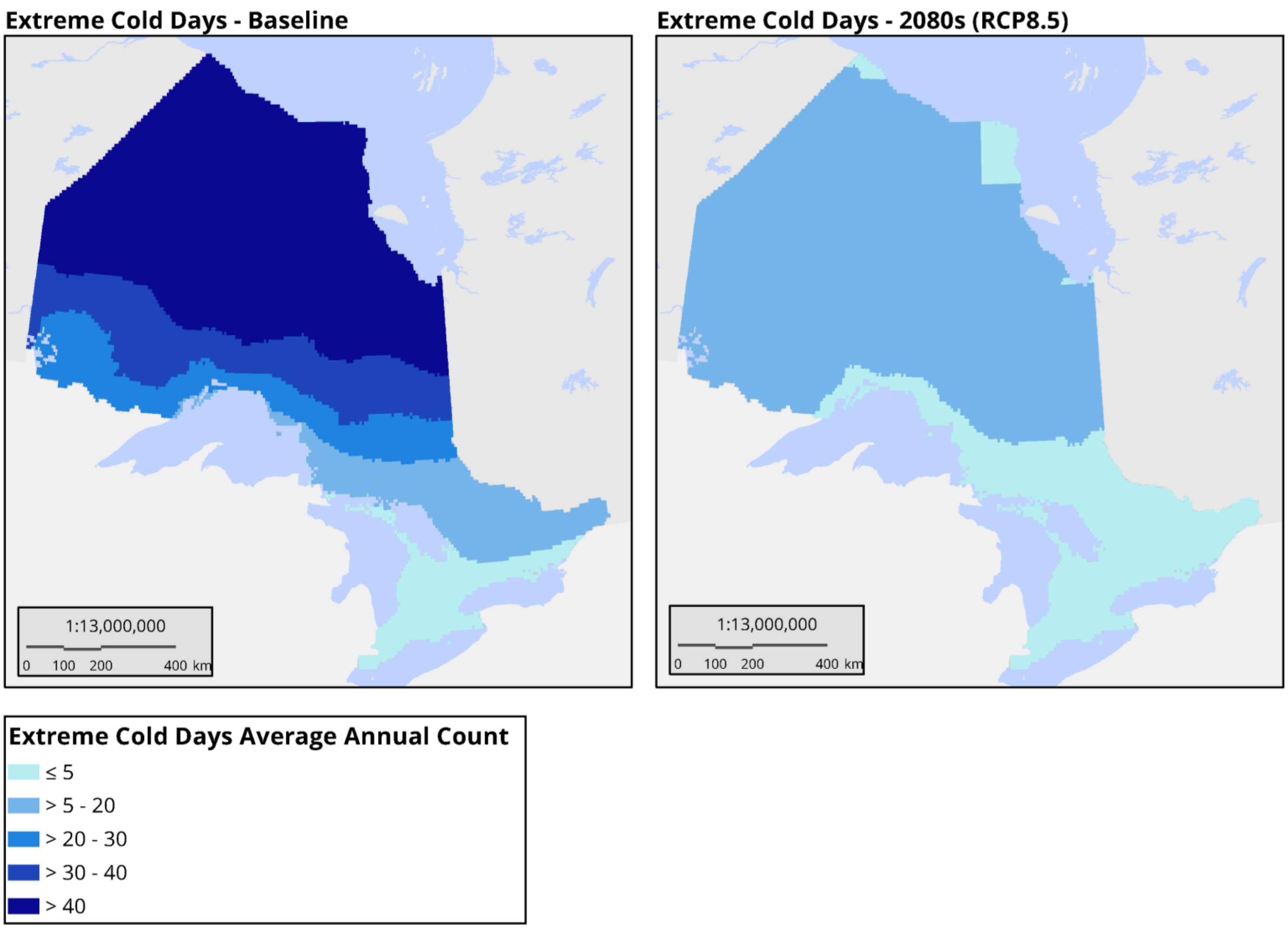
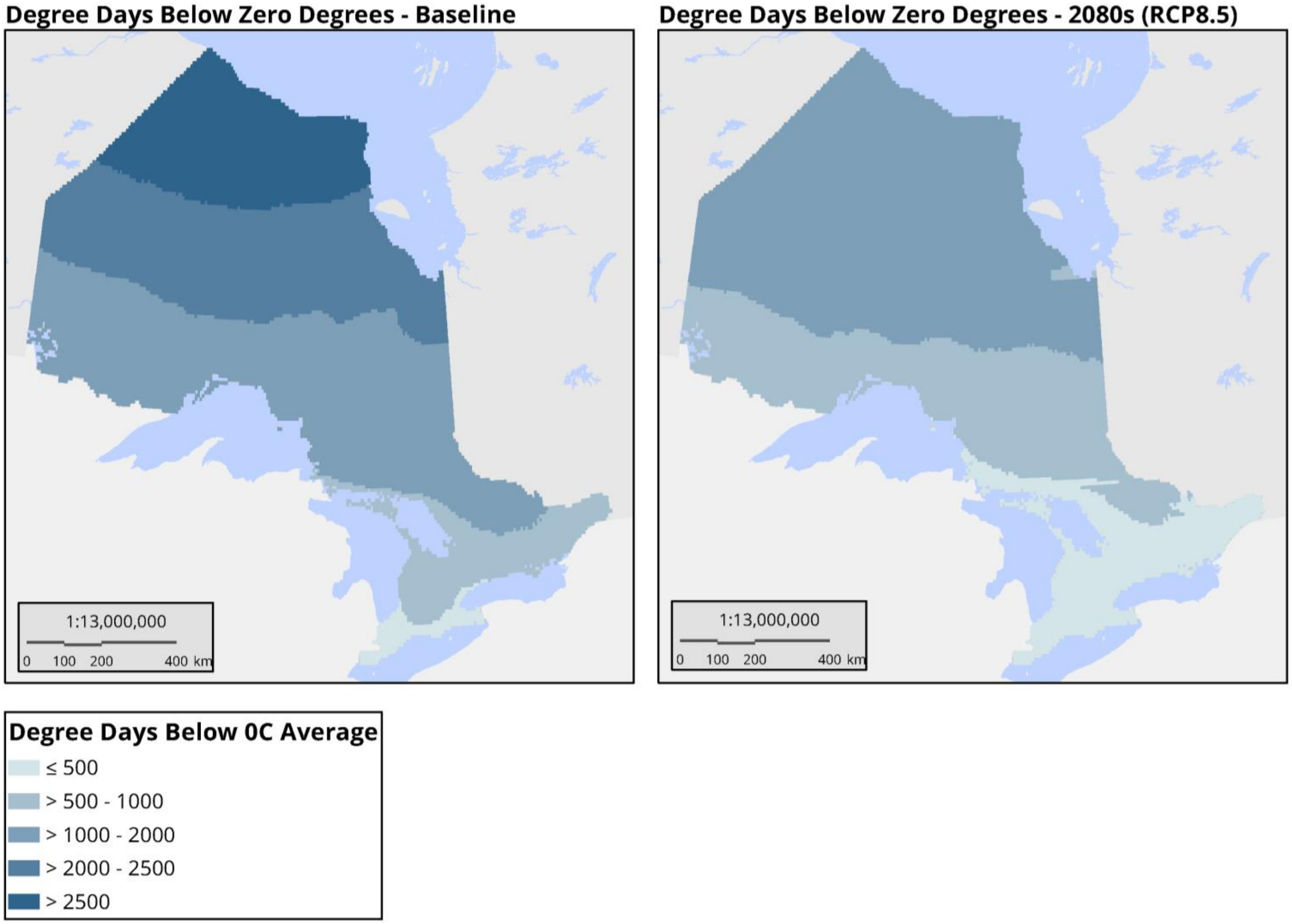


Figure 3.6: Degree Days < 0°C. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.



3.2.3 Temperatures and Growing-Related Conditions

Temperature-related variables considered within the PCCIA included Growing Season Length (in days/yr) and Growing Degree Days (GDD). The GDD indicator is a measure of the seasonal accumulation of heat where the mean temperature is greater than 5°C and is an important variable for both Natural Environment and Food and Agriculture conditions. As air temperatures continue to increase, both climate variables also indicate rising trends.

Under current conditions, Growing Season Length is longest in Southwest Ontario, which experiences an average of just over 206 days per year. Central and Eastern Ontario also experience extended growing season length at 198 days per year and 181 days per year, respectively. Unsurprisingly, regions in northern Ontario (Northeast, Northwest, and the Far North) exhibit relatively shorter growing seasons, ranging from about 143 days/year to 158 days per year. Regardless of how quickly GHG emissions are reduced or mitigated, Growing Season Length is expected to increase across all regions of Ontario and future time periods (Figure 3.7)

Results determined for Growing Degree Days indicate a similar result as Growing Season Length, with significant increases anticipated in all regions. Seasonal accumulation of heat (e.g. measured in average degrees per year) is highest in Southwest, Central and Eastern Ontario, though rising heat in areas further north may lead to several impacts or changes, such as in species or in agricultural production (Figure 3.8). These changes are described further in Section 5.0 (Food and Agriculture) and Section 7.0 (Natural Environment).

Figure 3.7: Growing Season Length. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

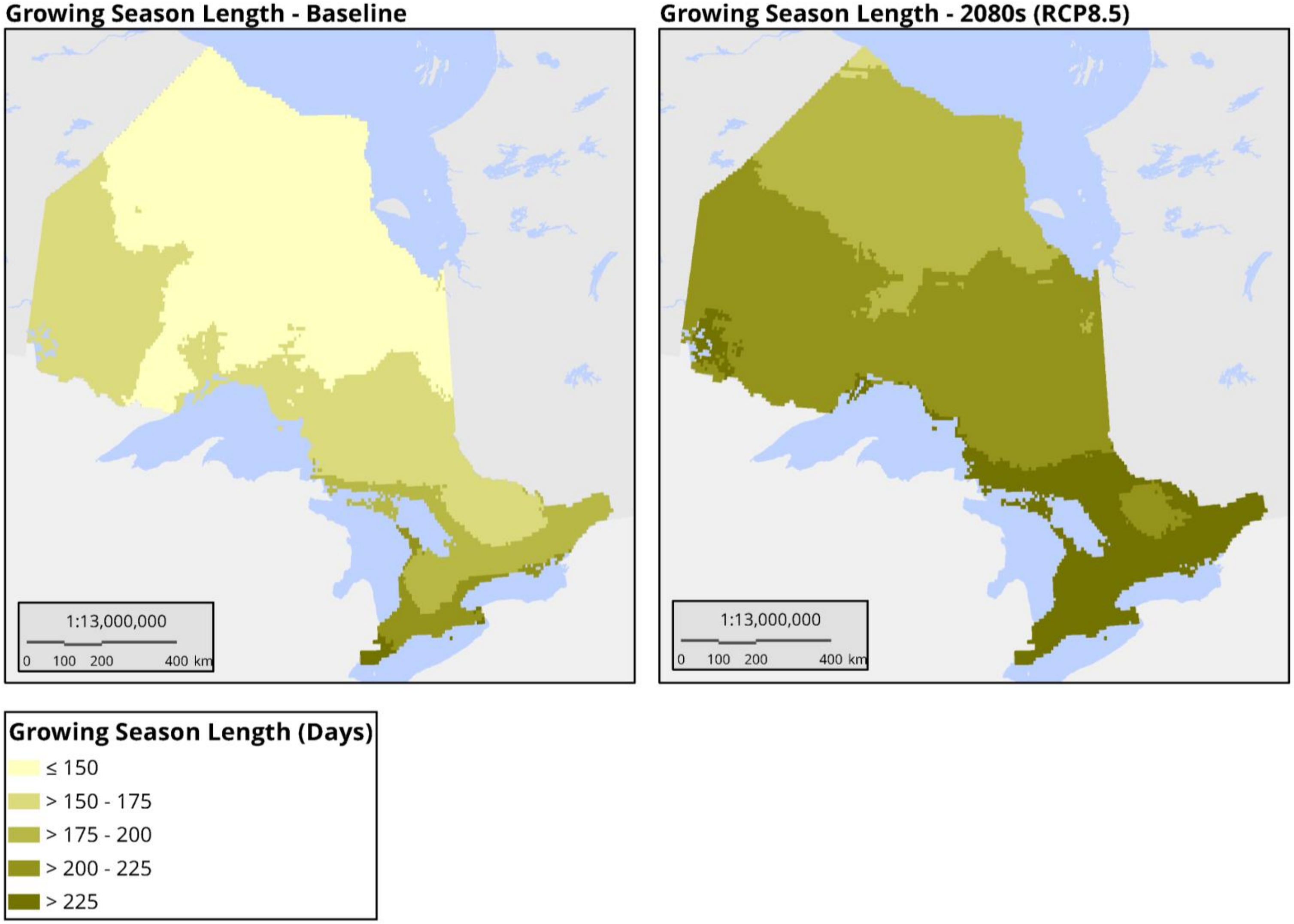
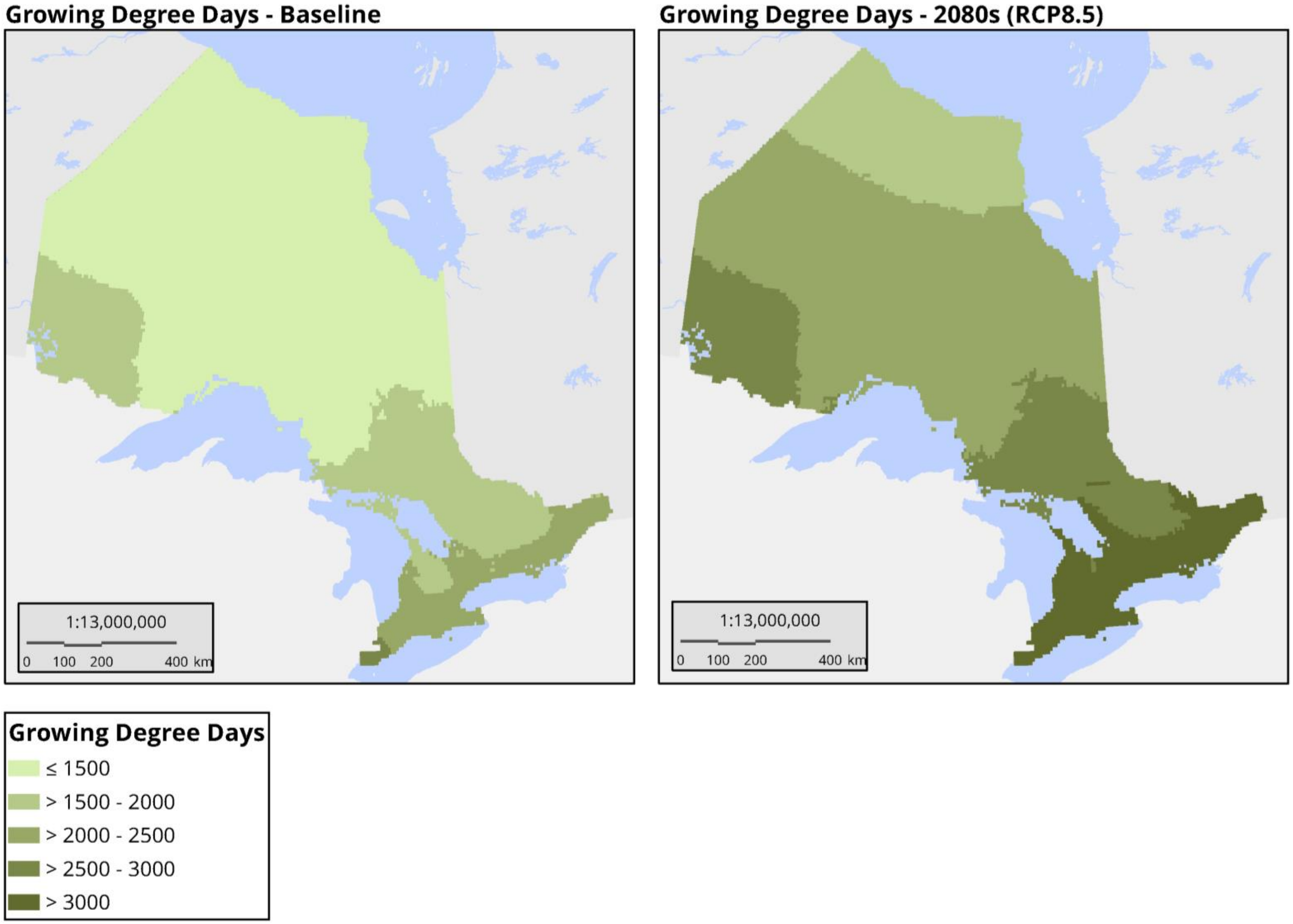


Figure 3.8: Growing Degree Days (5°C). The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.



3.2.4 Precipitation

Precipitation conditions are described for all seasons except winter, which is described in Section 3.2.5 explicitly and in greater detail associated with rain and snow. Seasonal precipitation conditions across Ontario are more variable than temperatures, with the Far North, Northwest and Northeast regions experiencing somewhat less average precipitation, particularly in spring. Southwest and Eastern Ontario currently experience the highest average Total Precipitation across non-winter seasons. Seasonally, historical precipitation tends to be higher in autumn compared to summer conditions.

A summary of precipitation across spring, summer and autumn based on historical data indicates the direction of change associated with future projections (Figure 3.9 to Figure 3.11). Notably, future Spring and Autumn Precipitation are increasing across all regions, with the extent of these increases highest in the springtime. This can be particularly impactful due to the risk from flooding or rain on frozen ground. Future summertime conditions, on the other hand, exhibit no notable change compared to current climate conditions. This implies that while air temperatures rise, summer conditions may be punctuated by periods of wetter or potentially drier conditions which can be particularly impactful for streamflow, water levels, agricultural production, ecosystems, and infrastructure.

Figure 3.9: Mean Spring Precipitation. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

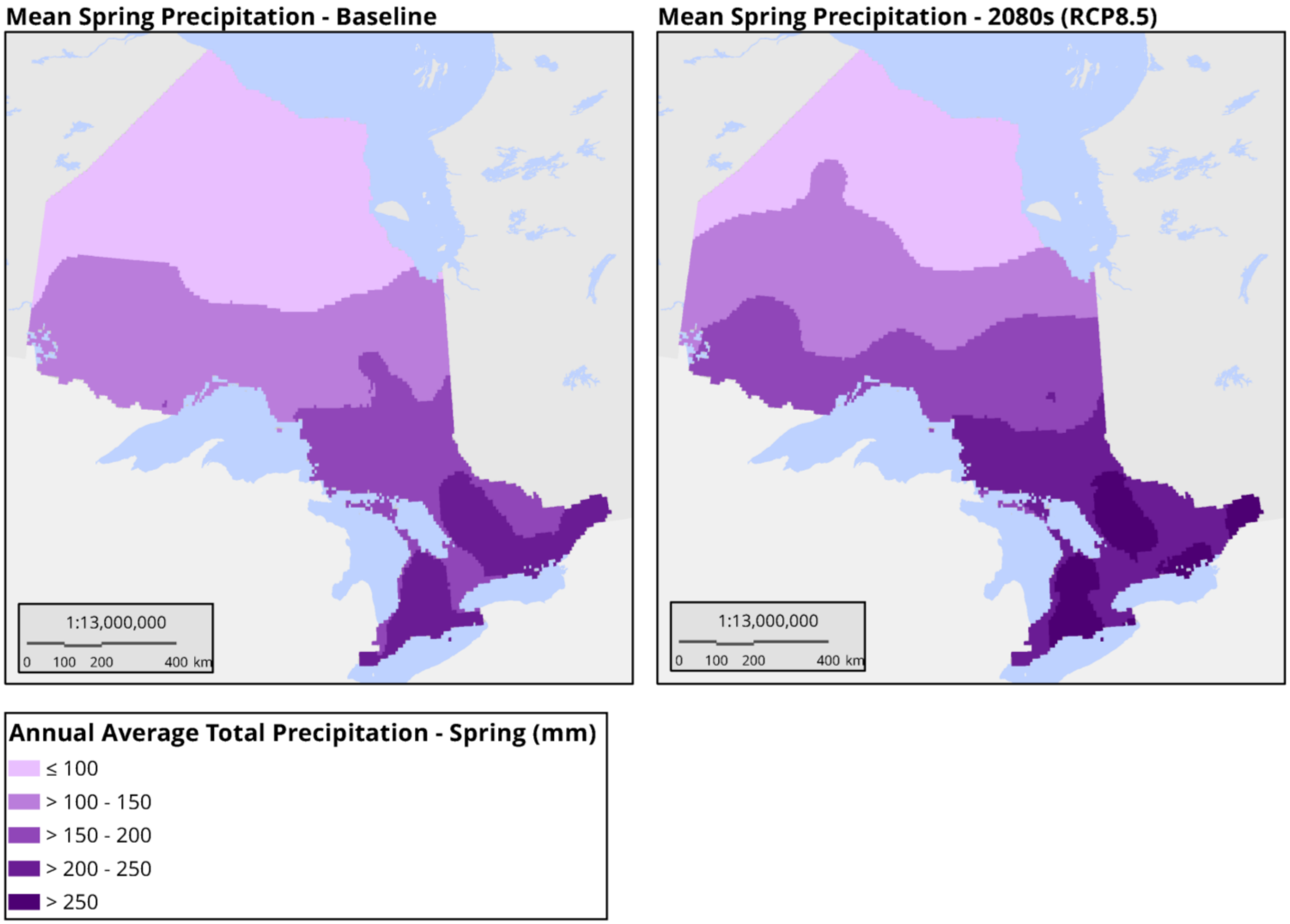


Figure 3.10: Mean Summer Precipitation. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

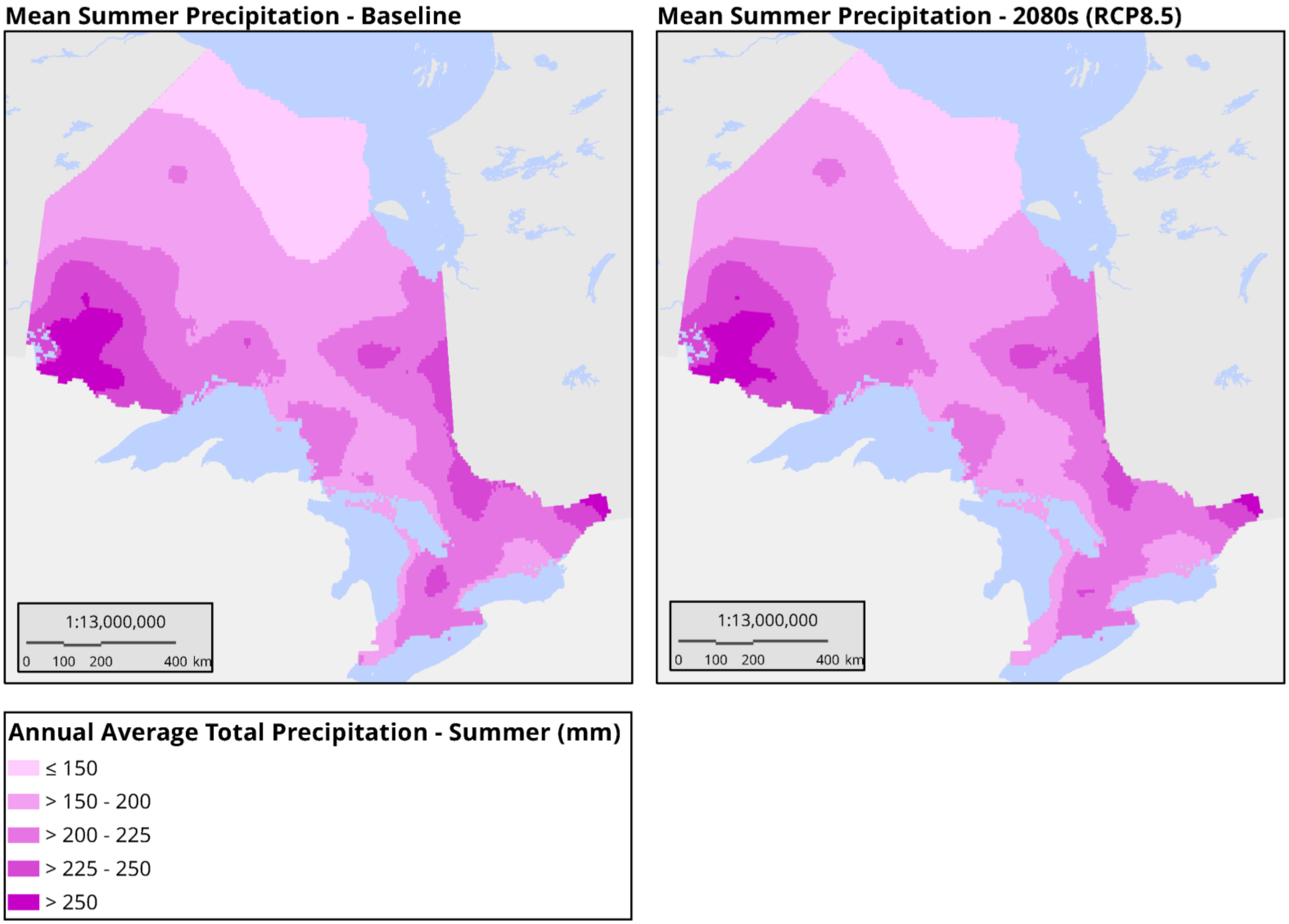
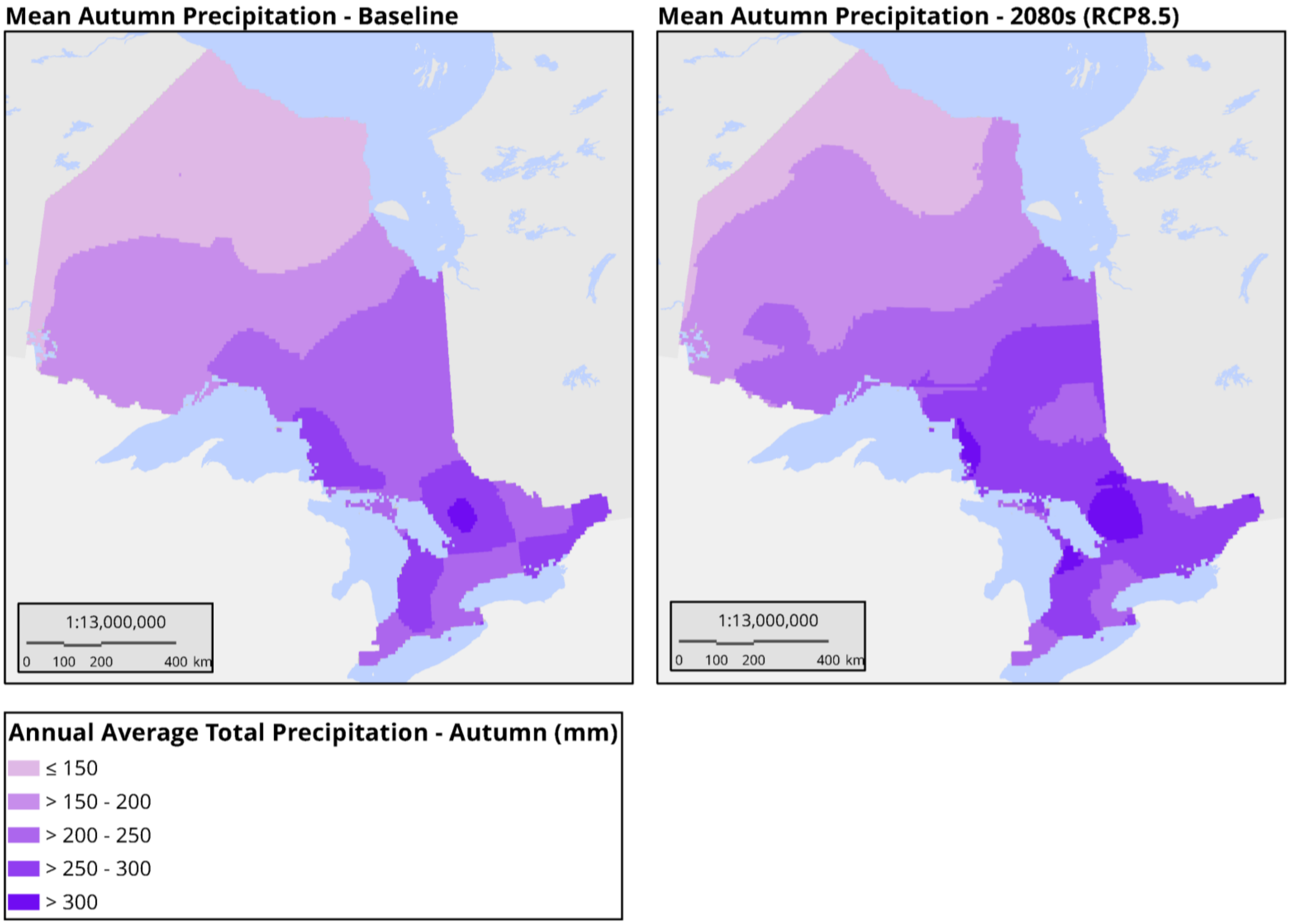


Figure 3.11: Mean Autumn Precipitation. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.



3.2.5 Winter Precipitation

Winter precipitation poses unique impacts and risks to all Areas of Focus assessed within the PCCIA. This season has therefore been explicitly captured within a separate climate grouping. It is represented by two climate variables: Mean Winter Precipitation, and Rain:Snow Ratio. Mean Winter Precipitation reflects the total amount of precipitation falling between December and the end of February, both as rain and snow, whereas the Rain:Snow Ratio reflects the percent rain falling in the wintertime. It should be noted that in most regions of the province, winter-like conditions occur during shoulder seasons, specifically the months of March and November, so the changes in winter precipitation may be more pronounced. Rain-on-snow events can be particularly problematic for infrastructure and other systems in light of frozen conditions or in systems that may be closer to capacity due to ice and snow melting.

Results for Winter Precipitation indicate increases, particularly under a high emission scenario – RCP8.5. Regionally, there is a greater extent of change projected in Southwest and Eastern Ontario, followed by Central and Northeast Ontario. Northwest Ontario and the Far North still exhibit increases but to a less significant extent (Figure 3.12).

Examining the Rain:Snow Ratio provides a much more consistent picture across the province. Historically, Southwest and Central Ontario have experienced the highest amount of rain falling in the winter season, with Rain:Snow Ratios measuring 39.4% and 34.3%, respectively. Eastern Ontario has experienced a substantial amount of rainfall during this season, with a Rain:Snow Ratio of around 26.3% historically. Regions further north largely experience snowfall, with Rain:Snow Ratios ranging from 1.3% (Far North) to 8.4% (Northeast). In the future, all regions are expected to experience more rain falling during the winter season, with the largest increases in winter rain projected for Central, Eastern and Southwest Ontario (Figure 3.13). In the northern regions, initial increases in snowfall (triggered by greater water holding capacity in the atmosphere due to warming temperatures, and longer periods of open water) are expected to be followed by declines and more precipitation falling as rain, thereby increasing the Rain:Snow Ratio.

Figure 3.12: Mean Winter Precipitation. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

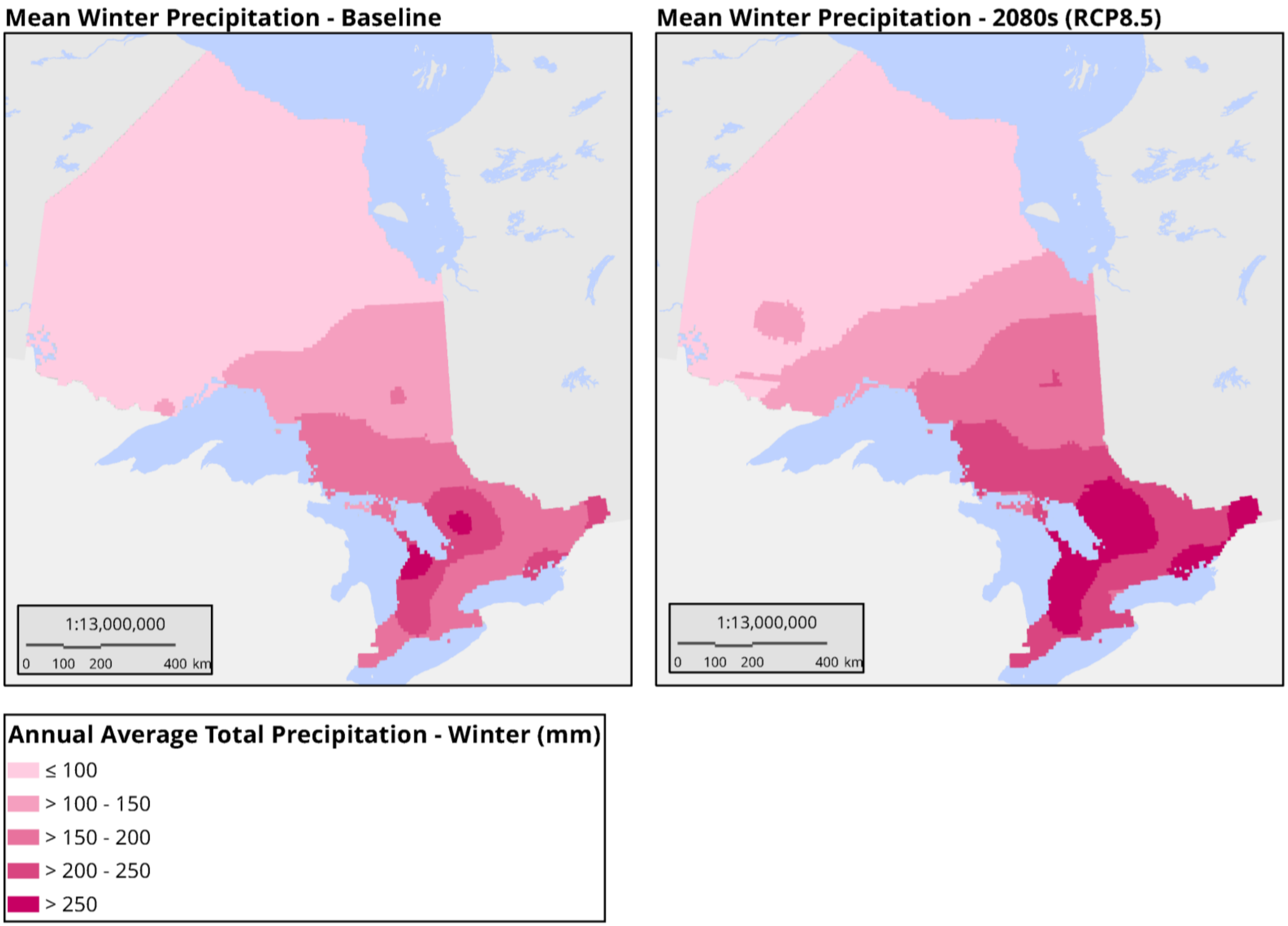
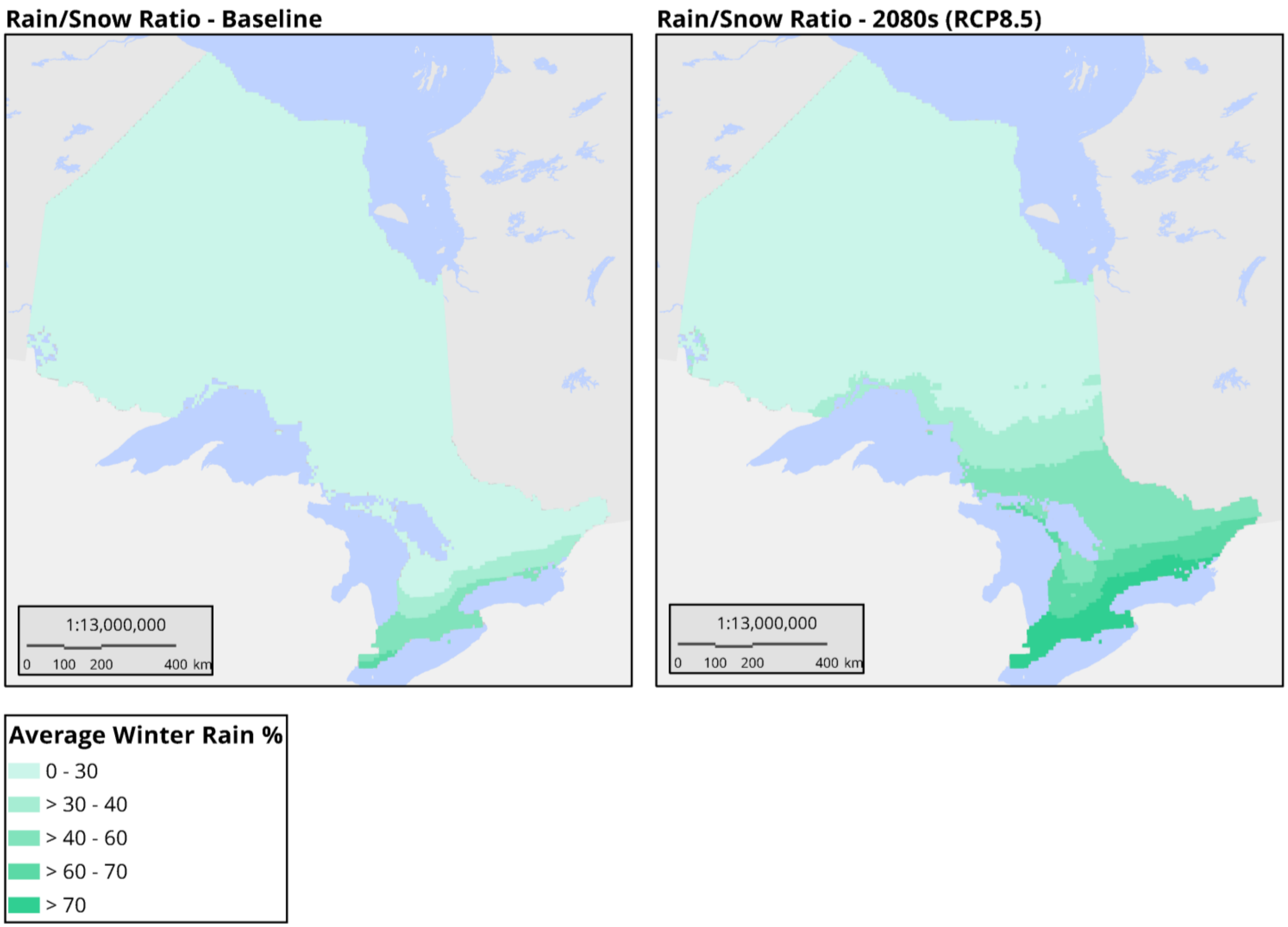


Figure 3.13: Rain:Snow Ratio. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.



3.2.6 Extreme Precipitation

Within the context of the PCCIA, Extreme Precipitation was represented using two climate variables: 1-Day Maximum Precipitation and 3-Day Maximum Precipitation. Appendix 4 provides a detailed discussion of the methods used to derive and project these variables. It should be noted that sub-daily (e.g. hourly) precipitation was not assessed as part of the scope due to the level of uncertainty in future projections but also the scale and scope at which information was required (e.g. regional averages). Future climate characterizations of Ontario could benefit from sub-daily future extreme precipitation analyses.

Extreme precipitation events can lead to devastating consequences for all Areas of Focus, including flooding and infrastructure damage, injuries and detrimental health effects, habitat degradation and decreased water quality, soil erosion and crop damage, as well as disruptions to services and the economy.

Under current conditions, 1-Day Maximum Precipitation varies quite significantly across Ontario, even considering regional averages. With Extreme Precipitation, more localized variability can be expected, and it is important to acknowledge regional averages do not always reflect specific communities or experiences within one watershed. Across Ontario, the Southwest region has historically experienced the largest 1-Day Maximum Precipitation amounts across the entire year (e.g. an average of 102 mm in one day). This can be compared to Eastern Ontario (91 mm in one day), Central Ontario (85 mm in one day), Northwest Ontario (81 mm in one day), Northeast (79 mm in one day) and the Far North (52 mm in one day). In the future, 1-Day Maximum Precipitation amounts are projected to increase in all regions of the province, and higher frequency scores reflect this increase by the end of the century (2080s) in all regions (Figure 3.14).

3-Day Maximum Precipitation displays a similar trend, although somewhat muted compared to 1-Day Maximum Projections. It is important to note that 3-Day Maximum Precipitation typically is more large-scale in nature (e.g. low pressure systems) and not necessarily reflective of highly convective extreme events that some regions in Ontario experience in the summer season. Additionally, the 3-Day Maximum Precipitation amounts represent the annual average over all seasons combined, and in some locations Summer Precipitation shows little changes which can offset increases in other seasons. Figure 3.15 illustrates current and future (2080s) 3-Day Maximum Precipitation across Ontario. Slight increases and significant variability can be observed in this climate variable.

Figure 3.14: Maximum Short Duration Precipitation. The map on the left illustrates absolute current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.

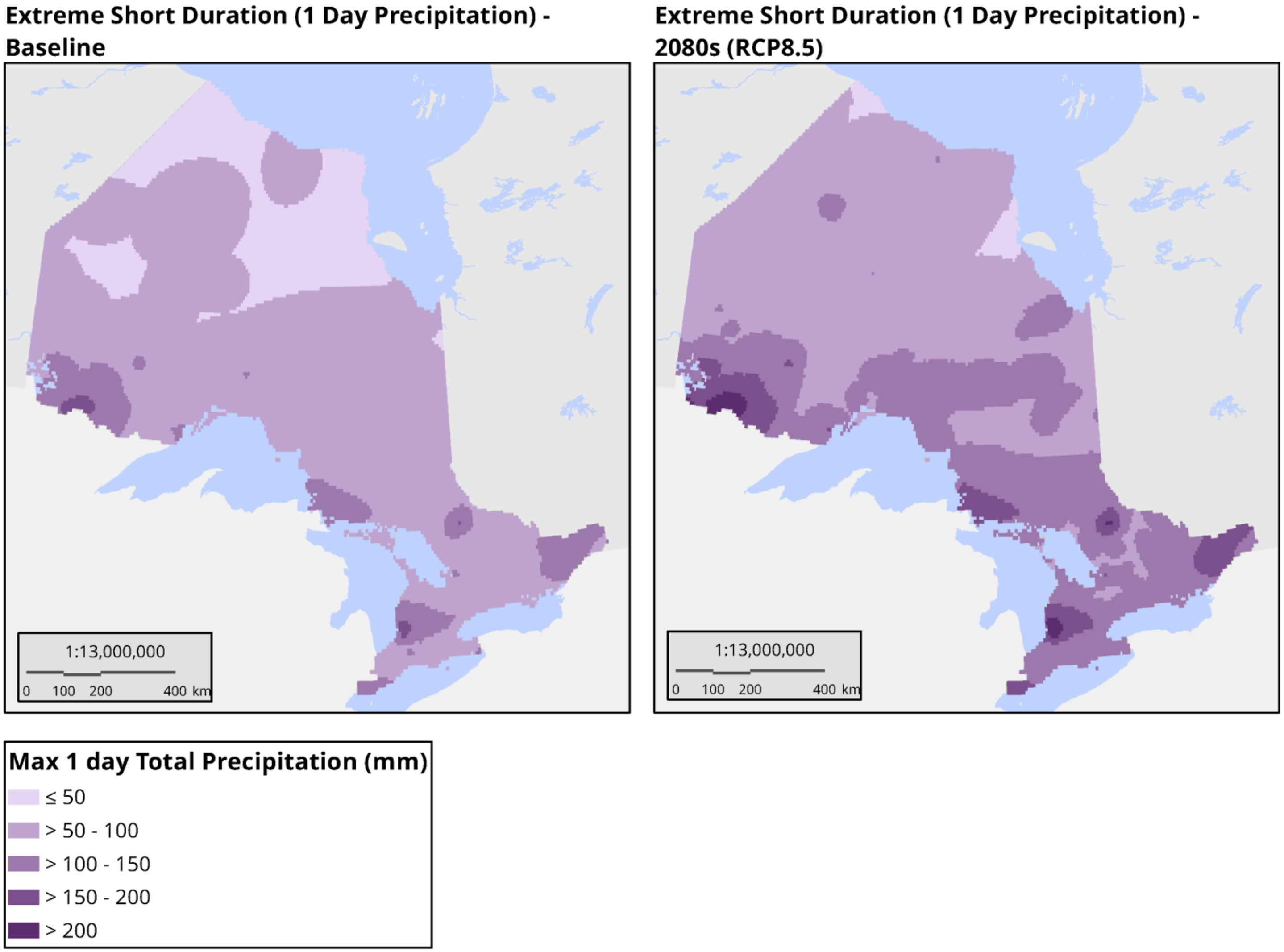
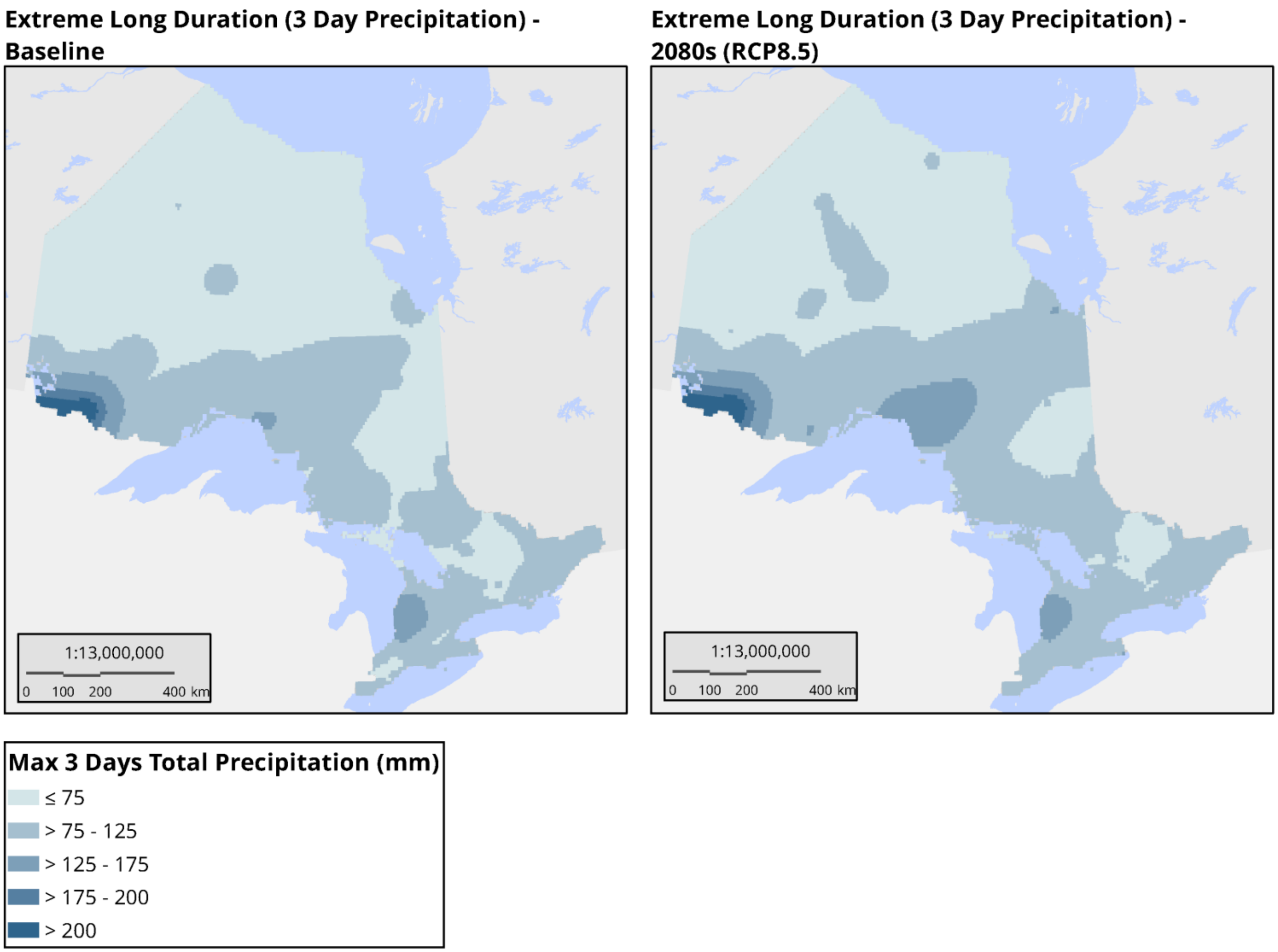


Figure 3.15: Maximum Long Duration Precipitation. The map on the left illustrates current conditions and can be compared with the map on the right showing 2080s conditions under RCP8.5.



3.2.7 Drought and Wildfire

Drought and wildfire conditions were represented within the PCCIA using two climate variables: 1) Annual Moisture Deficit and 2) Average Wildfire Return Period in years. Appendix 4 provides a detailed description of the methodologies used to derive these two variables and data interpretation.

Dry conditions or drought indicates slight increases in Moisture Deficit across all regions of Ontario (Figure 3.16). However, frequency scores determined for Drought (see Section 3.3) do not indicate moderate or large changes from existing conditions to warrant an increase in scoring. Importantly, drought is particularly challenging to represent due to the need to factor in evapotranspiration and the numerous definitions of drought used by various communities (e.g. climatological, agricultural drought, etc.).

Wildfire was characterized based upon the average Wildfire Return Period determined by climate and presence of burnable material. The values and methodology for deriving this variable were obtained directly from the Canadian Forestry Service (CFS). Historically, wildfire occurs most often in the Far North, Northwest, and Northeast regions. Figure 3.17 illustrates current Wildfire Return Periods and can be compared with those by the end of century (2080s) and as regional averages. As an illustrative example, the regional average wildfire return is 614 years in the Far North, but that is projected to decrease (indicating increased frequency) to 183 years by end of century under the high emissions scenario (RCP8.5).

Figure 3.16: Moisture Deficit (mm). The map on the left illustrates current Moisture Deficit conditions and can be compared with the map on the right showing 2080s Moisture Deficit conditions under RCP8.5.

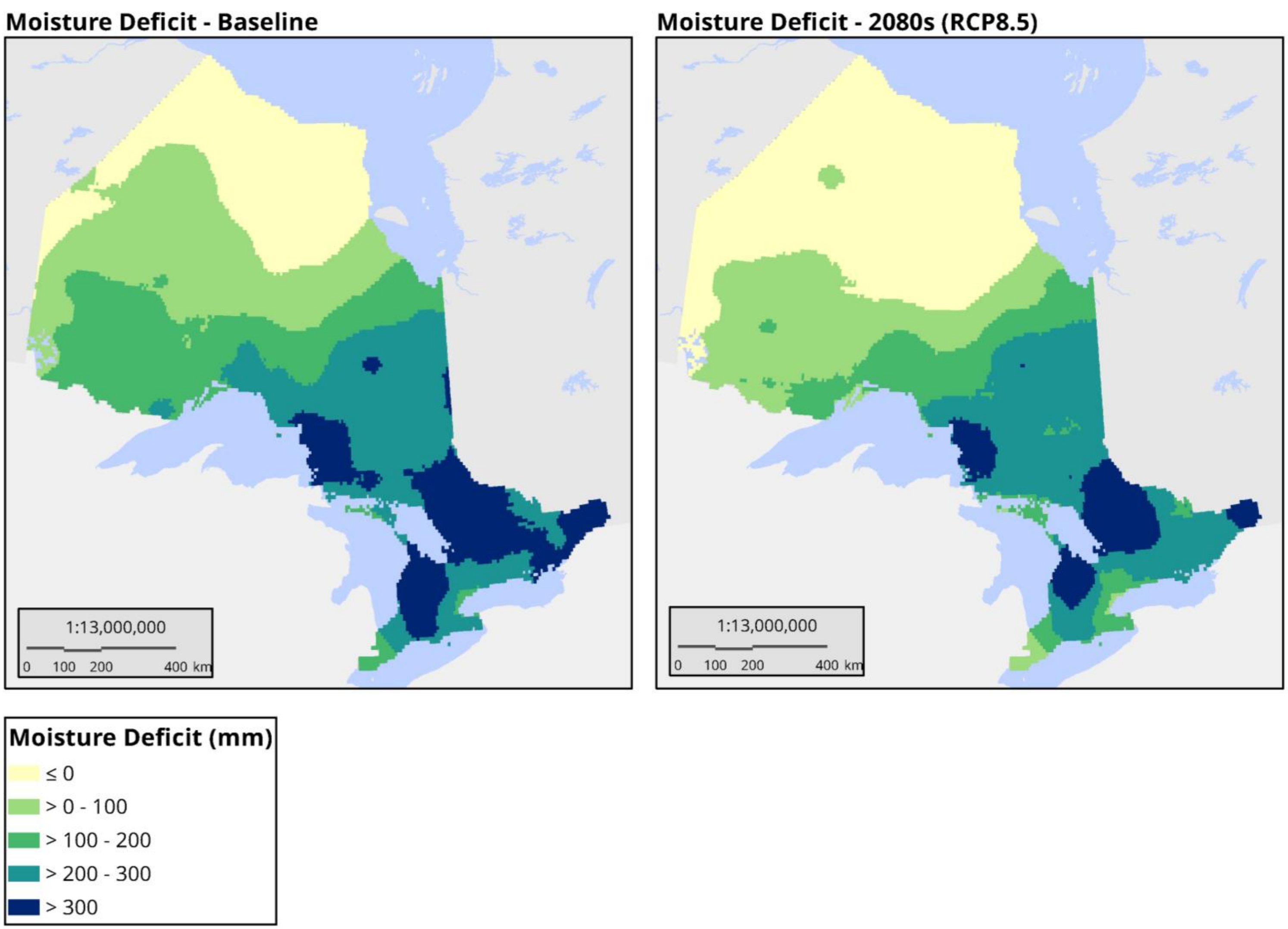
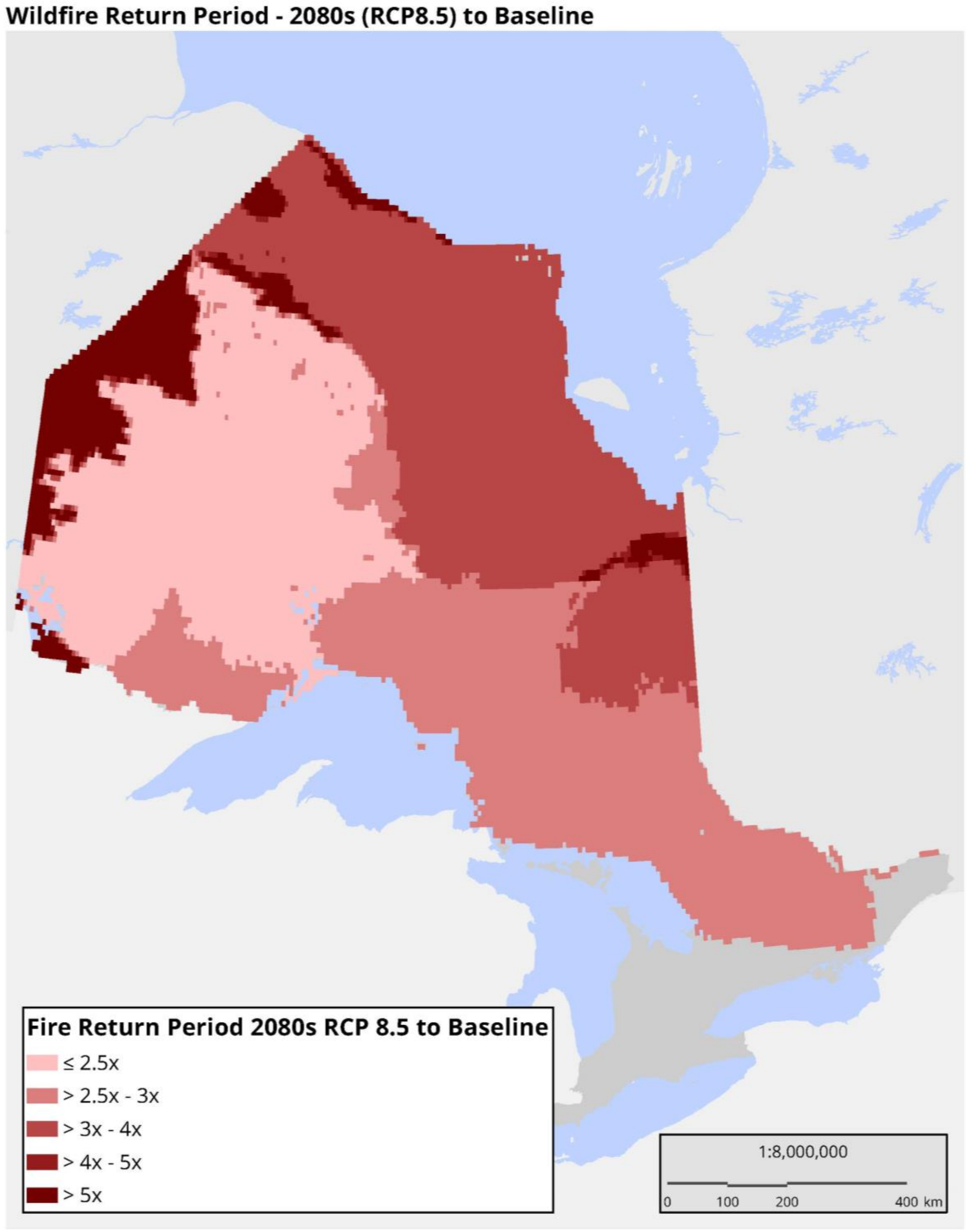


Figure 3.17: Wildfire Return Period Frequency. The map illustrates the change in wildfire frequency from the baseline timeframe to the 2080s timeframe.



3.3 Interpreting Climate Information for Use in Risk Evaluation

The development of climate information (e.g. historical data and future projections) is a foundational step in evaluating risk. However, additional steps are needed to evaluate the frequency at which climate variables within climate groupings may occur now and in future time periods (e.g. 2050s and 2080s). It is important to distinguish between absolute climate conditions and interpreted climate variable frequency scores used in risk scoring. This evaluation, by climate variable, and change in frequency (either no change, positive or negative) is one of three major components of evaluating risk.

To enable a multi-variable risk scoring approach in assessing climate risk, one of the methodologies which can be applied is the calculation of a 'Normalized Z-Score'. The result of this approach (or Z-Score) is unitless and therefore has value when combining variables which are different (e.g. temperature, precipitation, and winds). Z-Scores are taken from statistical literature and represent the deviation of a population of observed climate (or other) variable from its historical condition. The Z-Score is useful since it can be considered a metric of the difference of a variable from its observed normal 'range'. The Normalized Delta (or Normalized Z-score) is used in the analysis as a measure of a variable's departure from 'average' conditions. Essentially, the larger the Z-score, the greater the change and therefore the greater the risk going forward. Appendix 4 describes the development of the Z-Score in additional details, and Appendix 2 indicates all criteria used in evaluating risks (including climate variable frequency). Using this approach, Z-Score results of each grid cell across Ontario resulted in the evaluation of climate variable frequency scores based on the criteria presented in Table 3.4.

Table 3.4: Climate Variable Frequency Scoring Criteria

Frequency of Climate Variable Score	Category (Change in Frequency)	Definition – Amount of Change from Baseline[2]
1	Significant Negative	Large negative change from current climate
2	Slight Negative	Moderate negative change from current climate
4	Baseline/No Change	Similar to current climate
8	Slight Positive	Moderate positive change from current climate
16	Significant Positive	Large positive change from current climate

[2] °C, degree days, or % of change from baseline conditions.

The five-step scale (Table 3.4) was used to attribute numerical scores based on the principle of “equal distribution of importance” for each category, doubling the value/score between each integer – 1, 2, 4, 8, 16 to show that each subsequent category is weighed double, compared to the previous one. The current climate (1981 to 2010) frequency of all variables was set at 4 to represent a baseline in current conditions under which future frequency scores either increase or decrease, associated with the climate variable (e.g. extreme cold and extreme heat frequency in 2050s receive frequency scores lower and higher than 4, respectively, due to their differing trends). The future climate variable categorization depended upon the future departures of the climate variable from the historical condition according to the Z-Score. In the normalized Z-Score equation above, the ‘value’ was the projected value of the climate indicator. The mean and standard deviation remained the historical computed values for 1981 to 2010.

Table 3.5 provides a summary of each climate variable used in the PCCIA and the frequency scores determined for the 2050s and 2080s, under a moderate emissions scenario (RCP4.5) and a high emissions scenario (RCP8.5). Historic climate data and changes from the baseline used to determine frequency scores are contained in Appendix 5. Frequency scores (ranging from 1 through 16) can be thought of as one component in scoring risk across all Areas of Focus and Geographic Regions of Ontario.

Table 3.5: Summary of Climate Variable Frequency Scores Used in Risk Characterization[3]

Climate Variable	Region	Units	Climate Variable Frequency Scores			
			2050s RCP4.5	2080s RCP4.5	2050s RCP8.5	2080s RCP8.5
High and Extreme Temperatures						
Extreme Hot Days >30°C	Central Region	days/yr	16	16	16	16
Extreme Hot Days >30°C	Eastern Region	days/yr	16	16	16	16
Extreme Hot Days >30°C	Far North Region	days/yr	8	16	16	16
Extreme Hot Days >30°C	Northeast Region	days/yr	16	16	16	16
Extreme Hot Days >30°C	Northwest Region	days/yr	16	16	16	16
Extreme Hot Days >30°C	Southwest Region	days/yr	16	16	16	16
Cooling Degree Days	Central Region	degrees/yr	16	16	16	16
Cooling Degree Days	Eastern Region	degrees/yr	16	16	16	16
Cooling Degree Days	Far North Region	degrees/yr	8	16	16	16
Cooling Degree Days	Northeast Region	degrees/yr	16	16	16	16
Cooling Degree Days	Northwest Region	degrees/yr	16	16	16	16
Cooling Degree Days	Southwest Region	degrees/yr	16	16	16	16
Low Temperatures						
Extreme Cold Days < -25°C	Central Region	days/yr	4	4	4	4
Extreme Cold Days < -25°C	Eastern Region	days/yr	4	4	4	4
Extreme Cold Days < -25°C	Far North Region	days/yr	1	1	1	1
Extreme Cold Days < -25°C	Northeast Region	days/yr	2	1	1	1
Extreme Cold Days < -25°C	Northwest Region	days/yr	2	1	1	1
Extreme Cold Days < -25°C	Southwest Region	days/yr	4	4	4	4
Degree Days <0C	Central Region	degrees/yr	4	2	2	1
Degree Days <0C	Eastern Region	degrees/yr	2	2	2	1
Degree Days <0C	Far North Region	degrees/yr	1	1	1	1

[3] The scoring methods for the Wildfire index by using the standard deviation (SD) of the historical range of frequencies results in a time range which is much larger than other variables, since it can span between a few to thousands of years. For this reason, it did not properly reflect the potential wildland fire occurrence expected in Ontario, and therefore the variable has not been included in this table.

Climate Variable	Region	Units	Climate Variable Frequency Scores			
			2050s RCP4.5	2080s RCP4.5	2050s RCP8.5	2080s RCP8.5
Degree Days <0C	Northeast Region	degrees/yr	2	1	1	1
Degree Days <0C	Northwest Region	degrees/yr	2	1	1	1
Degree Days <0C	Southwest Region	degrees/yr	4	2	2	2
Temperature						
Growing Degree Days	Central Region	degrees / yr	16	16	16	16
Growing Degree Days	Eastern Region	degrees/yr	16	16	16	16
Growing Degree Days	Far North Region	degrees/yr	8	16	16	16
Growing Degree Days	Northeast Region	degrees/yr	16	16	16	16
Growing Degree Days	Northwest Region	degrees/yr	8	16	16	16
Growing Degree Days	Southwest Region	degrees/yr	16	16	16	16
Growing Season Length	Central Region	days/yr	16	16	16	16
Growing Season Length	Eastern Region	days/yr	16	16	16	16
Growing Season Length	Far North Region	days/yr	8	16	16	16
Growing Season Length	Northeast Region	days/yr	16	16	16	16
Growing Season Length	Northwest Region	days/yr	8	16	16	16
Growing Season Length	Southwest Region	days/yr	16	16	16	16
Precipitation						
Mean Spring Precipitation	Central Region	mm	4	8	8	16
Mean Spring Precipitation	Eastern Region	mm	4	8	8	16
Mean Spring Precipitation	Far North Region	mm	4	4	4	4
Mean Spring Precipitation	Northeast Region	mm	4	8	8	16
Mean Spring Precipitation	Northwest Region	mm	4	4	4	8
Mean Spring Precipitation	Southwest Region	mm	8	8	8	16
Mean Summer Precipitation	Central Region	mm	4	4	4	4
Mean Summer Precipitation	Eastern Region	mm	4	4	4	4
Mean Summer Precipitation	Far North Region	mm	4	4	4	4
Mean Summer Precipitation	Northeast Region	mm	4	4	4	4

Climate Variable	Region	Units	Climate Variable Frequency Scores			
			2050s RCP4.5	2080s RCP4.5	2050s RCP8.5	2080s RCP8.5
Mean Summer Precipitation	Northwest Region	mm	4	4	4	4
Mean Summer Precipitation	Southwest Region	mm	4	4	4	4
Mean Autumn Precipitation	Central Region	mm	4	4	4	4
Mean Autumn Precipitation	Eastern Region	mm	4	4	4	4
Mean Autumn Precipitation	Far North Region	mm	4	4	4	4
Mean Autumn Precipitation	Northeast Region	mm	4	4	4	4
Mean Autumn Precipitation	Northwest Region	mm	4	4	4	4
Mean Autumn Precipitation	Southwest Region	mm	4	4	4	4
Winter Precipitation						
Mean Winter Precipitation	Central Region	mm	4	4	4	8
Mean Winter Precipitation	Eastern Region	mm	4	4	8	8
Mean Winter Precipitation	Far North Region	mm	4	4	4	4
Mean Winter Precipitation	Northeast Region	mm	4	4	4	8
Mean Winter Precipitation	Northwest Region	mm	4	4	4	4
Mean Winter Precipitation	Southwest Region	mm	4	4	8	8
Rain:Snow Ratio	Central Region	% rain in winter	16	16	16	16
Rain:Snow Ratio	Eastern Region	% rain in winter	16	16	16	16
Rain:Snow Ratio	Far North Region	% rain in winter	4	4	4	16
Rain:Snow Ratio	Northeast Region	% rain in winter	8	8	16	16
Rain:Snow Ratio	Northwest Region	% rain in winter	4	8	8	16
Rain:Snow Ratio	Southwest Region	% rain in winter	16	16	16	16
Extreme Precipitation						
Extreme Precipitation (3-day)	Central Region	mm	4	4	4	4
Extreme Precipitation (3-day)	Eastern Region	mm	4	4	4	4
Extreme Precipitation (3-day)	Far North Region	mm	4	4	4	4
Extreme Precipitation (3-day)	Northeast Region	mm	4	4	4	4
Extreme Precipitation (3-day)	Northwest Region	mm	4	4	4	4

Climate Variable	Region	Units	Climate Variable Frequency Scores			
			2050s RCP4.5	2080s RCP4.5	2050s RCP8.5	2080s RCP8.5
Extreme Precipitation (3-day)	Southwest Region	mm	4	4	4	4
Extreme Precipitation (1-day)	Central Region	mm	4	4	4	8
Extreme Precipitation (1-day)	Eastern Region	mm	4	4	4	8
Extreme Precipitation (1-day)	Far North Region	mm	4	4	4	4
Extreme Precipitation (1-day)	Northeast Region	mm	4	4	4	8
Extreme Precipitation (1-day)	Northwest Region	mm	4	4	4	8
Extreme Precipitation (1-day)	Southwest Region	mm	4	4	4	8
Drought						
Drought	Central Region	mm	4	4	4	4
Drought	Eastern Region	mm	4	4	4	4
Drought	Far North Region	mm	4	4	4	4
Drought	Northeast Region	mm	4	4	4	4
Drought	Northwest Region	mm	4	4	4	4
Drought	Southwest Region	mm	4	4	4	4

Table 3.5 can be best interpreted using a series of illustrative examples. Absolute conditions in Extreme Hot Days, for example, indicate that the largest increases in the variable are projected to occur in Southwest, Central and Eastern Ontario by the end of the century. In fact, current conditions indicate that these regions experience, on average up to 18 days over 30°C per year. By the end of century (2080s), projections indicate this number to rise significantly over 60 days per year across Southwest, Central and Eastern Ontario. In terms of extreme heat, climate variable frequency scores have been determined to be ‘16’ (large increase from baseline) except for the Far North region under a moderate emissions scenario RCP4.5, which is expected to be ‘8’ (moderate increase from baseline). This may appear to suggest that the Far North may not be impacted as much and as quickly – but that is not the case. Examining only one climate variable for a particular geographic region does not tell the entire story, and one must remember these are average conditions across climate normal periods (30-years). Increased variability and temperature swings across all regions of Ontario could be expected.

In the Far North, the frequency of Extreme Cold Days (less than -25°C) is expected to be reduced the fastest in this region, with frequency scores of ‘1’ in all future time periods regardless of emissions scenario. A frequency score of ‘1’ denotes a large decrease from baseline conditions. In real world conditions, this represents a drop from a regional average of about 55 Extreme Cold Days per year under current conditions down to only 12 days in the Far North by the end of century. Across other regions of Ontario, Extreme Cold Days are also declining and at a faster rate of change in northern regions compared to Southwest, Central and Eastern Ontario. It must be acknowledged that just because climate variable scores remain at ‘4’ for Southwest, Central and Eastern Ontario, it does not indicate a lack of decline in extreme cold conditions in the future. Frequency scores are based upon standard deviations away from mean conditions, so in these regions the criteria were not met to lower the frequency from ‘4’ to ‘2’, or to ‘1’. In other words, compared with other regions, the change is more significant in the Far North, given that Extreme Cold Days are already fewer and become even less in number in Southwest, Central and Eastern Ontario.

Other notable reflections regarding climate variable frequency scores include the following:

- Cold Days (<-25°C) and Degree Days < 0°C are the only two climate variables where frequency is decreasing.
- Mean Spring Precipitation is the most regionally uneven variable in terms of its increasing frequency, with scores some regions (e.g. Southwest, Central, Eastern and Northeast) showing increases up to a frequency score of ‘16’ by the 2080s, and others (e.g. Northwest) showing increasing frequency but not to the same extent. In the Far North region frequency scores remain unchanged for this climate variable.

- Rain:Snow Ratio is particularly dynamic across Ontario, with all regions showing increasing frequency of more rain falling during winter. Southwest, Central and Eastern regions show large increases in frequency compared to baseline (scores of '16'), with the Northeast, then Northwest and the Far North also increasing but at slightly lesser paces.

Several other variables (e.g. Mean Summer Precipitation, Mean Autumn Precipitation, Mean Winter Precipitation, Extreme Precipitation, Drought) are projected to change (described above with data summarized in Appendix 5) but frequency scores indicate no changes or increases by the 2080s (e.g. extreme short duration precipitation, wildfire).

Climate variable frequency scores, organized by climate variable and for each region, are one of three major components of evaluating risk, and as a result climate variables and associated risks are further characterized by Area of Focus (see Sections 5.0 to 9.0).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4.0 Socio-Economic Projections

Socio-economic development will drive Ontario's new infrastructure, industrial development, and land-use, as well as influence demographics such as migration and population structure. A socio-economic profile was prepared for the PCCIA to help anticipate how Ontario populations and assets will change in the future. This profile creates the backdrop against which climate change unfolds and informs other considerations and pressures alongside climate change. These equally dynamic factors can contribute positively and negatively to climate change (more or less GHG mitigation and degrees of embedded adaptation), but also inform new or enhanced adaptation needs across regions and sectors.

4.1 Approach to Developing Socio-Economic Projections

Similar to climate models and projections of climate change, projections of socio-economic factors assume a wide range of variables and yield a wide range of plausible future scenarios. Consideration of several of these plausible futures in the context of the PCCIA would create a significantly larger analysis portfolio, thus a single "middle of the road" socio-economic projection that balances socio-economic challenges for adaptation and mitigation was developed. This relatively conservative scenario is based on the Shared Socioeconomic Pathway 2 (SSP2), published by the Intergovernmental Panel on Climate Change (IPCC). This pathway is deemed to most closely resemble the current trajectory of development for Ontario and was therefore selected for this assessment. SSP2 considers an integrated global model to estimate population and economic growth for a climate scenario that lies between RCP4.5 and ECP8.5. By selecting SSP2, this enables a pathway between RCP4.5 and RCP8.5 (both of which are applied to the PCCIA) and avoids making broad scale assumptions regarding fossil-fueled development (SSP5), regional rivalry (SSP3), significant inequality (SSP4) or widespread sustainability (SSP1). Under SSP2 social, economic, and technological trends do not shift significantly from historical patterns, with development and income growth continuing to proceed unevenly (Fricko et al., 2017). SSP2 also assumes that internationally, progress is slow towards achieving sustainable development goals, environment systems continue to be degraded, but the overall intensity of resource and energy use declines (Riahi et al., 2016).

Socio-economic projections should not be classed as 'predictive' but rather be used to provide a plausible and consistent reference case from which to assess different climate scenarios and consider the relative scale and importance of anticipated impacts. In other words, this single scenario is used to identify plausible changes in socio-economic factors that are related to climate change alone and not differing pathways of socio-economic change. It should be noted that since this analysis for the PCCIA took place in 2021, updated demographic trends, reflecting increased federal immigration targets have become available (Ontario Ministry of Finance, 2022). In addition, as noted in the Appendix 6, the population projections used for the

PCCIA were found to lie roughly halfway between Ontario's Reference population projection to 2046 and Ontario's Low population projection to 2046.

The projections include a set of demographic and economic indicators that are spatially constrained at the Ontario census division level and then applied to the six PCCIA regions in Ontario. The twelve socio-economic metrics and indicators available are summarized below in Table 4.1.

Table 4.1: List of Socio-Economic Indicators Used in the PCCIA

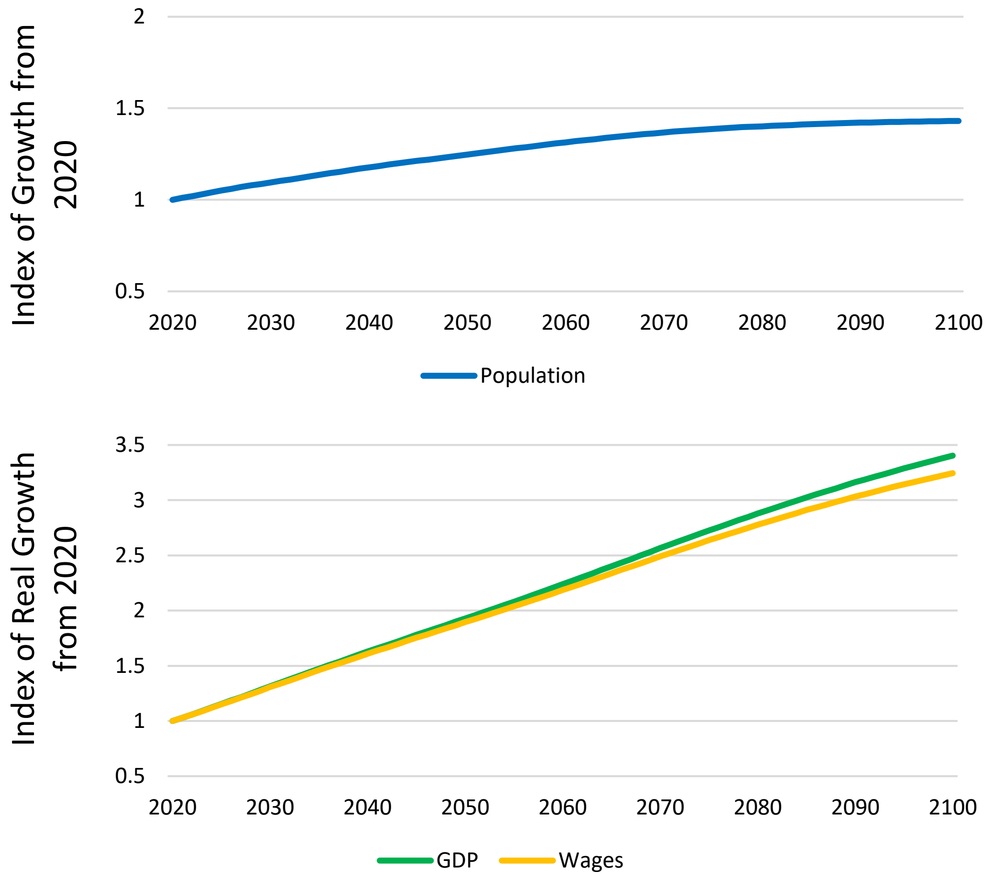
Category	Metric or Indicator	Dimensions of Data in Addition to Census Division and Year
Demographics	Population	19 Age groups (5-year age groups)
	Population Density	N/A
	Households	N/A
	Household Size	N/A
Housing	Housing Stock	5 Housing Types
Economics	Gross Domestic Product	20 Industry Categories (2 Digit level NAICS)
	Industry Output	20 Industry Categories (2 Digit level NAICS)
	Employment	20 Industry Categories (2 Digit level NAICS)
	Employment Rate	N/A
	Wages	20 Industry Categories (2 Digit level NAICS)
	Low Income Measure After Tax (LIM -AT)	3 age groups
	Investment in Construction Capital Formation	17 Building and Engineering Structure Types

A detailed methodology to develop the projection and each of the indicators are provided in the socio-economic projection report in Appendix 6. Broadly, the global SSP2 scenario provides published country level population and economic growth projections that are downscaled to Ontario to provide demographic trends (population, age structure) and economic trends (consumption levels and patterns, size of labour force) and are consistent with global damage functions associated with climate change. The projection covers every annual year between 2020 and 2100; however averaged values are also provided for three time periods of interest (current, 2040 to 2070 and 2070 to 2100). While the global damage functions and climate sensitivity of the SSP2 scenario don't align specifically to Ontario's circumstances, the projection is parameterized within a long-term globally consistent frame in which national policies will develop.

4.2 Summary of Results and Application to the PCCIA

Compared to today, the socio-economic projection anticipates slowing population growth and an aging population distribution such that by 2100, the fraction of the population over the age of 65 rises to 35% from 18% today (see Figure 4.1). The average growth rate of the gross domestic product (GDP) also starts to decline in the later part of the century, although only slightly.

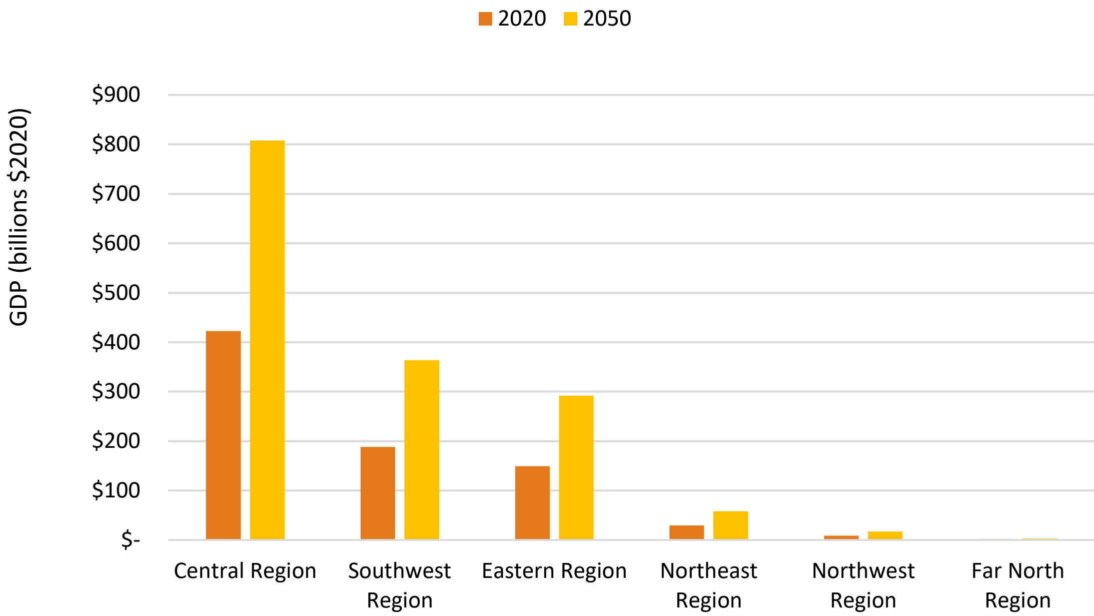
Figure 4.1: Index of Major Socio-Economic Indicators for Ontario (2020 to 2100)



The socio-economic projection shows relatively even growth of GDP between the six regions, with the Central region contributing 52% to 53% of Ontario's GDP in both 2020 and 2050 (see Figure 4.2).

The distribution of housing types also shifts significantly into the future with larger growth in attached or semi-detached dwellings and apartments. Additional indicators and how they change in time and/or by region and census division are provided in the detailed report in Appendix 6.

Figure 4.2: Projected GDP by Geographic Region in 2050s



Socio-economic indicators were applied to the PCCIA by Area of Focus and included those most applicable and influential for each sector or theme. The sum of those indicators became the final suite that was calculated and used in the PCCIA. The selection was constrained to three to five indicators for each Area of Focus in order to make the calculations manageable for the assessment. The socio-economic projection data were used to inform components of future risk scoring and evaluation. Area of Focus teams applied the socio-economic projection data to estimate the population, employment, or assets at risk for future time periods and across different regions of Ontario.

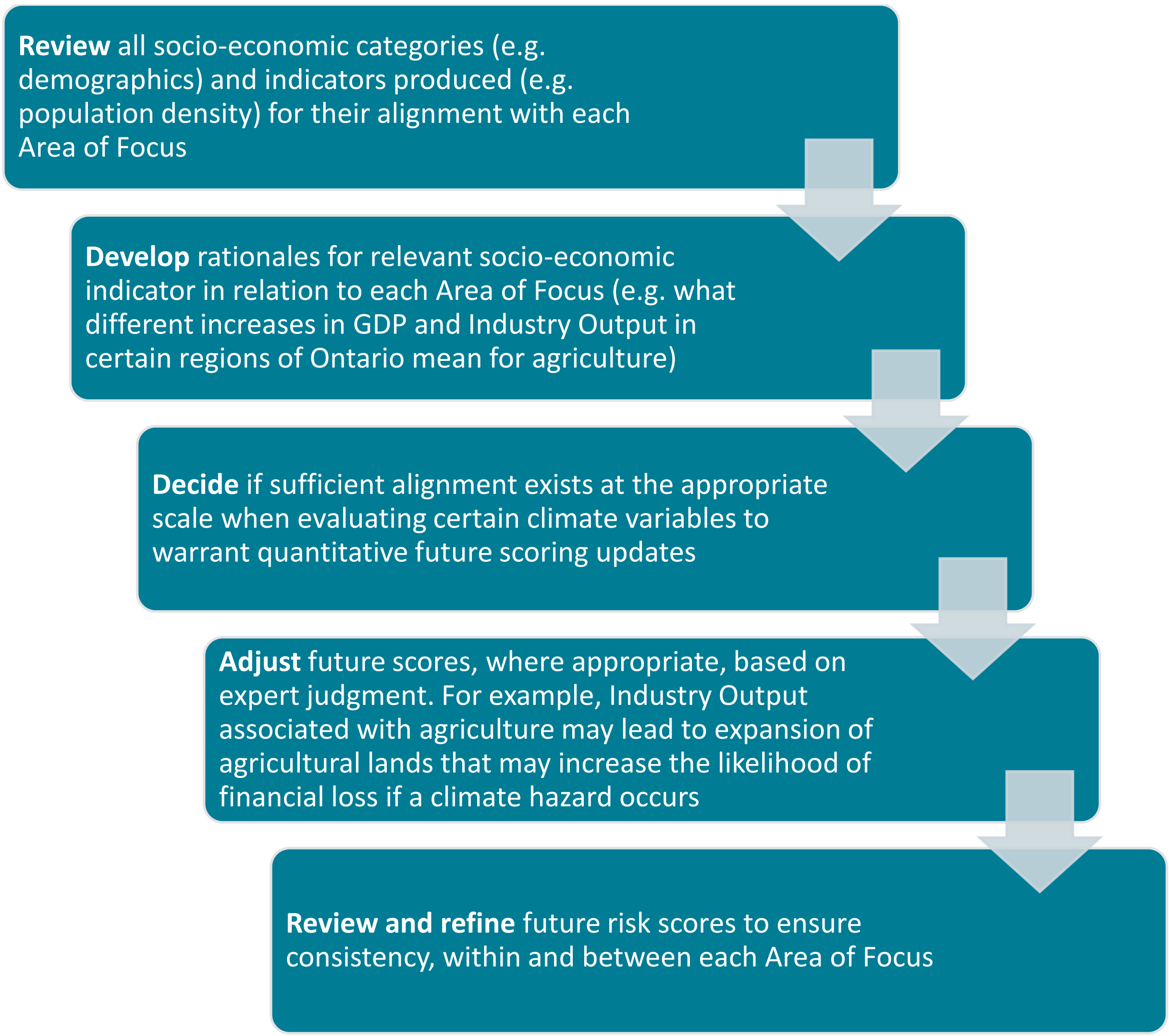
More specifically, socio-economic data were used to adjust likelihood (of an impact occurring) and the severity (of a consequence should it occur) scores for a given Area of Focus, by region and in future time periods. The data helped reveal how changes to, for example, population size, could lead to more people exposed to climate change between different time periods and hence how relative individual risk scores would change over time. Table 4.2 provides an overview of the socio-economic indicators selected and applied to analysis and evaluation under each Area of Focus. Further information on how each Area of Focus applied these indicators to scoring processes can be found throughout Sections 5.0 to 9.0.

Table 4.2: Socio-economic Indicators Applied to Areas of Focus

Area of Focus	Socio-economic Indicators
Food and Agriculture	Population
	GDP
	Employment
	Capital Formation
Infrastructure	Housing Stock
	Population Density
Natural Environment	Housing Stock
	Population Density
	GDP
People and Communities	Population
	Population Density
	Capital Formation
	Low Income Measure
Business and Economy	Socio-economic indicators assessed as part of this PCCIA did not warrant quantitative changes in risk scores at the firm level for the Business and Economy Area of Focus. Socio-economic changes and transitions relevant to several Business and Economy industries are characterized qualitatively in Section 9.

Specific rationales and assumptions were developed and considered for each Area of Focus, and in some cases down to the Level 1 and 2 granularities. For example, where socio-economic changes constrain or put pressures on specific Natural Environment Level 2 categories, scores were changed to reflect worsening conditions or increased exposure. In other Areas of Focus, increased investment in some industries implied more capacity to respond and thus consequence scores were not changed. In some cases, socio-economic indictors provided information that shifted sector or system outcomes in opposing directions. In these cases, without knowing which of the two indicators could be more dominant, the presence of these counter-influential indictors implies that no influence will be experienced and thus scores remained unchanged. Figure 4.3 below demonstrates the logic applied to each Area of Focus a) if the socio-economic projection data could be used to update future scoring quantitatively; and b) the logic or rationale used to consider in making future scoring changes.

Figure 4.3: Generalized Approach to using Socio-Economic Projections to Update Future Risk Scoring



It is important to acknowledge that changes to the climate risk scores that were influenced by socio-economic indicator projections are not uniform across all of Ontario and were considered according to regional socio-economic projections. To supplement and/or justify the information provided in the socio-economic projections, literature review was undertaken to consider historical context in relation to future potential socio-economic changes. For example, increasing industry output associated with agriculture may be projected in Northeast and Northwest regions however, these regions have been characterized as having insufficient infrastructure to enable significant growth of the agriculture industry to date to support agricultural operations (Chapagain, 2017). In this case, the likelihood of a climate event impacting agriculture may increase, but not until sufficient infrastructure has been developed. On the other hand, increasing industry growth in more southern regions of Ontario may be constrained due to land use change and lead to intensification with more production on a similar proportion of agricultural lands (which may increase the financial consequences of a climate event occurring). In both cases, the future risk could be increasing – but for different reasons and over different time periods.

The decision to adjust risk scores was Area of Focus-specific and all changes are noted in the PCCIA analysis, Sections 5.0 to 9.0. Risk results characterized under each Area of Focus have considered and incorporated socio-economic projection information where appropriate. The application of the socio-economic projections is only one supporting tool used to inform components of climate risk scoring and in some cases were used only qualitatively (e.g. not to adjust future scores) because socio-economic indicators that were available, including their resolution, did not reveal information useful to assessing the impact of individual climate events.

5.0 Food and Agriculture Area of Focus

5.1 Overview

Ontario's agriculture and food sector is sensitive to regional climatic conditions, with changing temperature and precipitation patterns directly influencing productivity and other facets of the sector. While changing climate conditions may present potential opportunities for agriculture in Ontario (e.g. longer growing and grazing seasons), such benefits will likely be offset by negative impacts, resulting in declining productivity, crop failure, and livestock fatalities. Several field crop and fruit and vegetable commodities (e.g. corn, cereals, soybeans, grapes, field vegetables) are expected to face 'very high' climate risk by the end of the century (Table 5.1).

While managing uncertainty is common within Ontario's food and agricultural sector, climate change is expected to amplify existing current risks and introduce new risks for food producers across the province. If appropriate adaptation action is taken to limit the risks, and measures are put in place to support potential opportunities for Ontario's food and agriculture sector, there could be some positive impacts experienced across the province.

Table 5.1: Summary of Climate Risks to Food and Agriculture (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Most at Risk Regions Abbreviations[4]	
FN - Far North	E - Eastern
NE - Northeast	C- Central
NW - Northwest	SW - Southwest

Food and Agriculture Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Field Crops				C, E, SW
Fruits and Vegetables				C, E, SW
Livestock				C, E, SW

[4] 'Most at risk regions' are those that display highest risk scores operating under RCP8.5. For more details on regional risk breakdown by Level 1 category, see Appendix 9.

5.2 Food and Agriculture in Ontario

Ontario's food and agriculture sector plays an important role in the province's economy, landscape, and society. The sector employs over 700,000 people (approximately 10.3% of provincial employment) and contributes approximately $45 billion to the provincial GDP (6.4% of total GDP) (Ontario Ministry of Agriculture, Food and Rural Affairs, 2022c). Ontario is identified as Canada's top agri-food exporting province, with $19.6 billion in agri-food exports recorded in 2021 (Ontario Ministry of Agriculture, Food and Rural Affairs, 2022c).

The sector is multi-faceted, and includes primary agricultural producers, input and manufacturing providers, food and beverage processors, food distributers, food retailers and wholesalers, and food service providers (Statistics Canada, 2021h). Ontario's agri-food sector is inextricably linked to systems within and outside of the sector, including infrastructure, economic, and natural systems (see Section 10.1 for a cross-sectoral analysis of Ontario's food system and food security). For the purposes of the PCCIA, the Food and Agriculture Area of Focus is comprised of only primary agriculture production industries (e.g. crop and livestock production), with other supporting segments covered under Infrastructure (Section 6.0) and Business and Economy (Section 9.0).

Primary agricultural production in Ontario is quite diverse, with the province producing over 200 commodities on 11.76 million acres of agricultural land (Agricorp, 2019; Statistics Canada, 2022a). Between 2016 and 2021 there was a 2.5% decline in total number of farms across Ontario (Statistics Canada, 2022a). However, total farm cash receipts and capital have continued to increase across the sector (Ontario Ministry of Agriculture, Food and Rural Affairs, 2022c).

Grain and oilseed farms are the most common type of agricultural production in the province, followed by beef cattle and dairy production. Hog, poultry, fruits, and vegetable production make up a smaller proportion of farms across the province but remain as significant economic contributors to the sector (Ontario Ministry of Agriculture, Food and Rural Affairs, 2022c). Dairy, vegetable, and soybean production are the top earning commodities by farm receipts in Ontario (Statistics Canada, 2021h). Ontario is also the leading greenhouse vegetable producer in Canada, representing 71% of total national production in 2020 (Statistics Canada, 2022a).

Prime agricultural areas are classified as lands with appropriate combinations of soil characteristics and climate suitability to support specialty and common primary agricultural operations. According to the Canada Land Inventory, only 0.5% of the Canada's land is categorized as Class 1 farmland, and over half of this land is located in Ontario (Ontario Ministry of Agriculture, Food and Rural Affairs, 2022d). The Provincial Policy Statement (PPS) and other provincial plans and guidance documents are used to help identify, designate, and protect these lands (Government of Ontario, 2017b; 2019; 2020f).

Prime agricultural areas in the province are largely located south of the Canadian Shield (Central, Southwest, and Eastern regions). As a whole, Southwest and Central Ontario are amongst the richest agricultural regions in Canada, with Class 1 – 3 lands, favourable climate, access to fresh water and supporting needed agri-food infrastructure systems. Eastern Ontario also has large areas that contribute to agricultural production for the province. Ontario's northern regions also include prime agricultural areas, supporting well-established dairy, beef, grain, oilseed, fruit, and vegetable industries (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021d; 2022d).

5.3 Defining Food and Agriculture in the Context of the PCCIA

Climate change impact assessment within the Food and Agriculture Area of Focus is concentrated on the direct and indirect impacts on primary agricultural production and considers the greatest drivers of future risk, the magnitude of consequence and impacts, and how impacts fluctuate by region of the province.

The Food and Agriculture Area of Focus has been divided into three Level 1 categories to capture major primary agricultural production systems in Ontario. Figure 5.1 provides a summary of each Level 1 and 2 categories assessed as part of Food and Agriculture. Each of these categories were then further divided into several Level 2 categories to capture major commodities produced across the province. For additional details, Appendix 1 provides a characterization of the Level 1 and 2 categories assessed for this Area of Focus.

Level 1 and 2 categories under this Area of Focus were developed by applying the following criteria:

- Alignment with relevant North American Industrial Classification System (NAICS) codes
- Relevance as it relates to Ontario's primary agricultural systems (e.g. major commodities produced)
- Statistics Canada census information on agricultural production for provincial regions

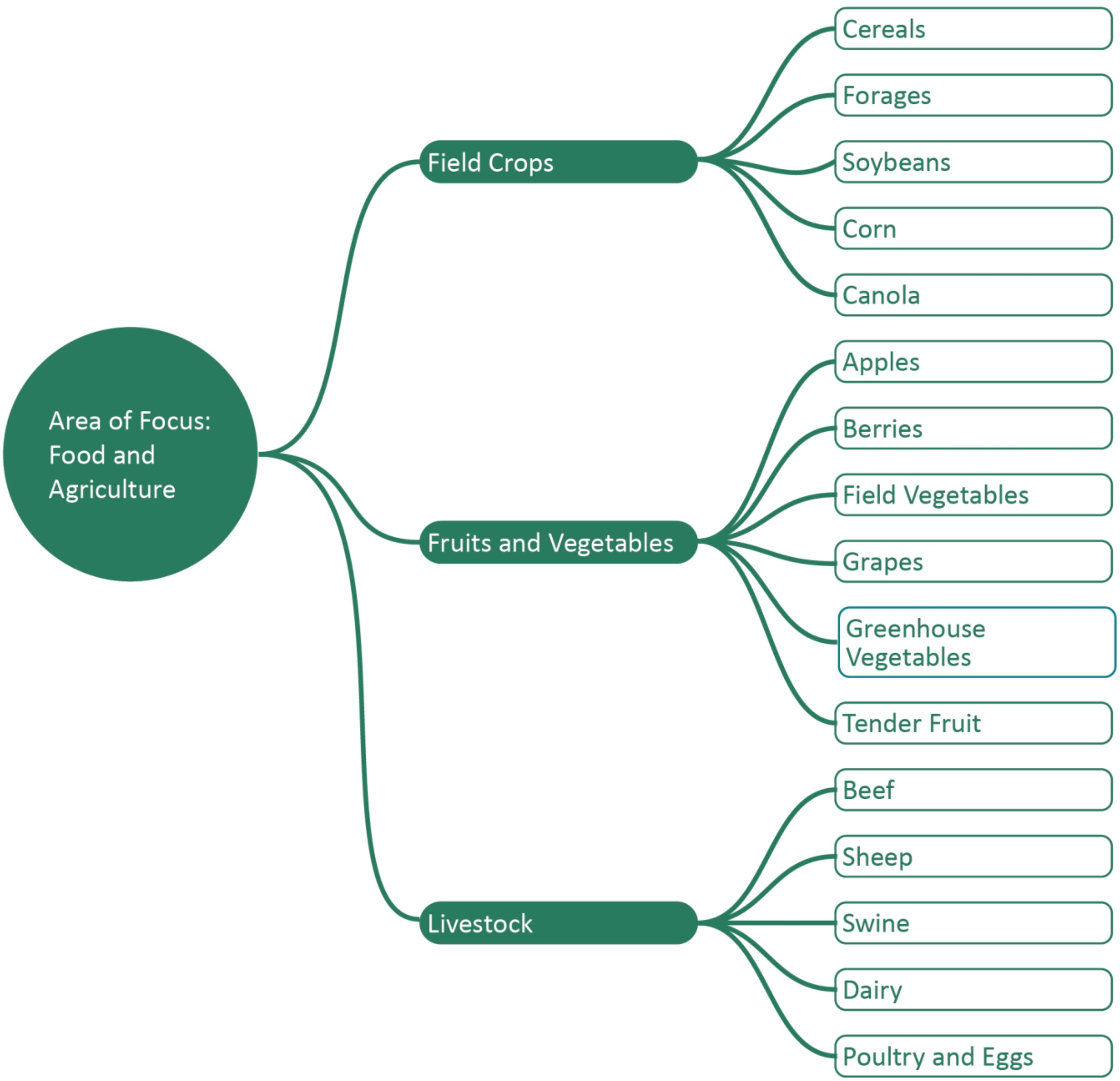
Level 2 categories were only assessed in regions with considerable coverage or where they have larger contribution to Ontario's food and agriculture sector. In each region, several factors were considered to capture the most relevant production types. These included:

- Significant portion of total farm cash receipts
- Significant portion of farmable land
- Significant contribution to regional employment or economic activity

- Available spatial data for assessment
- The potential for shifts in a Level 2 category within a region
- The ability to identify climate variable thresholds

By applying these criteria, the Far North region was scoped out of this Area of Focus, as there is currently limited primary production within the region.

Figure 5.1: Structure of the Food and Agriculture Area of Focus in the Context of the PCCIA



5.4 Food and Agriculture Risk Snapshot across Ontario

Summary of Risks

Changing climate is already impacting agricultural production across Ontario, with impacts expected to continue and amplify in the future. Across the three Level 1 categories under this Area of Focus, a total of 924 unique climate risk scenarios were identified and subjected to quantitative assessment.

All commodities across each region are expected to experience some level of increased risk from current levels to the end of century, exacerbated or influenced by projected changes in climate variables, socio-economic projections, regional characteristics, production values, and exposed losses. As noted, the indirect impacts associated with climate change are not included in the quantitative risk analysis, indicating that some risk profiles may be underrepresented, from a holistic risk perspective. Considerations of indirect impacts are described throughout Section 5.7 for each Level 1 category.

By mid-century, increases in climate risk are anticipated for several field crop and fruit and vegetable commodities, with the most immediate increase observed for certain species of apples. By the end of century, both the field crop and fruit and vegetable Level 1 categories are expected to see an increase in risk, with most Level 2 categories exhibiting 'high' and 'very high' risk profiles. This increase is largely driven by risk increases for corn, cereals, forages, soybeans field crop commodities, and apples, grapes, and field vegetable communities. Livestock commodities, such as dairy, beef, poultry and eggs, and swine, are also expected to see an increase in risk, but to a lesser extent compared to the other two Level 1 categories, with scores increasing from 'medium' and 'high' risk profiles by mid-century under a high emissions scenario (RCP8.5).

Figure 5.2 illustrates risk scores for the Level 1 categories assessed, by region, under current, 2050s and 2080s time periods. Future time periods illustrate risk results under RCP8.5 - a high GHG emission trajectory. Regionally, a greater increase in risk is observed for Southwest, Central and Eastern Ontario by mid-century across this Area of Focus, with Northeast and Northwest regions increasing in risk by the end-of-century across several Level 2 categories. The lag in increased risk scores across northern regions of the province is linked to exposure to climate variables (e.g. extreme heat) and the application of socio-economic indicators, projecting northern agricultural industry expansion in the latter half of the century. Once industry expands in these regions (e.g. investment in supporting infrastructure and agriculture production), it is anticipated that northern regions of the province will produce increased agricultural outputs, and consequently exhibit greater exposure to climate-related risks.

Key Climate Drivers

The Food and Agriculture Area of Focus is exposed to multiple climate variables that lead to climate-related risks for crop and livestock production. Climate variables interact with field crop, fruit, vegetable, and livestock production resulting in direct impacts to plants, yield losses, and compromised animal development and reproduction among other impacts. Indirect impacts stem from climate variables interacting with pests and diseases, soil, and water resources, as well as infrastructure and supporting systems critical for crop and livestock production.

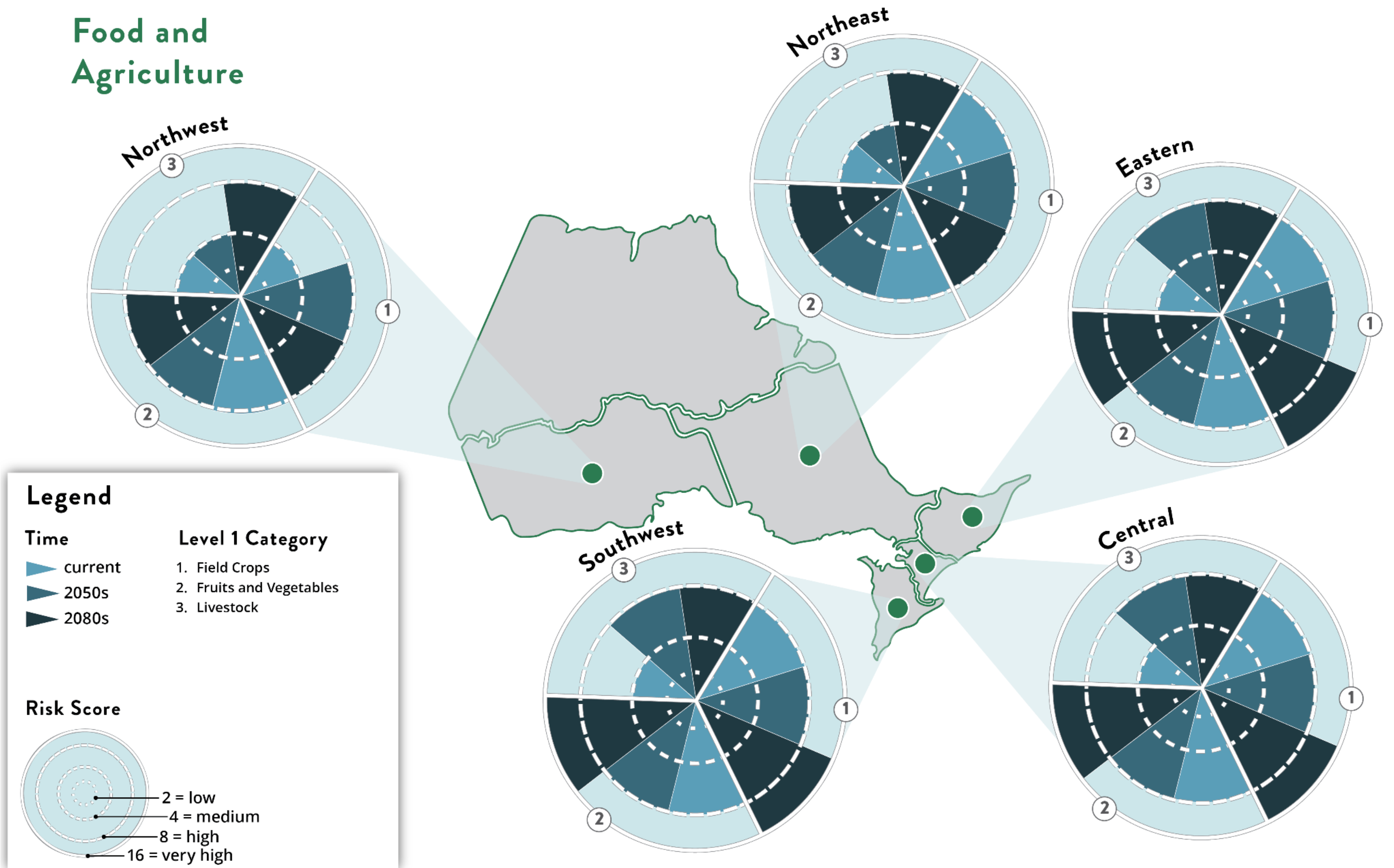
Key climate drivers to the risk scenarios assessed under this Area of Focus are listed in Table 5.2. These include Extreme Hot Days, Degree Days <0°C, and Moisture Deficit (proxy for drought conditions), which are the main drivers of 24%, 19% and 17% of all risk scenarios, respectively. Additionally, growing season length and extreme precipitation climate variables were also impactful for risk scenarios assessed under Food and Agriculture. A full list of all major climate variables that are driving the highest risks to Ontario's Food and Agriculture Area of Focus by Level 1 category and region is available in Appendix 8.

Table 5.2: Main Climate Variables Assessed for Food and Agriculture Area of Focus

Climate Variable	Proportion (%) of Area of Focus Risk Scenarios
Extreme Hot Days	**24%**
Degree Days <0°C	**19%**
Moisture Deficit/ Drought	**17%**
Other Variables	**40%**

The total number of climate variables assessed in scenarios for different Level 1 categories ranged from four for Livestock, to eight for Field Crops, and 10 for Fruits and Vegetables. The types of hazards assessed for Level 2 categories depended on their sensitivity and geographic distribution. Importantly, the three climate variables in Table 5.2 are present across all Level 1 categories: Field Crops, Fruit and Vegetables, and Livestock, while others (e.g. Growing Season Length, Extreme Precipitation, and Mean Spring Precipitation) were only assessed for Field Crops and Fruits and Vegetables. The Wildfire Return Period variable was assessed for Livestock and Field Crops, but not for Fruits and Vegetables, largely because it occurs predominantly in Northeast and Northwest regions where Fruit and Vegetable production is currently limited. Direct impacts associated with the main climate interactions include crop damage, poor nutrient uptake by crops, reduced crop quality and yield, reduced plant and animal productivity, greater livestock mortality and crop loss. See Section 5.7 for detailed descriptions of direct and indirect impacts and consequences.

Figure 5.2: Current and Future Risk Profiles by Region Assessed for Food and Agriculture (RCP8.5)[5]



[5] Appendix 13 provides an alternative visual format of the presented risk results by Level 1 category and region for this Area of Focus.

5.5 Approach to Assessing Climate Impacts on Food and Agriculture

As described in Section 2.0 of this report, Areas of Focus were used to assess climate impacts to systems and sectors in a systematic and scalable manner. In this regard, the impacts within the Food and Agriculture Area of Focus were quantitatively evaluated by the direct impacts identified to major commodities produced across Ontario. The magnitude of consequence for each interaction was assessed by financial losses associated with direct impacts to each Level 2 category. Indirect impacts to this Area of Focus were not included in the quantitative portion of the assessment of risk, but qualitative characterization is provided based upon each Level 1 category in Section 5.7.

The magnitude of consequence under this Area of Focus was evaluated based on the financial loss associated with direct impacts to each assessed Level 2 category. Literature, historical production, yield and insurance claim data and socio-economic projections were used to support consequence scoring. The extent of yield loss for crop and livestock products (e.g. milk) sustained under each of the 924 scenarios was quantified, based on the ranges shown in Table 5.3.

Table 5.3: Consequence Criteria for the Food and Agriculture Area of Focus

Consequence Score	Category	Definition – Amount of Yield or Commodity Loss Quantitatively Measured as % Loss
16	Very High	>50%
8	High	>30% to 50%
4	Medium	>10% to 30%
2	Low	>5% to 10%
1	Very Low	0% to 5%

The likelihood of impact for each scenario was assessed by considering the probability of impact associated with each risk scenario (e.g. likelihood of the described loss in a given year). Probability ranges for each score category is shown in Appendix 2.

Generally, the strength of evidence for this Area of Focus ranged from medium to high, with the exception of a handful of interactions where research remains limited. For example, the risk scenarios for wildfire impacts on field crop and livestock production were rated low in strength of evidence, as even with evident impacts, there is limited research available on the magnitude and likelihood of the associated consequences for Ontario agriculture.

Climate impacts were identified for each Level 1 category by assessing risk at the scale of each identified Level 2 commodity type and associated regions. For Level 2 categories that included several commodity types (e.g. cereals), a proxy commodity (e.g. winter wheat) was selected based on regional relevance and existing production data. In other words, certain Level 2 risk scores do not depict overall risk for all commodities within a Level 2 category, rather present a representation of risk for the category based on the selected proxy commodity.

To update risk consequence scores for the 2050s and 2080s time periods, socio-economic projections were considered along with specific assumptions on agriculture development in different regions across Ontario, discussed in Box 3.

Box 3: Application of Socio-Economic Projections to Food and Agriculture

As described in Section 4.0, socio-economic projections were applied to risk evaluation based on the influence on likelihood of consequence and magnitude of impact for each risk scenario. For the Food and Agriculture Area of Focus, four socio-economic indicators were applied to the likelihood of consequence across each Level 1 category, these included: population growth, GDP and industry output, employment, and capital formation (indicating investment) for the sector. For example, the likelihood of consequence was raised by one level for the 2050s and 2080s across Southwest, Central and Eastern regions based on population growth and industry expansion and investment (increasing sensitivity and exposure). Whereas the likelihood of consequence was increased by one level for Northeast and Northwest regions of Ontario for the 2080s, but not the 2050s. This was due to longer-term projected growth and industry expansion in the northern regions of the province and the requirement for significant infrastructure and development to enable growth of the agriculture industry and support agricultural operations.

5.6 Limitations of Food and Agriculture Area of Focus

A more granular assessment of climate change was constrained by several factors and stand as valuable input for further specific assessments in the sector, or, as part of subsequent provincial-scale climate change impact assessment. These limitations are described briefly below.

Non-Climatic Influences

Climate change is considered one of many challenges facing agricultural production in Ontario, including land-use pressures, declining ecosystem and soil health, labour shortages, and shifting market conditions. Other non-climatic factors also influence agricultural productivity including geographic location and topography, soil type and quality, type of cultivars and species, and on-farm management techniques and practices (Morand et al., 2017; Brklacich and Woodrow, 2016). When interpreting the quantitative risk scores under this Area of Focus, it is important to consider that scores reflect only direct climate impacts to Level 1 and 2 categories, and do not consider how non-climatic pressures and factors could influence current and future risk scores.

Food System Interdependencies

As noted, the Food and Agriculture Area of Focus is scoped to primary agriculture production industries (e.g. crop and livestock production). Food processing, manufacturing, retail, and related services are not covered under this Area of Focus. Instead, climate impacts to these subsectors have been grouped under the Business and Economy Area of Focus in Section 9.0. Cascading impacts and interdependencies (e.g. supporting infrastructure) within and outside of Ontario's food and agriculture sector as they relate to food security, have been covered qualitatively under Cross-Sectoral Considerations in Section 10.1.

Proxy Selection

Defining commodity types to include in the assessment of the Food and Agriculture Area of Focus was an important step in the process and proved challenging. Based on the scope and scale of the PCCIA, specific proxy commodities were selected as representative commodities for certain Level 2 categories. The selection of proxy commodities was based on climate sensitivity and exposure identified through literature review, regional production and insurance claim data, and expert judgement. However, the application of proxy commodities does constrain risk scores for certain Level 2 categories to specific commodities (e.g. winter wheat was selected as a proxy commodity for the cereals Level 2 category for appropriate regions). The selection process may have been improved by (further) consultation with other subject-matter experts.

5.7 Current and Future Climate Risks

5.7.1 Field Crops

Overview

Ontario field crop production was assessed as a Level 1 category under the Food and Agriculture Area of Focus. Field crop production is the most common type of primary agriculture in Ontario. Major field crops (e.g. grain and oilseed commodities) grown in Ontario include soybeans, corn, wheat, canola, oats, and barley. The selection of commodities grown across the province varies depending on the climate and land suitability of each region, market drivers, and the needs of producers (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a).

Field crops produced across the province are inherently vulnerable to weather and climate conditions, due to direct exposure and sensitivities. Research suggests that Ontario's changing climate could present opportunities for field crop production driven by longer growing seasons, milder winters, and fewer frost days (Morand et al., 2017; Qian et al., 2019). However, this assessment found that the benefits are likely to be offset by the risks associated with increased frequency and intensity of extreme weather events, variability in seasonal temperatures, and changing precipitation patterns at critical crop development phases (Zaytseva, 2016; Apostoli, 2021; Chapagain, 2017).

The assessment results indicate that field crop risk profiles across all regions of the province will be 'high' or 'very high' by the end of century. A greater increase in risk is observed for Southwest, Central and Eastern Ontario by mid-century (2050s), with Northeast and Northwest regions increasing in risk by the 2080s. The lag in increased risk scores across northern regions of the province is linked to exposure to extreme climate conditions (e.g. extreme heat) and the application of socio-economic indicators, projecting northern agricultural industry expansion in the second half of the century. As industry further expands in these regions, it is anticipated that northern regions of the province will produce increased agricultural outputs and consequently, exhibit greater exposure to climate risks. The higher risk scores in Southwest, Central and Eastern Ontario are reflective of existing exposure and sensitivity to changing climate conditions.

High temperatures, extreme precipitation events, and drought conditions were found to be the greatest drivers of future risk to Ontario's field crop operations and production. The type and magnitude of risks are expected to vary across agricultural regions of the province, depending on regional acreage, commodities grown, intensification of production, and land, soil, and climate conditions. Additionally, indirect climate impacts to field crop production introduce another layer of complexity that influences how climate risks will materialize or cascade within and across crop regions of the province. As noted, the indirect impacts on Level 1 and 2 categories are not included in the risk scores, and therefore individual scores may not provide a holistic representation of the impacts that climate change poses to field crop production. Qualitative descriptions of indirect impacts on field crop production are provided below, to accompany risk scores.

Direct Impacts

This section describes the quantitative scores for direct risks assessed for the Level 2 categories under Field Crops. Over 400 separate risk interactions were assessed for Field Crops, considering how changes in climate variables could lead to impacts on each commodity type. Each scenario was evaluated under current and future timeframes and for the relevant provincial regions. The assessment has drawn on research, provincial production and insurance data, socio-economic data, and literature to inform scenario development and consequence scoring related to direct climate impacts on field crop production.

Table 5.4 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 5.5, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 5.4: Illustrative Risk Scenario Examples for Field Crop Level 2 Categories

Level 2 Category	Illustrative Risk Scenarios	Strength of Evidence
Soybeans	A short-term high intensity precipitation event occurring during the early growth stages (spring), leads to flooded fields, waterlogged soils and drowning of sensitive soybean varieties for over two days. Flood-sensitive soybean types have been shown to experience up to a 77% decline in yield under this scenario, mainly caused by limited plant survival and seed emergence. This event would result in significant financial consequences for farm-revenue and would require replanting.	**Medium**
Corn	A sustained Moisture Deficit during pollination and fertilization periods, results in tassel and leaf damage, decreased pollen viability, poor silk development and insufficient ear size. Moisture stress will also increase risks related to developing stalk rot and exacerbate the feeding injury of corn leaf aphids. These impacts could lead to a yield reduction of 20 to 50% depending on the severity of the Moisture Deficits, ultimately reducing productivity and farm-revenue.	**High**
Cereals	Changing winter precipitation patterns can cause widespread winterkill in sensitive winter wheat varieties. This scenario could result in poor emergence and considerable yield losses, resulting in the requirement for spring replanting (if conditions are adequate).	**Medium**
Forages	An extreme heat event with temperatures reaching +34°C causes scorching of alfalfa and significant yield loss. These conditions also increase risks related to pest and disease outbreaks, such as the Potato Leafhopper, possibly exacerbating yield losses. This would result in significant revenue loss for farms and potential livestock feed shortages.	**Medium**

Level 2 Category	Illustrative Risk Scenarios	Strength of Evidence
Canola	A prolonged (minimum of three days) extreme heat event (+28°C during day and +16°C during nights) occurs during early flowering period, resulting in heat damage and abortion of flowers of spring canola varieties. This results in significant yield damage and ultimately loss of farm-revenue.	**Medium**

Soybeans

Soybeans have become the largest row crop by acreage in the province and are Ontario's greatest agricultural export commodity (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a). Soybeans grown in Ontario are used for specialty food grade markets, oil production and livestock feed. In recent years close to three million acres of soybeans have been grown annually across the province (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021a).

In recent years, approximately two million acres of land in Southwest Ontario have grown soybeans, comprising almost 70% of provincial harvest (Statistics Canada, 2017). Over 500,000 acres of land harvest soybeans in Eastern Ontario, which comprises approximately 19% of all soybeans grown in the province. Central Ontario typically grows over 250,000 acres of soybeans annually, representing the top commodity grown in the region. Northern regions of the province are limited due to the amount of available crop heat units and land suitability, and therefore the commodity is less commonly grown in these regions (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021d).

The impact assessment found that extreme precipitation and extreme heat are key climate variables driving future risk to soybean production. Risk to soybean production is found to increase from a 'high' risk score to a 'very high' risk score by the 2080s (operating under RCP8.5), in Southwest, Central and Eastern regions, with extreme heat being less of a threat in Northeast Ontario.

As noted, extreme precipitation was identified as one of the most relevant climate variables to soybean production, with short-duration extreme precipitation occurring in the spring season being particularly impactful. Soybeans are particularly sensitive to flooding in their early growth stages, which can directly reduce crop yields (Hatfield et al., 2011; Motha and Baier, 2005; Sullivan et al., 2001). For example, should short-duration extreme precipitation occur during the planting season, water logging of fields and complete submergence of the plant, can cause significant crop damage and yield losses, resulting in associated financial consequences. (Kucharik & Serbin, 2008; Bootsma et al., 2005). Where heavier clay soils with inadequate drainage are located across Ontario (e.g. Eastern region), crops are more vulnerable to impacts of flooding, waterlogging, and crusting, resulting in yield losses (Pearson et al., 2008; Linkemer et al., 1998; Morand et al., 2017).

Corn

Corn is the second largest field crop grown throughout Ontario, with 2.1 million acres of grain corn harvested in 2021 (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021a). Corn is produced across the province for both feed (60% of production) and industrial (40% of production) uses. A significant acreage is also planted to corn silage to be used for livestock feed (0.25 million acres) (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a). For the purposes of this assessment, grain corn has been selected as the representative commodity.

Grain corn is most widely grown in Southwest Ontario, with acreage in recent years totaling over 1.5 million acres. Eastern Ontario is also a large provincial producer of the commodity, with approximately 450,000 acres of corn grown annually. Central Ontario typically grows over 200,000 acres of corn annually, representing the second highest commodity grown in the region (behind soybeans). The northern regions of the province are limited due to amount of available crop heat units and land suitability, and therefore is less commonly grown in these regions (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021d).

Climate risks to corn production in Ontario are expected to increase by the 2080s across Southwest, Central and Eastern Ontario. Several climate variables were identified as being impactful to corn yields, especially at critical stages of plant development (Cabas et al., 2010; Zaytseva, 2016; Gaudin et al., 2015). For example, Moisture Deficit was used as a climate indicator of drought conditions. The magnitude and duration of Moisture Deficits can lead to a lack of water for critical growth. Prolonged lack of water during the growing season can have serious impacts on corn production including limited growth and development, increased pest and disease outbreaks, and elevated exposure of plants to extreme heat (He et al., 2018; Zaytseva, 2016; Qian et al., 2013; 2019). Risks are often exacerbated for rainfed corn crops grown on soils with low water holding capacity (Hatfield et al., 2012; 2018). While Ontario's agriculture is mainly rainfed and irrigation continues to be limited for common field crop production, producers, especially in the southern regions of the province (Southwest and Central), may be more likely to consider irrigation options for traditional field crop production, as growing season conditions become increasingly hot and dry. (Shifflett et al., 2014; Xu and Fox 2017; Xu et al.,2019; 2020).

Cereals

Cereal commodities make up a large portion of the cropping system in Ontario, grown on approximately 25% of the arable land (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a). Winter wheat is the most widely grown cereal crop in Ontario followed by spring barley, spring wheat, and oats. Cereals offer many benefits to producers, including improved soil structure and manure management options (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a).

Winter wheat was selected as a proxy commodity for cereals in Southwest, Central, Eastern and Northeast Ontario, based on production in the regions and identified climate sensitivities. Oats were selected as a Level 2 proxy for Cereals in the Northwest region, based on acreage and production data, in comparison to other cereal crops produced in the region.

As a Level 2 Field Crop category, winter wheat presented increasing future risk across all regions, with Southwest, Central, Eastern regional risk profiles increasing to 'very high' by the 2080s. Extreme heat and winter precipitation are the main climate variables driving future risk to winter wheat productivity. For example, winter cereal production can be significantly impacted during the winter and early spring period by frost heaving, icing, low temperatures, and snow mould (Cabas et al., 2010; Moran et al., 2017). Icing and drowning conditions throughout the winter and early spring is one of the main reasons for winterkill in Ontario. For example, in 2019, winterkill from icing conditions in the spring led to the largest winterkill event in the history of Agricorp's winter wheat plan (Agricorp, 2020).

Regions with limited sub-surface drainage and heavy-textured soils are particularly sensitive to these impacts. For example, varieties grown in the Eastern Ontario tend to have greater icing tolerance; those grown in Central Ontario's snow belt require snow-mould tolerance, and commodities grown in heavy clays of the Southwest region, require greater resistance to frost heaving (Moran et al., 2017). Under a changing climate, increased freeze-thaw cycles, rapid snowmelt, and warming shoulder season temperatures, may increase the likelihood of impacts associated with winterkill in winter cereal commodities (Bélanger et al., 2002; 2006).

Forages

Forages are another major Ontario crop, providing feed for Ontario's livestock industry. Forage production is an important component of crop rotations on many farms. Forage crop rotations provide several environmental benefits, including reduced soil erosion, and improved soil health and organic matter (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a). Hay and haylage are grown on 831,000 ha (2,000,000 acres), while there are 239,000 ha (600,000 acres) of seeded pasture and 415,000 ha (1,037,000 acres) of natural pasture. The value of forage production is estimated to be nearly 10% of Ontario's agricultural production (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a).

Southwest and Eastern Ontario comprise the majority of forage acreage, reporting over 600,000 acres and 520,000 acres in 2020, respectively. Central Ontario typically harvests over 150,000 acres of forage crop annually. Over 120,000 acres was seeded in Northeast Ontario in

2019, and over 50,000 acres in Northwest Ontario (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021a).

For the purposes of this assessment alfalfa was selected as a proxy commodity to represent forage crops. Alfalfa is the highest-yielding perennial forage crop grown in Ontario and the most frequently grown forage legume. It is higher yielding and produces more protein per unit area than other forage legumes. Alfalfa can be grown alone but is often grown in mixed stands with various grass species (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a; Moran et al., 2017). The risk profiles for forage crops in Southwest, Central, and Eastern regions increase from 'medium' to 'high' by the 2050s, and to 'very high' by the 2080s. In Northeast and Northwest Ontario, the risk profile increased from a 'medium' to a 'high' score by the 2050s and remains at this score for the 2080s.

Similar to winter cereals, climate conditions that increase risks from winterkill are particularly impactful to alfalfa development. Warming fall temperatures and increased precipitation leading to wet saturated soils, can compromise winter hardening and contribute to winterkill risks (Belanger et al., 2006). Extreme heat is also likely to drive future risk to alfalfa production. The frequency, intensity and duration of heat waves can cause several impacts to forage production including, reduced photosynthesis, scorched leaves and stems, dead leaves and seeds, reduced pollen production and viability, and reduced grain number and weight (Moran et al., 2017; Jing et al., 2020). Impacts of extreme heat are exacerbated if coupled with prolonged drought conditions (Arshad et al., 2017). For example, 2020 was Agircorp's highest payout year for their Forage Rainfall Plan, with $6.6 million in payouts due to insufficient rainfall, causing dry spring and early summer conditions (Ontario Ministry of Agriculture, Food and Rural Affairs, 2020a; Argicorp, 2016).

Additionally, it is important to recognize the cascading impacts of declining productivity and quality in forage crops and pastures to the livestock sector (characterized further in Section 5.7.3). Climate-related impacts on forage crops can result feed shortages across the livestock sector (e.g. province-wide livestock feed shortages were experienced from the 2012 drought) (Tourangeau et al., 2019; Cordeiro et al., 2022). Declining feedstock quality and quantity could lead to animal health and welfare concerns and further financial losses for the sector (Moran et al., 2017; Reid et al., 2007).

Canola

Canola is a cool-season oilseed crop limited to temperate areas of Ontario. Canola is grown on approximately 45,000 acres across Southwest, Central and Northeast regions of the province (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017a). Both spring and winter canola varieties require well-drained soils. The commodity is a less commonly grown cash crop in Ontario, but winter canola specifically, has been on the rise in Southwest and Central Ontario in response to rising yields, linked to advancements in hybrid seeds and market drivers (Moran et al., 2017; Kamchen, 2021; Qian et al., 2018). Currently, risk to canola is scored as a 'medium' and increases to a 'high' score for the future time periods. The risk profile for canola could increase further with acreage rising over recent years, increasing exposure of the crop to climate conditions (Kamchen, 2021; Wu & Ma, 2018).

In this assessment, heat stress associated with extreme temperatures, was identified as the greatest driver of future risk for canola production in Ontario. Canola plants can be damaged from extreme heat conditions and can result in 'brown seed' and 'heat blast' (Qian et al., 2013; 2018; 2019; Moran et al., 2017). Brown seeds are produced when canola is subjected to extended periods of high temperatures and moisture stress due to dry conditions during the pod fill stage. Heat blast occurs in response to heat stress during the flowering period and the pod development period, the result is often abortion of flowers or pods. Both impacts can result in significant plant damage, yield losses and unmarketable products (Moran et al., 2017; Wu and Ma, 2018).

Table 5.5: Risk Scores for Field Crop Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Field Crops	Soybeans	Central Region	High	High	Very High
Field Crops	Soybeans	Eastern Region	High	High	Very High
Field Crops	Soybeans	Northeast Region	High	High	High
Field Crops	Soybeans	Southwest Region	High	High	Very High
Field Crops	Corn	Central Region	High	High	Very High
Field Crops	Corn	Eastern Region	High	High	Very High
Field Crops	Corn	Northeast Region	High	High	High
Field Crops	Corn	Southwest Region	High	High	Very High
Field Crops	Cereals	Central Region	Medium	High	Very High
Field Crops	Cereals	Eastern Region	Medium	High	Very High
Field Crops	Cereals	Northeast Region	Medium	High	High
Field Crops	Cereals	Northwest Region	Medium	High	High
Field Crops	Cereals	Southwest Region	Medium	High	Very High
Field Crops	Forages	Central Region	Medium	High	Very High

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Field Crops	Forages	Eastern Region	Medium	High	Very High
Field Crops	Forages	Northeast Region	Medium	High	High
Field Crops	Forages	Northwest Region	Medium	High	High
Field Crops	Forages	Southwest Region	Medium	High	Very High
Field Crops	Canola	Central Region	Medium	High	High
Field Crops	Canola	Northeast Region	Medium	High	High
Field Crops	Canola	Southwest Region	Medium	High	High

Indirect Impacts

This section explores several indirect climate impacts that can compound the identified direct risks or introduce additional climate-related pressures to field crop production in Ontario.

Drought and extreme heat conditions are expected to impact water availability and supply for field crop producers, resulting in increased demand, and requiring allocation restrictions. Ontario field crop producers could experience water use limitations (e.g. irrigation and field application constraints), causing disruptions to farming operations, impacts to productivity, and revenue losses for farms (Reid et al., 2007; Disch et al., 2012). This could be exacerbated based on the timing and magnitude of water use restrictions and associated drought conditions (De La Cueva Bueno et al., 2017). Water scarcity could be amplified by increased demand for water by other sectors, especially in regions of the province where access to water is already a constraint on agriculture production (e.g. Northwest region) (Reid et al., 2007; Disch et al., 2012).

Both flooding and drought conditions have been found to have negative impacts on soil health, driven by increased soil erosion, degradation of organic matter, and accelerated sediment transport. This could result in a reduction of soil regulation and quality, declining productivity, increased disease outbreaks from pests and pathogens, and the requirement for additional inputs (e.g. pesticides) to offset impacts to soil fertility. The indirect impacts could result in overall farm revenue losses for producers (Ontario Ministry of Agriculture, Food and Rural Affairs, 2018; McConkey et al., 2011; Moran et al., 2017). Additionally, the number of spring days where unfrozen ground is not protected by snow, crops or residue cover, is projected to extend with climate change and will contribute to soil erosion. The worsening conditions of soil erosion may have immediate and long-term impacts on field crop production in Ontario (McConkey et al., 2011).

Flooding conditions are expected to impact nutrient export and leaching, causing input losses and declined productivity for producers. Saturated soils and flooding conditions can also cause implications for field applications of fertilizers and pesticides (Motha and Baier, 2005; Kling et al., 2003). Impacts may result in increasing inputs and nutrient management costs. With accelerated export of nutrients, producers may be required to adopt and implement new management practices (e.g. controlled tile drainage, conservation tillage, filter strips or cover crops) to mitigate risks to the surrounding watershed (Ontario Ministry of Agriculture, Food and Rural Affairs, 2018; Mervin and McLarty, 2017).

There is increasing evidence that climate change will impact the distribution and prevalence of agricultural pests, diseases, and non-native species in Ontario. Milder winters and lengthened growing seasons result in a greater chance of over-wintering survival, increased cycles and northward expansion of pests and diseases, including invasive species (Baute, 2020; Reid et al., 2007). Monitoring and surveillance programs have observed pests typically found in southern and central United Stated migrating to Southwest Ontario (Philip, 2015; Hatfield, 2012). Additionally, research has found that higher temperatures and drier conditions can be more impactful to natural enemies of pests, further increasing pest expansion and prevalence. Under a changing climate, it is becoming increasingly difficult and complex to model pest and disease ranges and prevalence, contributing to productivity losses and costs for field crop producers. Losses related to pest and disease include reduced crop yields and revenue, increased inputs/control costs, and contribute to access limitations to export or domestic markets (Boland et al., 2004; Philip, 2015; Hatfield, 2012).

Changes in climate can also impact the role of pollinator species (pollination and dispersal of seeds) in plant reproduction and crop production, leading to productivity and economic losses (Section 5.7.2 further describes the indirect impacts associated with declining pollinator species to fruit and vegetable production) (Apostoli, 2021, Harris et al., 2016; Kling et al., 2003).

Extreme weather events can result in cascading impacts related to electricity supply, agriculture infrastructure and transportation failures. The cascading impacts from infrastructure system failures are discussed in more detail under Food Security in Section 10.1.

5.7.2 Fruits and Vegetables

Overview

Fruits and vegetables across Ontario are produced under diverse soil and climatic conditions. Over 125 different fruit and vegetable crops are grown on 245,000 acres of land (Ontario Fruit & Vegetable Growers Association, 2022). As an economic contribution, fruits and vegetables contribute more than $4.2 billion in activity per year, employing over 30,000 people directly on-farm (Ontario Fruit & Vegetable Growers Association, 2022). Approximately 43% of this value is field grown and 57% produced in greenhouse operations (OPMA, 2021).

Fruit and vegetable production is critically important as part of Ontario's import and export markets, with over two billion pounds of produce, both local and imported, distributed through the Ontario Food Terminal in Toronto. In 2019, total export values of fruits and vegetables exceeded two billion dollars (Ontario Ministry of Agriculture, Food and Rural Affairs, 2019). Commodity prices for fruits and vegetables differ based on consumer demand, international markets, crop yield, and the commodity itself. From 2000 to 2019, as an example, raspberry and strawberry farm gate prices ($/tonne) rose the largest, compared with other fruits such as peaches and apples (Ontario Ministry of Agriculture, Food and Rural Affairs, 2019). For the purposes of the PCCIA, six Level 2 categories were used to assess the risks associated with direct impacts to fruits and vegetable production. However, it is critical to recognize the diversity and extent of all fruit and vegetable production, and the unique growing conditions and sensitivities that exist.

Numerous climate change impacts to fruit and vegetables can occur, and are highly dependent on the season, stage of growth of the crop, and the duration or extent of the climate event itself (e.g. drought within one year compared to a multi-year drought). Not all fruits and vegetable growers may experience impacts to the same extent. For example, if fruit trees are impacted or damaged to an extent where they are unable to produce fruit, impacts could be felt over several years, rather than only be reflective of financial loss within one year. Multi-year and cascading impacts are particularly important for fruit and vegetable production, and these are described as indirect impacts below.

The fruit and vegetable sector in Ontario could play an important role in advancing food system resiliency, such as reducing the significant reliance of Ontario on fruit and vegetable imports (approximately $7.3 billion in imports annually). For example, a report produced in 2020 by the Greenbelt Foundation (2020) found that expansion of certain crops could result in an increase of $135 million in farm-gate revenue and bolster local production (thereby food system resilience) by growing fresh grapes, pears, strawberries, garlic, eggplant, sweet potatoes, apples, snap peas, and cabbage, as well as technical advancements such as vertical farming (Greenbelt Foundation, 2020).

Direct Impacts

The following provides brief characterizations of each Level 2 category assessed for fruits and vegetables across Ontario. Close to 300 separate risk interactions were assessed for the Fruit and Vegetables Level 2 category, considering how changes in climate variables could lead to impacts on each commodity. Risk scenarios were evaluated under current and future timeframes and for the relevant provincial regions.

Table 5.6 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 5.7, at the end of this section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 5.6: Illustrative Risk Scenarios for Fruits and Vegetables Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Apples	The occurrence of spring frost conditions or temperatures dipping to below -2.2°C in the spring after apple flowers have budded can cause a 10% kill in apple production if apple buds have reached the first pink stage in the Springtime. A temperature dipping below -4.4°C at the same stage can result in a 90% kill in apple crops in a given year. Some cultivars do provide some level of protection against winter damage, such as McIntosh which is considered hardier. Gala is considered to be a moderately hardy cultivar against winter damage. For more cold tolerant species like apples, winter injury is more common at colder locations, or away from the influence of the Great Lakes – like Eastern Ontario.	**Medium**
Berries	Temperatures around 22°C to 25°C, high relative humidity, and plant surface wetness caused by rain, overhead irrigation, fog, or dew provide an ideal environment for Botrytis. Raspberry plants are susceptible during bloom and again as the fruits ripen. The direct impacts of this scenario are that impacts such as brown or black sunken lesions develop on green or ripe fruit, daughter plants die, outer leaves die prematurely, or plant collapse occurs from crown	**Low**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
	rot. Losses can exceed 50% when conditions are favorable, even on well-managed (actively managed) fields.	
Field Vegetables	Extreme Hot Days can lead to yield losses for several field vegetable crops. Yields of five vegetables in the Brassicaceae family showed some damage due to hot weather in August. For cauliflower, cabbage, and rutabaga there was roughly a 10% yield loss for every 10 days that the temperature reached 30°C or above during the growing season.	**High**
Grapes	Increasing air temperatures and frequency of heat poses the highest risk to Vitis vinifera varieties of grapes – and specifically those used in the production of ice wines in Niagara such as Riesling and Vidal varieties. Ice wines require a hard freeze (-8C or colder) after ripening. If air temperatures warm to the point where this condition is not met or a freeze does not come quickly enough, rotting will occur, and the crop will be lost. This scenario will result in the rotting, reduction, and potential for total loss in icewine production in a given harvest. For non-ice wine grape varieties, extreme heat will change the aroma, size, alcohol, and sugar concentration and thus quality of non-ice-wine production resulting in declining yields and changing grape conditions.	**High**
Greenhouse Vegetables	Lower greenhouse temperatures can increase production time and flowering time. Cold conditions slow the uptake of water and nutrients. As a result, the number of crops that can be produced in a given amount of space over the spring season decreases. Plants will take longer to flower and depending on the outdoor weather, more money could be spent heating each crop since it is in the greenhouse longer. Cold temperatures require a greater energy usage to heat greenhouses also requiring more investments.	**Low**
Tender Fruit	Drought and dry conditions impact tender fruit several different ways. It can slow and/or kill tree growth required prior to fruit, decrease fruit juiciness, lead to fruit doubling, deep suture disorder, cause fruit shriveling or internal browning, lead to reduced root growth, decrease in pollen	**Low**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
	viability and cause yield loss. Drought causing severe stress over 10 days particularly in the early season is problematic and can lead to reduced maturity and moderate yield loss. Drought occurring mid or late season has less impact on tree growth but may still lead to the same quality impacts described above.	

Apples

There are 15 main varieties of apples grown on nearly 14,000 acres in Ontario, as of 2019. The province's major apple-producing areas are along the shores of Lake Ontario, Lake Erie, Lake Huron, and Georgian Bay. In recent years, Ontario's apple crop has averaged about 0.25 million metric tonnes or 13.7 million bushels (Ontario Ministry of Agriculture, Food and Rural Affairs, 2019; 2020c). Climate impacts on apple production were assessed across Southwest, Central and Eastern Ontario. Regionally, no significant variation was found between these three regions based on current or future risks to apples at the scale of the assessment. However, risks to apples are expected to rise across all regions. Under current climate conditions, risks were determined to be 'high'. Regardless of how quickly greenhouse gas emissions are reduced (e.g. RCP4.5 or RCP8.5), risks to apples are expected to increase to 'very high' by the 2050s and stay 'very high' out until end of the century.

Based on the possible severity of consequences, current 'high' risks to apples are being driven by extreme heat, extreme precipitation, and springtime conditions, such as a late frost. These events can lead to numerous direct impacts on apples (Rochette et al., 2004). The occurrence of frost conditions or temperatures dipping to below -2.2°C after apple flowers have budded can cause a 10% kill in apple production, if apple buds have reached the first pink stage. If temperatures drop below -4.4°C at the same stage, it can result in a 90% kill in apple crops for a given growing season (Ontario Ministry of Agriculture, Food and Rural Affairs, 2013; 2017c). For many apple tree varieties, temperatures that exceed roughly 32°C can result in heat stress, reducing photosynthesis process and stunting growth (Beckerman, 2006). One adaptive measure being undertaken is the planting of new hybrid tree varieties in areas where older tree varieties could no longer withstand. Drought can also impact apples in several ways, slowing tree growth required prior to fruit, reduced root growth, fruit shriveling and ultimately yield loss.

Berries

Berries (e.g. strawberries, raspberries, and blueberries) are grown across the province, mostly around major urban centres. Other types of berries grown in the province include blackberries, currants, gooseberries and cranberries. Berry crops are generally grown on the best agricultural soils, requiring excellent drainage and high organic matter for optimum production. In 2019 Ontario berry crops were grown on 3,400 acres of land and had annual farm gate value of over $44 million (Ontario Ministry of Agriculture, Food and Rural Affairs 2017c; 2019). Climate risks were evaluated across all regions of Ontario except for the Far North. Strawberries, raspberries, blueberries, and blackberries were used to inform the characterization of possible climate risks to berry growers.

The level of current risk ('high') is being driven, in part, by extreme heat conditions and dry conditions or drought. In the future, increasing air temperatures combined with wetter conditions pose 'high' risks associated with infections and disease, that may result in more chronic challenges for berry growers (Calleja, 2011). Extreme heat for example may lead to impacts in a raspberry field, with warm to hot air temperatures and high relative humidity leading to the development of anthracnose (Ontario Ministry of Agriculture, Food and Rural Affairs, 2009). This disease could affect the fruit, flowers and petioles and cause daughter plants to die, outer leaves to die prematurely or the plant may collapse from crown rot. Risk of anthracnose may increase for berry produces, as the disease is favoured by warm temperatures (>18°C) and wet conditions. Yield losses due to the anthracnose can exceed 50% when conditions favour disease development, even in well-managed fields.

Moisture conditions for berries is critical in production for berry size, and while excessive moisture must be avoided, periods of 20 to 30 days without significant precipitation during the growing season may result in catastrophic yield losses (Bushway et al., 2008). Springtime conditions will likely become increasingly variable over time, with late spring frosts continuing to pose high risks to berries. The extent of damage to berries highly depends on the type of cultivar. For example, a late spring frost on highbush blueberries may lead to freeze injury to the fruit, dieback, and winter injury to swollen flower buds, potentially leading to upwards of 50% yield loss of crop production (Cline & Fernandez, 1998).

Field Vegetables

Field vegetables are grown on over 160,000 acres of Ontario farmland. Major field vegetables grown in Ontario include sweet corn, potatoes, green peas, tomatoes, green and wax beans, carrots, and pumpkins. Ontario field vegetables (excluding potatoes) gate value in 2019 was over $590 million (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017c; 2019). Climate risks to field vegetables were evaluated across Southwest, Central and Eastern Ontario using representative commodities, where appropriate, such as cabbage, potatoes, and tomatoes.

Significant regional differences were not found at the scale of assessment, and risks were estimated to be 'high' under current climate conditions and increase to 'very high' by the 2080s. High risks now are being driven, in part, due to springtime conditions, as well as extreme precipitations and drought.

Impacts to field vegetables are incredibly variable, and dependent on the crop grown, soil conditions and the intensity or duration of the climate event that occurs. Wetter conditions and/or extreme precipitation events (longer duration) may lead to proliferation of disease and would prevent growers from effectively distributing measures to fight those diseases (e.g. spraying). Too much rain, especially if delivered in frequent showers, causes several problems such as poor transplant conditions, increased seed and seedling disease, soil compaction, delayed or missed cultivation, and waterlogging. Extreme heat conditions may lead to reduced yield due to heat damage (Hatfield & Prueger, 2015) – with cabbage and some other crops (e.g. cauliflower, rutabaga) showing 10% yield loss for every 10 days temperatures exceeded 30°C during the growing season (Warland et al., 2006). Extreme heat can reduce fruit set of tomatoes or lessen plant development growth. Drought stress can also dominate or worsen heat stress to some field vegetables (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021e). For example, leaf area and water content of tomato cultivars, dry weight and shoots all decreased when drought conditions occurred with yield declines of between 13 to 26%, depending on flowering and fruit development stage (Zhou et al., 2017; Cui et al., 2019). Similarly, potatoes are impacted by water stress and drought due to shallow root systems, with yield loss dependent on stage of growth (e.g. less than 5% loss during vegetative growth compared to over 65% yield loss if drought occurs during tuber maturation).

Grapes

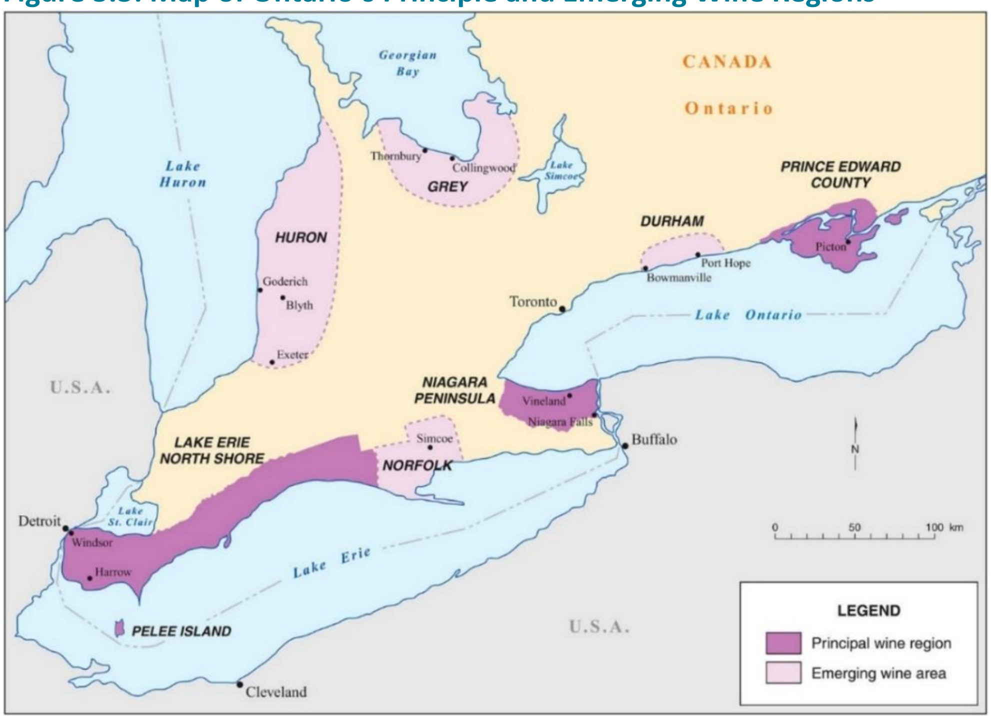
The Niagara Peninsula is the province's largest grape growing region, followed by Essex-Kent. Prince Edward County is an emerging area for grape production. Vitis vinifera types account for approximately 55% of Ontario's production and the trend is increasing each year. Ontario produces over 85% of Canada's domestic wines and the gate value of grapes in 2019 was over $112 million (Ontario Ministry of Agriculture, Food and Rural Affairs2017c; 2019). Figure 5.3 illustrates the regions where grapes are grown and aeras of emerging opportunity.

Climate risks to grapes were evaluated in both Southwest and Central Ontario, recognizing that significant local areas are present within these regions, where impacts may be felt the most. Risks to grapes were determined to be 'medium' under current climate condition but rising in both regions to 'high' by the 2050s and to 'very high' by the end of the century. Depending on how quickly greenhouse gas emissions are mitigated, risks to grapes may not rise as substantially. For example, it is only under the high emissions scenario RCP8.5 in the 2080s that risks reach a 'very high' score (see Appendix 7).

Grape production is at risk from numerous climate drivers. For example, extreme heat in the growing season may lead to higher grape sugar concentrations or reduced acidity and higher pH; thereby increasing alcohol concentration, creating excessive bitterness and flabby tastes and likelihood of spoilage (Shaw, 2016). Rising temperatures can also reduce the grape harvest window, reduce berry size, and alter aromatics. Depending upon the grape variety grown, impacts may be particularly significant. Icewine production, for example, may experience total yield loss if a hard freeze (-8°C or colder) does not occur after ripening (Hewer, 2020).

Winter injury to grapevines also poses risks to grapevines and is estimated to lead to 5 to 15% of crop loss globally each year. Spring frosts or other winter injuries can lead to extensive impacts, with single freeze events having historically caused total crop loss in some areas of Northeast U.S (Mosedale et al., 2016). Increases in seasonal precipitation or extreme precipitation, on the other hand, can lead to proliferation of diseases that prevent growers from distributing measures to fight diseases.

Figure 5.3: Map of Ontario's Principle and Emerging Wine Regions



Source: Shaw, 2016

Greenhouse Vegetables

Greenhouse vegetables in Ontario are grown on over 3,000 acres and include tomatoes, cucumbers and peppers. 2019 gate value for greenhouse vegetables was $376 million, $339 million, and $301 million for tomatoes, cucumbers, and peppers, respectively (Ontario Ministry of Agriculture, Food and Rural Affairs, 2014; 2019). Climate risks to greenhouse vegetables were assessed for Southwest, Central and Eastern Ontario given their prominence in these regions of the province. Assessment results indicate that risks to greenhouse vegetables and production now and under current climate conditions is considered ‘medium’. In the future, that score is expected to increase to ‘high’ by the 2050s and stay ‘high’ by the end of the century (2080s).

Climate risks to greenhouse vegetables were driven by three major climate variable groups: extreme precipitation, high and extreme temperatures, low temperatures, as well as general growing-related conditions. These climate drivers can lead to yield and financial losses through 1) increasing production time and flowering time such in the event of extreme cold (Ontario Ministry of Agriculture, Food and Rural Affairs, 2014), 2) increased costs to heat greenhouses, 3) increased need for temperature regulation particularly during extreme heat in the summer season (Hendricks, 2012), 4) impacts to growth and loss of vegetables in the event of extreme heat, and 5) disruption to sources and inputs required for productive growing conditions. Extreme heat, as an example, can lead to poor pollination and immature growth if temperatures are not regulated and rise above 32°C in the day or 24°C during the night (Dias et al., 2016).

Tender Fruit

Tender fruit production includes peaches and nectarines, pears, sweet and sour cherries, plums, and apricots. In 2019 tender fruit were grown on over 12,500 acres of land in Ontario. The most important tender fruit-growing area in Ontario is the Niagara Peninsula, followed by Essex and Kent counties and Lake Huron shoreline (Huron and Lambton counties). Ontario tender fruit gate value in 2019 was almost $83 million, the largest share ($27.5 million) attributed to peaches (Ontario Ministry of Agriculture, Food and Rural Affairs, 2019; Rochette et al., 2004).

Climate risks to tender fruit were evaluated across Southwest, Central and Eastern Ontario – and no significant regional differences are expected in future risk results. Risks to tender fruit are currently rated as ‘high’ and expected to stay at ‘high’ risk in all future time periods. Risks are being driven, in part from winter injury, extreme cold and spring frost conditions. As temperatures rise and these impacts become less frequent, risks remain high due to the increasing frequency of extreme heat and extreme precipitation. Additionally, increasing unpredictability of low temperature (e.g. spring frosts) is expected under a changing climate, indicating sustained risk from low temperatures.

Tender fruit production can be impacted in numerous ways (Rochette et al., 2004). A well-characterized risk to tender fruit is the occurrence of late frost after Growing Degree Days have enabled fruit flower buds to form. A late spring frost that occurs when fruit trees are in full bloom can cause up to a 90% loss in yield when temperatures dip below -5°C, for less than 1-hour in duration (SF Gates Contributor, 2021). Extreme Hot Days can cause stress to fruit trees, as well as workers, and make it challenging to complete orchard work on a timely basis (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021f). Peak injury is from noon until late afternoon each day, especially when skies are clear, although solar radiation can be high under cloudy conditions as well. Wetter conditions occurring into tender fruit harvest season have also been shown to decrease fruit sweetness. Extreme precipitation can cause physical damage to flowers, essential for pollination and the fruit formation process (Hunter & Slingerland, 2008). Drought and dry conditions can slow or kill fruit tree growth, decrease fruit juiciness, lead to fruit doubling, cause shriveling, reduced root growth and decreased pollen viability. Drought causing severe stress over 10 days, particularly in the early season is problematic and can lead to reduced maturity and moderate yield loss.

Table 5.7: Risk Scores for Fruit and Vegetables Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Fruits and Vegetables	Apples	Central Region	High	Very High	Very High
Fruits and Vegetables	Apples	Eastern Region	High	Very High	Very High
Fruits and Vegetables	Apples	Southwest Region	High	Very High	Very High
Fruits and Vegetables	Berries	Central Region	High	High	Very High
Fruits and Vegetables	Berries	Eastern Region	High	High	High
Fruits and Vegetables	Berries	Northeast Region	High	High	High
Fruits and Vegetables	Berries	Northwest Region	High	High	High
Fruits and Vegetables	Berries	Southwest Region	High	High	High
Fruits and Vegetables	Field Vegetables	Central Region	High	High	Very High

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Fruits and Vegetables	Field Vegetables	Eastern Region	**High**	**High**	**Very High**
Fruits and Vegetables	Field Vegetables	Southwest Region	**High**	**High**	**Very High**
Fruits and Vegetables	Grapes	Eastern Region	**Medium**	**High**	**Very High**
Fruits and Vegetables	Grapes	Southwest Region	**Medium**	**High**	**Very High**
Fruits and Vegetables	Greenhouse Vegetables	Central Region	**Medium**	**High**	**High**
Fruits and Vegetables	Greenhouse Vegetables	Eastern Region	**Medium**	**High**	**High**
Fruits and Vegetables	Greenhouse Vegetables	Southwest Region	**Medium**	**High**	**High**
Fruits and Vegetables	Tender Fruit	Central Region	**High**	**High**	**High**
Fruits and Vegetables	Tender Fruit	Eastern Region	**High**	**High**	**High**
Fruits and Vegetables	Tender Fruit	Southwest Region	**High**	**High**	**High**

Indirect Impacts

The following section provides several indirect impacts specifically relevant to fruit and vegetable production; however, many of the indirect impacts already described for field crops (see Section 5.7.1) are also relevant to fruit and vegetable growers (e.g. soil health, nutrients management, invasive species and pests, and water supply). It is critical to acknowledge that just because risk scoring has not been assigned for indirect impacts, it does not imply they are less impactful. In many cases, insufficient quantitative data exists to evaluate quantitative risks based upon these indirect or cascading impacts to fruits and vegetables.

Limits to water availability, notably in the context of areas that have high irrigation requirements, will lead to impacts on fruits and vegetable growers. This may be particularly exacerbated during hot summers where low flow conditions are observed, which can lead to increased proliferation or presence of pathogens after water contact and before consumption (FAO and WHO, 2021; US EPA, 2022). Climate change can affect waterborne pathogens through changes in precipitation and runoff, driving the transport of fecal waste and nutrients to waterbodies where irrigation may be sourced, as well as through changes in sunlight, air temperature and evaporation, moisture conditions, salinity, and other factors (US EPA, 2022). Historically from 1910 through 2010, climate events have been linked to the occurrence of numerous waterborne disease outbreaks – particularly due to heavy rainfall and flooding (US EPA, 2022). As an example, in Ontario, in 2000, heavy rainfall (134mm) between May 8 and 12 resulted in surface runoff containing pathogens from manure to enter a well supplying drinking water and resulted in seven deaths and 2,300 ill residents (Salvadori et al., 2009).

Not all fruit and vegetable growers may experience climate impacts to the same extent. For example, if fruit trees are impacted or damaged to the point where they are unable to produce fruit, impacts could be felt over several years rather than only be reflective of financial loss within one year. Similarly, combined weather events or prolonged drought (e.g. multi-year agricultural drought) could lead to impacts to soil quality and materials and reduce yields over a longer period of time.

Indirect impacts are also important on greenhouse production. As described earlier, greenhouse production comprises a significant portion of vegetable production across Ontario. These systems rely on critical inputs such as power supply, water supply, nutrients, and cultivated varieties, among others. If infrastructure systems (e.g. electrical distribution lines) fail due to extreme weather events or overloading during summer months, producers may be unable to regulate temperatures and conditions inside the greenhouse. This is particularly problematic during extreme heat or summer months when temperature regulation is critical for growth.

Climate change impacts on honeybee colonies and other pollinators include rising air temperatures, shifting growing seasons, extreme weather and drought which disrupt plant flowering (Cox-Foster, 2021). Increasing temperatures will create conditions when pollinator species' thermal limits are exceeded and result in range and timing shifts (Soroye et al., 2020, Sirois-Delisle & Kerr, 2018; Kerr et al., 2015). Climate change may also compound other impacts on honeybees and other pollinators. Invasive pests will drive additional use of some pesticides which remove floral resources and result in reduced reproduction, impact memory and navigation and possibly death (Aoun, 2020). Pollination, as a regulating ecosystem service, is further described and characterized in the Natural Environment Area of Focus (Section 7.0).

The noted impacts translate into significant risks for crops relying upon pollinators for healthy production. In Ontario, 32 crops such as field orchard fruit (apples, peaches, cherries), berries (blueberries, strawberries, cranberries), nuts, oilseed crops and some field crops (e.g. cucumber, tomato, pumpkin, squash, etc.) are pollinated by bees and other animals (Terpstra, 2017). Fruit and seed yields increase, and in some cases the fruit is of higher quality, when many bee species are present, whether in undisturbed ecosystems or in managed production areas (Cox-Foster, 2021). A study completed in the western U.S. (Young, 2016) found that changing climate conditions between 2011 and 2015 resulted in a five-week shift for peak plant-pollinator interactions with the result being a drop in median flower abundance of 68%. These findings reinforce the importance of cultivating a diverse set of wild bee species for agriculture, as diversity helps build resiliency to climate impacts (Young, 2016). In Ontario, many growers invest in beehive rentals to achieve better pollination and work closely with beekeepers to keep pollinators healthy (Ontario Ministry of Agriculture, Food and Rural Affairs, 2014).

5.7.3 Livestock

Overview

Livestock production in Ontario was assessed as a Level 1 category under the Food and Agriculture Area of Focus. Major types of livestock in the province include dairy and beef cattle, pigs, sheep, and poultry which are present in commercial farming operations in all regions of the province except the Far North (Statistics Canada, 2022a).

Research suggests that warmer temperatures could be beneficial for livestock production in Ontario, resulting in longer growing and grazing seasons, increased availability of quality feed throughout the year, and lower energy costs (Morand et al., 2017). The changing climate may also introduce new or accentuate existing risks to livestock production, most importantly heat stress. Different types and breeds of livestock respond differently to temperature and precipitation conditions throughout their life cycles, some exhibiting higher sensitivity, and as a result greater mortality, decreased growth and reduced fertility (Bernabucci, 2019).

This impact assessment has identified extreme temperatures, drought conditions and low temperatures as the main drivers of direct risks to livestock production, with regional differences contributing to the magnitude of risks. Risks for livestock that are predominantly raised indoors (poultry and swine) are largely driven by extreme heat and low temperatures that impact conditions in barns as well as during transportation between farms and to abattoirs. Importantly, livestock are also affected by the changing climate indirectly, through impacts on pasture, forages and water supply, as well as farm infrastructure.

Direct Impacts

The assessment has drawn on research, literature, and census data to inform scenario development and consequence scoring related to direct climate risks on livestock production. Quantitative risk scores for direct risks that were assessed for Level 2 livestock categories are discussed below for Beef, Dairy, Sheep, Swine, and Poultry and Eggs. In total, over 240 separate risk interactions were assessed, with each scenario considering how climate variables may lead to impacts on each Level 2 category. Every scenario was evaluated under current and future (2050s and 2080s) timeframes.

For ruminant livestock (beef and dairy cattle, sheep) extreme heat, low temperatures and drought are important climate variable groups driving current and future risks across the province. Wildfire is a significant risk factor in Northeastern and Northwestern regions of the province, for current and, increasingly, future time frames. For future scenarios, risks attributed to low temperatures are expected to decrease, while risks driven by extreme heat and drought conditions are anticipated to increase.

Table 5.8 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 5.9, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 5.8: Illustrative Risk Scenarios for Livestock Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Dairy	A three-day heat wave that would result in decreases in milk yields (12 kg/day per cow) and lower fertility (26% lower conception rate) impacting farm revenue and timing of operations (e.g. calving). Increased susceptibility to diseases (e.g. lameness due to long periods of not lying down, mastitis) in heat stressed cows would occur.	**High**
Beef	A heat wave lasting around three days, causing substantial levels of heat stress, with carryover effects of stress for the period after the heatwave ends. Calves as well as dark-coloured beef cattle on a high-energy diet, carrying lots of body condition, will be the first affected by heat and humidity, experiencing increased susceptibility to diseases and weight loss.	**High**
Sheep	Dry spring and early summer conditions result in soil-Moisture Deficit, lower-quality feed and pasture losses. Drought-struck sheep face limited grazing opportunities, and develop abnormal eating habits, facing malnutrition, range ketosis, low immunity, germ recrudescence, amplified effects of parasites and infectious diseases. Inability to provide adequate feed and ample water to	**Medium**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
	sheep leads to premature selling/culling of animals and decreases in farm cash receipts.	
Swine	Transporting pigs in poorly ventilated trucks over large distances on summer days, with air temperature over 26°C, would result in heat stress in sows and finishers, reducing meat quality and causing animal losses on arrival and in transit.	**High**
Poultry and eggs	High air temperatures (over 27°C), lasting three to seven days. Egg farmers can expect to see a one percent drop in production for every one-degree increase in temperature above the optimal temperature of 23°C. For every degree above 24°C a drop of one percentage point in production can be expected in breeders and the hens will never fully recover. Broilers, particularly older, heavier ones, will experience over 30% decreases in daily weight gain. Production will usually stay one or two per cent below normal after heat stress. Increases in susceptibility to disease will be present in all poultry types.	**Medium**

Dairy

Dairy cattle in Ontario are raised on nearly 3,800 farms engaged in breeding, raising, and handling of dairy calves, heifers and cows (Statistics Canada, 2022b). The total number of dairy cattle in the province is over 485,000 animals (Statistics Canada, 2022b). Dairy products generate close to $2 billion in market receipts and are Ontario's top agricultural commodity (Ontario Ministry of Agriculture, Food and Rural Affairs, 2016d). Similar to beef cattle, the majority of beef farms are located in the Southwest region, followed by Eastern, Central, Northeast and Northwest regions (Statistics Canada, 2022b).

Extreme heat has been identified as the most relevant climate variable for dairy cows in Ontario. Dairy cows are particularly sensitive to high air temperatures due to additional metabolic heat generated during lactation. Exposure to heat over 32°C results in heat stress causing impacts such as reduced feed intake, lower milk yields (12 kg/day per cow), and reproductive problems (e.g. 26% lower conception rate), impacting farm revenue and timing of operations such as calving (West et al., 2003; Campos and Schenkel, 2017). Additionally, heat stress compromises cows' immune systems, making them vulnerable to disease, while extreme levels of heat stress result in an increased likelihood of mortality (27% greater mortality rate compared to a period with no heat stress) (Bishop-Williams et al., 2015). Carryover effects of stress are known to persist even after the heatwave ends.

Risk to dairy cattle is found to increase from 'medium' at present to 'high' by the 2050s and remain at that level in 2080s (operating under RCP8.5), in Southwest, Central and Eastern regions. In Northeast and Northwest Ontario risk to dairy cattle is 'medium' at present and in the middle of the century, increasing to 'high' by the 2080s.

Beef

Beef cattle in Ontario are raised on over 12,500 farms including nearly 8,000 cow-calf and feedlot operations engaged in breeding and handling of over 1.1 million beef cattle (Statistics Canada, 2022b). Farm gate sales revenue of Ontario's beef industry is almost $1.4 billion, with processing and retail revenue of $3.5 and $9 billion, respectively (Beef Farmers of Ontario, 2018). The majority of beef farms are located in the Southwestern region, followed by Eastern, Central, Northeastern and Northwestern regions (Statistics Canada, 2022b).

In this assessment high and extreme temperatures have been identified as one of the key hazards for beef cattle. Extreme heat results in heat stress and leads to reduced feed intake and compromised weight gains, changes in grazing patterns, increased water intake, higher respiration and heart rates, and causes illness and, in severe cases, even death in beef cattle (Brown-Brandl, 2018). Other consequences of heat stress include reduced productivity and fertility, lower birth weight and compromised immune systems (Macey et al., 2009). Prolonged heatwaves, particularly early in the summer season, before cattle have had a chance to acclimate to hot conditions are especially impactful. Quantification of effects is complicated by breed differences and other factors, with calves, animals with dark hides (e.g. Angus cattle), compromised immune systems, more fat cover being the most vulnerable, especially in cases when adequate feeding, hygiene and housing requirements are not fully satisfied (National Farm Animal Care Council, 2013a).

Overall risk to beef cattle is found to increase from 'medium' at present to 'high' by the 2050s and remain at that level in 2080s (operating under RCP8.5), in Southwest, Central and Eastern regions, with consistent 'medium' level of risk in Northeast and Northwest Ontario throughout the century.

Sheep

Ontario's 322,000 sheep are raised on nearly 2,800 farms, representing sheep, lamb and wool industries (Statistics Canada, 2022c). The largest number of sheep farms are located in Southwestern Ontario (predominantly in Grey, Bruce, Huron and Wellington counties). Farm cash receipts for Ontario's sheep sector were $73.7 million in 2016, coming from meat and wool sales (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017b).

In this assessment prolonged drought conditions over the growing season are the key climate driver for grazing sheep in Ontario. Dry spring and early summer conditions result in soil-

Moisture Deficit, lower-quality feed and pasture losses (Ontario Ministry of Agriculture, Food and Rural Affairs, 2016b). Drought-struck sheep face limited grazing opportunities, and develop abnormal eating habits, facing malnutrition, low immunity, germ recrudescence, and amplified effects of parasites and infectious diseases (Court, 2007). Inability to provide adequate feed and ample water to sheep can lead to buying over-priced feed or culling or prematurely selling livestock at low prices (Ding et al., 2011). Regions with low water-holding capacity soils are particularly vulnerable to drought, with long-lasting multi-year impacts and increased costs for sheep farmers.

Sheep are very resilient and can thrive in different climate and weather conditions, provided adequate heat and cold abatement measures are in place (National Farm Animal Care Council, 2013b). Climate-related risk for sheep is found to be ‘medium’ at present and expected to remain at that level in the 2050s and 2080s (operating under RCP8.5), in all regions.

Swine

The swine sector in Ontario includes farming operations engaged in breeding and handling of pigs. In 2021 there were over four million pigs managed on 2,437 farms, with the annual number of marketed pigs of over 5,400,000 (Statistics Canada, 2022d). Southwest Ontario (primarily Perth, Huron and Wellington/Dufferin and Oxford counties) is the center of Ontario’s swine industry, both in terms of the number of farms and the number of animals raised. Farm cash receipts for Ontario’s swine sector were $1.12 billion in 2016 (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017b).

In this assessment high and extreme temperatures have been identified as one of the key hazards for swine. Pigs have the lowest heat tolerance compared to other livestock (with comfortable range between 18°C and 24°C), therefore the impacts of high air temperatures are very pronounced, both in indoor and outdoor farming systems (Ross et al., 2015). Impacts of heat stress on pigs depend on their age, weight and genetics and include compromised production efficiency (especially in high-yielding breeds), reduced and inconsistent growth, decreased feed efficiency, poor sow performance, and increased mortality (Mayorga et al., 2019). Most pigs in Ontario are raised in indoor operations and face adverse weather conditions directly during transportation to new facilities or for slaughter. Transportation on days with high air temperatures (over 26°C) can result in high levels of heat stress, animal fatigue, elevated heart rates, reduced meat quality, injuries and death (Brockhoff et al., 2018; Rioja-Lang et al., 2019).

Risk to swine is found to increase from ‘medium’ at present to ‘high’ by the 2050s and remain at that level in 2080s (operating under RCP8.5), in Southwest, Central and Eastern regions. In Northeast and Northwest Ontario risk to swine is ‘medium’ at present and in the middle of the century, increasing to ‘high’ by the 2080s.

Poultry and Eggs

The poultry and eggs sector in Ontario includes farming operations engaged in breeding and handling of chickens, ducks, turkeys and gamebirds. Chickens and ducks can be a source of eggs, meat or both; turkeys and gamebirds are raised for meat. In 2021 there were over 53,800,000 chickens (laying hens, pullets, broilers and roasters) and 2,453,000 turkeys managed on 8,051 and 1,816 farms, respectively (Statistics Canada, 2022e). Farm cash receipts for Ontario's poultry sector (chicken, eggs and turkeys) were over $1.6 billion in 2019 (Ontario Ministry of Agriculture, Food and Rural Affairs, 2017b).

In this assessment high and extreme temperatures have been identified as one of the key hazards for poultry. Hot weather conditions have significant impacts on poultry, including reduced growth, egg production and size, and shell density (Saeed et al., 2019; Ward et al., 2020). Birds experiencing heat stress have increased susceptibility to diseases, repressed reproduction, decreased hatchability of embryos, hormonal imbalance and tissue damage, with severe heat stress leading to high mortality rates (Kinsley, 2008). Temperatures over 27°C and especially 30°C are particularly harmful to poultry stock, with heat-related impacts exacerbated by high humidity and other environmental factors such as increased bird density, feed and/or water deprivation, inadequate ventilation, vaccine reaction and the presence of diseases or parasites (National Farm Animal Care Council, 2016; 2017).

Risk to poultry and eggs is found to increase from 'medium' at present to 'high' by the 2050s and remain at that level in 2080s (operating under RCP8.5), in Southwest, Central and Eastern regions. In Northeast and Northwest Ontario risk to poultry and eggs is 'medium' at present and in the middle of the century, increasing to 'high' by the 2080s (see Table 5.9).

Table 5.9: Risk Scores for Livestock Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Livestock	Dairy	Central Region	Medium	High	High
Livestock	Dairy	Eastern Region	Medium	High	High
Livestock	Dairy	Northeast Region	Medium	Medium	High
Livestock	Dairy	Northwest Region	Medium	Medium	High
Livestock	Dairy	Southwest Region	Medium	High	High
Livestock	Beef	Central Region	Medium	High	High

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Livestock	Beef	Eastern Region	**Medium**	**High**	**High**
Livestock	Beef	Northeast Region	**Medium**	**Medium**	**Medium**
Livestock	Beef	Northwest Region	**Medium**	**Medium**	**Medium**
Livestock	Beef	Southwest Region	**Medium**	**High**	**High**
Livestock	Sheep	Central Region	**Medium**	**Medium**	**Medium**
Livestock	Sheep	Eastern Region	**Medium**	**Medium**	**Medium**
Livestock	Sheep	Northeast Region	**Medium**	**Medium**	**Medium**
Livestock	Sheep	Northwest Region	**Medium**	**Medium**	**Medium**
Livestock	Sheep	Southwest Region	**Medium**	**Medium**	**Medium**
Livestock	Swine	Central Region	**Medium**	**High**	**High**
Livestock	Swine	Eastern Region	**Medium**	**High**	**High**
Livestock	Swine	Northeast Region	**Medium**	**Medium**	**High**
Livestock	Swine	Northwest Region	**Medium**	**Medium**	**High**
Livestock	Swine	Southwest Region	**Medium**	**High**	**High**
Livestock	Poultry and eggs	Central Region	**Medium**	**High**	**High**
Livestock	Poultry and eggs	Eastern Region	**Medium**	**High**	**High**
Livestock	Poultry and eggs	Northeast Region	**Medium**	**Medium**	**High**
Livestock	Poultry and eggs	Northwest Region	**Medium**	**Medium**	**High**
Livestock	Poultry and eggs	Southwest Region	**Medium**	**HIgh**	**High**

Indirect Impacts

Risk scores in Table 5.9 are attributed to direct impacts discussed above and do not reflect indirect effects associated with climate change impacts on field crops, soil health, water quality and quantity, and damage to critical farm and rural infrastructure. Consequently, it is important to be aware of a certain degree of underestimation in Level 2 risks and consider additional climate-related pressures to livestock production, as discussed below.

It is recognized that the impacts of climate change on water quality and supply will have distinct effects on livestock production through changes in water availability for livestock watering, evaporative cooling, and hygiene maintenance (Ding et al., 2011). Extreme rainfall events and terrestrial run-off from surrounding agricultural lands can increase sources of contamination in adjacent and downstream watersheds, including ones used by grazing livestock for drinking.

Drought and extreme heat can contribute to decreased water availability, in part due to competition with other sector and industry uses (Thornton et al., 2009).

Feedstock quality and quantity affected by extreme temperature and precipitation events, drought and wildfire can lead to animal health and welfare concerns for grazing animals as well as livestock housed indoors (Ontario Ministry of Agriculture, Food and Rural Affairs, 2016a; 2016b). Declining pasture productivity as a result of drought conditions can lead to lowered immunity, ingestion of poisonous plants, dirt and sand by grazing animals (Rojas-Downing et al., 2017). Extreme precipitation can result in overly wet pastures or flooding, impacting grass growth and available grazing areas for cattle and sheep (Kyle, 2016). Increased temperature and moisture availability can impact the quality of feed crops and forages through variations in concentrations of water-soluble carbohydrates and nitrogen (Rojas-Downing et al., 2017), reducing digestibility and decreased nutrient availability for livestock swine (Thornton et al., 2009; Polley et al, 2013). This in turn would result in lower weight gains, decreased fertility and milk production in ruminants and.

Climate change, particularly higher temperatures and increases in precipitation variability affect the distribution and amplify the effects of parasites and infectious diseases in livestock (Rojas-Downing et al., 2017). Higher temperatures and increased humidity increase the rate of development of parasites and pathogens (e.g. listeria and salmonella), while flooding often provides favourable conditions for the development of water-borne diseases (CIAT, 2014). Changes in rainfall and temperature regimes as well as the frequency of extreme events may affect both the distribution and the abundance of disease vectors such as flies, ticks and mosquitoes (CIAT, 2014). Impacts to livestock health by spreading parasites, pathogens and diseases are particularly significant in extreme heat, drought and flooding conditions, all of which contribute to lowered immunity and increased susceptibility to disease (Martin and Noecker, 2006; Schoenian, 2018).

Heavy precipitation and other extreme events cause concerns to the livestock sector due to their impacts on electricity supply and transportation infrastructure. Power outages are a serious issue due to disruptions in electricity supply for critical purposes such as maintaining temperature in barns, milking equipment operation and more (Chang et al., 2007). Additionally, the ability to transport livestock to farms, abattoirs and other facilities can be inhibited due to impacts of extreme weather events to transportation infrastructure, resulting in animal distress and financial losses to producers.

5.8 Climate Change Opportunities

Within this assessment, no Level 1 or 2 risk scores within Food and Agriculture decreased under a changing climate. In other words, climate interactions with increasing risk scores (e.g.

extreme heat) outweighed any interaction that exhibited stable or declining risk scores (e.g. extreme cold) under this Area of Focus. In addition, the PCCIA Methodology Framework (External Resource – 1) adopts an approach of assessing the 'Most-Probable Worst-Case Event' for each interaction, meaning that potential opportunities or benefits within the sector may be understated within the quantitative assessment, as noted below.

Research indicates that the influence of a changing climate may have certain benefits for agricultural production in Ontario. Increased growing season length and available heat units have been found to present opportunity for not only regional expansion, but also for commodity types grown across Ontario. Warming temperatures may enable new and higher-yielding varieties to be grown across the province, where historical or current climate conditions have not been suitable (Qian et al., 2018; 2019; He et al., 2018). The caveat with earlier planting dates is that there may be an increased risk related to crop damage, failure and losses associated with unpredictable late frost events. As noted throughout Section 5.0, lengthened growing seasons and changing moisture patterns can increase the frequency and prevalence of pest and disease outbreaks for several commodity types (Baute, 2020; Ontario Ministry of Agriculture, Food and Rural Affairs, 2020b). Therefore, the potential favourable conditions associated with extended growing seasons and available heat units in Ontario are accompanied by considerable risks and potential losses.

Northern expansion of agricultural production is another potential opportunity associated with a warming climate and is well documented throughout literature (Ontario Ministry of Agriculture, Food and Rural Affairs,2021d; Robinson et al., 2020; Morand et al., 2017). Several studies in Ontario have found that climate change could present opportunities for the sector through longer growing seasons, increasing Growing Degree Days and available crop heat units (Morand et al., 2017; Qian et al., 2019). Crop production in northern regions of the province has previously been constrained by land suitability, inadequate drainage, and climate conditions. With increasing annual temperatures and available crop heat units, some northern regions of the province may experience opportunities related to agricultural expansion. Specifically, warming climate conditions have been projected to increase agricultural productivity across the Great Clay Belt in the Northeast region of Ontario (Robinson et al., 2020; Apostoli, 2021; Ontario Ministry of Agriculture, Food and Rural Affairs, 2021d). However, several socio-economic related barriers (e.g. infrastructure requirements, market access, policy and financial support, labour supply, low diversity in commodities etc.) have been identified as impeding expected agricultural expansion in the northern regions of the province (Apostoli, 2021; Chapagain, 2017). If capacity increases across northern Ontario (e.g. investment in infrastructure, tile drainage etc.), existing barriers may be overcome, and northern regions may experience opportunities related to lengthened growing seasons and increased commodity diversity (Apostoli, 2021; Chapagain, 2017).

5.9 Adaptive Capacity

5.9.1 Adaptive Capacity Summary

While Ontario's food and agricultural sector is intrinsically adaptive, changing climate conditions are challenging the sector's ability to adapt to emerging and intensified climate impacts and risks. Adaptive Capacity for the Food and Agriculture Area of Focus was evaluated across four over-arching categories: 1) technology 2) availability of resources, 3) governance measures, and 4) sector complexity (see Section 2.4.4 for definitions).

Overall, the Adaptive Capacity for each Level 1 category across the Food and Agriculture Area of Focus is rated as 'medium' (see Table 5.10). Building Adaptive Capacity across the four over-arching categories will help to strengthen the sector's ability to adjust and respond to changing conditions over time.

Table 5.10: Food and Agriculture Level 1 Category Adaptive Capacity Ratings[6]

Level 1 Category	Technology	Resource Availability	Governance	Sector Complexity	Overall Adaptive Capacity Rating
Field Crops	High	Medium	Medium	Low	**Medium**
Fruits and Vegetables	High	Medium	Medium	Low	**Medium**
Livestock	High	Medium	Medium	Low	**Medium**

5.9.2 Technology

Adaptive Capacity within the Technology category is rated as 'high' across all Level 1 categories. The agricultural sector is known for adopting new technologies to assist with production and productivity. For example, technological advancements in the sector include GPS guidance and drone technology, advanced drainage and irrigation systems, and precision machinery and technologies (Eyzaguirre and Warren, 2014; Dias et al., 2016). Additionally, crop and livestock genetic research and diversification is another technological advancement that can build significant capacity to address future climate-related impacts (Rojas-Downing et al., 2017; National Farm Animal Care Council, 2013a).

[6] Note these scores do not consider geographic location within the province. Please see Appendix 11 for regional Adaptive Capacity ratings.

The technology category of Adaptive Capacity also includes sectoral best practices and planning. On-farm infrastructure, technology and best practices influence the capacity of individual operations a significant amount. Producers implement adaptive measures regularly and seek new technologies to better manage on-site climate risks. These include irrigation and drainage optimization systems, water metering, soil conservation practices (e.g. tillage practices, crop rotation, cover cropping etc.), pest management practices (fertilizer and pesticide applications, scouting etc.), adaptive management (e.g. adjusting the timing of cropping operations etc.), and the selection of resilient cultivars and species (e.g. considering potential changes in lodging, disease and pest resistance, drought tolerance etc.) (Reid et al., 2007; Comer et al., 2017).

It should be noted that some of the technological adaptations may require significant improvements of infrastructure, such as greenhouse facilities, water sourcing and energy systems. These improvements have time and cost implications for shared and province-wide delivery of key infrastructure and equipment.

5.9.3 Resource Availability

Human, financial, and natural resources available to Ontario's agriculture producers are an important component of Adaptive Capacity. Resource Availability is ranked at a 'medium' Adaptive Capacity across this Area of Focus. From a financial resource perspective, the Canadian Agricultural Partnership (CAP) is a five-year (2018 – 2023), $3 billion investment program by federal, provincial, and territorial (FPT) governments that is a significant financial support mechanism used to strengthen and grow agricultural and agri-food sector. Although the CAP does not offer dedicated funding for adaptation actions, it includes climate change as one of its six priority areas at the national level, with opportunities of covering costs for research initiatives and programs around building climate resilience across the sector (Government of Canada, 2018; Ontario Ministry of Agriculture, Food and Rural Affairs, 2022a). Additionally, Agricorp, an agency of the Government of Ontario, delivers several business risk management programs (e.g. AgriStability), to support Ontario's agriculture producers by offsetting financial losses and protecting producers from large margin declines caused by any combination of production losses, adverse market conditions, or increased production costs (ArgiCorp, 2020).

The Canada-Ontario Environmental Farm Plan program is another resource available to farmers to offer guidance (though no financial assistance) to complete risk assessments and develop and implement action plans for addressing environmental issues relevant to their farms (Ontario Ministry of Agriculture, Food and Rural Affairs, 2022b).

On-farm financial adaptation strategies, to an extent, have been identified, such as carrying reserves (e.g. planning for bad years in advance by stocking away funds during good years), and diversifying revenues and taking advantage of on-farm tourism or farmer's markets in urban and semi-urban communities (Brklacich & Woodrow, 2016; OCCIAR, 2011). Nevertheless, financial limitations have been cited as a barrier to adaptation in Ontario and the ability of farmers to Invest in new technology or to re-tool for switching production or commodities in support of adaptive efforts (Wall et al., 2007; Reid et al., 2007).

From a human resources standpoint, the average number of farmers and labour supply has been declining in Ontario over recent years (Apostoli, 2021; Brklacich and Woodrow, 2016). Labour shortages, limited expertise, and low interest in agriculture education are cited as major social barriers for the sector (Apostoli, 2021; Chapagain, 2017). To support growth and build skills and expertise across the sector, OMAFRA offers workshops, resources, and e-Learning opportunities at no cost for the agri-food and agri-products sectors on a number of important best management practices and issues (e.g. growing farm profits, biosecurity, food safety) (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021b).

Natural resources and related ecosystem services (e.g. flood and erosion control, water filtering etc.), play a vital role in agriculture operations and productivity. Increased protection and conservation of ecosystems, especially in southern regions of the province with increasing urban development pressures, is imperative for increasing capacity across farming infrastructure, technology, and operations to better cope with emerging climate risks (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021b; Harris et al., 2016).

5.9.4 Governance

Governance was rated at a 'medium' capacity level across the three Level 1 categories of this Area of Focus. Several governance mechanisms, policies and institutions exist to support agricultural production in Ontario. Climate adaptation activities include long-term planning for potential water shortages, monitoring and surveillance programs for emerging crop and animal diseases and pests, supporting research into business risk management approaches, and enabling demand-driven knowledge transformation and transfer (KTT) through synthesis, exchange, dissemination, dialogue, collaboration and brokering among researchers and farmers (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021c).

Ontario Ministry of Agriculture, Food and Rural Affairs (Ontario Ministry of Agriculture, Food and Rural Affairs) has funded several climate change related research projects in Ontario and provides online resources on how climate change may impact the agricultural sector (Ontario Agri-Food Innovation Alliance, 2022). Additionally, the Ontario Federation of Agriculture (OFA) has taken an official position on climate change, recognizing its impacts and the urgency for policies and programs to enable effective adaptation (OFA, 2020). Depending upon the region, various policies and programs exist that could enable adaptation measures, such as Conservation Authorities' rural water quality programs and land protection designations. However, competing land-use priorities, particularly in the high-density regions of the province (e.g. Central and Southwest regions) present capacity constraints for the agriculture sector. Other important actions under governance include conducting regional-wide risk and opportunity assessments and developing regional scale adaptation plans (Belliveau, et al., 2006).

It is important to acknowledge that further cooperation and coordination between levels of government and institutions is required to advance adaptation efforts from the planning phases to implementation. Increased uptake and support of adaptation measures is required to build widespread climate resilience across field crop, fruit and vegetable and livestock producers in Ontario. Advancing the understanding of farmers' perceptions and integrating them in policy development could help to further improve widespread adaptation efforts across the sector. In addition, a comprehensive view of costs, time, and effort associated with adaptation required from the producer should be included to supportive policy frameworks to maintain sustainable production systems (Comer et al., 2017; Morand et al., 2017; Reid et al., 2007).

5.9.5 Sector Complexity

The final category of Adaptive Capacity assessed for this Area of Focus was Sector Complexity. This category was rated at a 'low' capacity level across all three Level 1 categories. Ontario's agriculture sector involves several key players and is influenced by complex external and internal forces. Commodity prices, financial markets, available technologies, health and safety regulations and institutional support all contribute to adaptation decisions and affect overall Adaptive Capacity (ArgiCorp, 2019). There are different levels of control over certain adaptations with some available for implementation at the decision of a single operator, and others being shaped by multiple stakeholders in farming, government and elsewhere (Belliveau, et al., 2006; Red et al., 2007; Comer et al., 2017). The sector is highly complex, resulting in a 'low' Adaptive Capacity ranking across all Level 1 categories under this Area of Focus.

5.10 Climate Adaptation Priorities

Within the PCCIA, current and emerging adaptation priorities with a relatively higher risk, and lower Adaptive Capacity were identified for each Area of Focus. In the context of the PCCIA, an adaptation priority is defined as any Level 1 or 2 category in a given region that has an Adaptive Capacity of 'medium' or lower and a risk score of 'high' or greater (see Appendix 12 for combined Level 1 and regional Adaptive Capacity ratings).

Each of the three Level 1 categories included under this Area of Focus have a 'medium' Adaptive Capacity, based upon considerations for technology, resource availability, governance, and sector complexity. When combining this with the regional Adaptive Capacity ratings, Central, Northeast and Northwest regions are found to have the greatest capacity constraints. This section provides further details on current and emerging adaptation priorities for the Food and Agriculture Area of Focus, considering levels of capacity and current and future risk scores.

Current Adaptation Priorities

There are a number of adaptation priorities that emerged for the current timeframe that relate to Level 1 and 2 categories of 'high risk' with corresponding 'medium' levels of Adaptive Capacity. The regional priorities are driven mainly by variances in regional Adaptive Capacity and the existing coverage of Level 2 commodities relative to each region. The current climate resilience priorities are summarized in Table 5.11.

Table 5.11: Current Food and Agriculture Adaptation Priorities

Current Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[7]
Soybeans	Central, Northeast	**High**	**Medium**
Corn	Central, Northeast	**High**	**Medium**
Apples	Central	**High**	**Medium**
Berries	Central, Northeast, Northwest	**High**	**Medium**
Field Vegetables	Central	**High**	**Medium**
Tender Fruit	Central	**High**	**Medium**

Based on the results of current risk and Adaptive Capacity (by Level 1 and region), several field crops and fruit and vegetable Level 2 commodities are identified as current resilience priorities. The high risk ranking across these Level 2 categories are driven by production losses associated with Extreme Hot Days, Degree Days <0°C (low temperature), Moisture Deficit and Extreme Precipitation Events (shorter term).

[7] See Appendix 12 for combined Adaptive Capacity ratings and associated scoring matrix.

Emerging Adaptation Priorities

Looking into the future, there are a number of emerging priorities under this Area of Focus by mid-century (see Table 5.12). These include the remaining field crop commodities (cereals, canola and forages) and greenhouse vegetables are considered to be emerging adaptation priorities for mid-century. In addition, livestock Level 2 categories, including beef, dairy, poultry and eggs, and swine are also emerging priorities in Central Ontario, with risk scores in Northeast and Northwest remaining as 'medium' in the 2050s. Grapes under the Fruit and Vegetables Level 1 category is not considered an emerging adaptation priority based on the capacity associated with the regions it was assessed for (Southwest and Eastern) (see Appendix 11 and 12 for regional and combined Adaptive Capacity ratings). The final Level 2 category under this Area of Focus, that is not considered a current or emerging adaptation priority is sheep production. This Level 2 category is relatively resilient to current and changing climate conditions, resulting in lower associated risks.

Table 5.12: Emerging Food and Agriculture Adaptation Priorities by Mid-Century (RCP8.5)

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[8]
Cereals	Central, Northeast, Northwest	**High**	**Medium**
Forages	Central, Northeast, Northwest	**High**	**Medium**
Canola	Central, Northeast	**High**	**Medium**
Greenhouse Vegetables	Central	**High**	**Medium**
Beef	Central	**High**	**Medium**
Dairy	Central	**High**	**Medium**
Poultry and eggs	Central	**High**	**Medium**
Swine	Central	**High**	**Medium**

[8] See Appendix 12 for combined Adaptive Capacity ratings and associated scoring matrix.

Advancing Adaptation

On-farm capacity plays a major role in the resilience of these field crop, fruit and vegetable and livestock Level 2 categories. The following on-farm practices can significantly increase on-farm capacity to respond to, and cope with climate-related risks:

- Selection of cultivars with resistance and tolerance to extreme climate conditions (e.g. drought conditions)
- Participating in production insurance programs where available (e.g. Agricorp)
- Growing more than one variety to help spread crop failure risk
- Disease and pest management practices (e.g. scouting; herbicide and fertilizer applications)
- Covering crops and no-till for soil health and conservation practices
- Tile drainage and controlled tile drainage
- Crop and pasture rotation
- Increase implementation of irrigation, fertilizer, pesticides, or fungicides
- Physical barriers (e.g. wind breaks, buffer strips)
- Retrofitting facilities and infrastructure (e.g. capacity of in barns, storage buildings)
- Changes in planting or harvesting dates, and proper monitoring and adaptive management techniques

With increasing climate risks to agriculture production, coupled with increased growth and intensification projected for Ontario, urban farming systems have been identified as an opportunity to increase productivity, support food security, minimize land requirements and increase climate resilience. Research on urban gardens (e.g. container, community, and rooftop) and vertical agricultural in southern Ontario has been advancing in recent years, where solutions for future food production can be demonstrated through utilizing urban spaces for producing various types of commodities (Durham Region, 2021; Waterloo Region, 2020; City of Toronto, 2012; TRCA, 2020).

Vertical farming is on the rise in Ontario, with six vertical farms operating in the province, making up half of vertical farm operations in Canada (Greenbelt Foundation, 2020). Vertical farming offers controlled climate conditions, biosecurity, pest protection and reduced input requirements for food production in the future (Benke and Tomkins, 2017). However, it should be noted that greenhouse food production is still at risk from climate change (as described in Section 5.7.2). The energy supply required for vertical farming operations is significant and could have maladaptive outcomes if energy sources are carbon intensive (e.g. the expansion of operations could result in increased greenhouse gas emissions). Research is still emerging on vertical farming, with a better understanding of regulatory frameworks required to support expansion in Ontario (Greenbelt Foundation, 2020). Overall, the expansion of urban or vertical farming operations cannot begin to substitute existing agricultural production outputs across the province, highlighting the requirement for on-farm adaptation practices and supporting measures.

The PCCIA Adaptation Best Practices (ABP) Report (External Resource – 2) includes adaptation options for food and agriculture, based on the identified adaptation priorities. A high-level summary is provided in Table 5.13. The PCCIA ABP Report provides more detail on specific adaptation practices that can be taken to build capacity across Level 1 and 2 categories.

Table 5.13: Adaptation Options for the Food and Agriculture Area of Focus

Adaptation Category	Examples of Adaptation Measures
Projects or Programs	- Strengthen monitoring and surveillance programs for pest and disease management. - Expand decision support tools for on-farm water, soil and nutrient management. - Enable demand-driven knowledge transformation and transfer through collaboration between researchers and farmers.
Research and Development	- Support and advance research on agricultural expansion opportunities under a changing climate. - Research and development on new and climate-resilient varieties/breeds and livestock nutrition regimes. - Support technological research and advancements on precision agriculture, advance drainage and irrigation systems.
Investment and Incentives	- Support and advance research on agricultural expansion opportunities under a changing climate. - Research and development on new and climate-resilient varieties/breeds and livestock nutrition regimes. - Support technological research and advancements on precision agriculture, advance drainage and irrigation systems.
Policy and Regulation	- Support and advance research on agricultural expansion opportunities under a changing climate. - Research and development on new and climate-resilient varieties/breeds and livestock nutrition regimes. - Support technological research and advancements on precision agriculture, advance drainage and irrigation systems.

6.0 Infrastructure Area of Focus

6.1 Overview

In recent years, Ontario has experienced the impact of infrastructure failures related to extreme weather and changing climate conditions. It has become clear that climate-related impacts on infrastructure are complex, with interdependencies existing between and across different infrastructure systems, including transportation, energy, water, and telecommunications.

This impact assessment finds that all infrastructure across Ontario face climate risk. In fact, not a single asset included in this assessment is considered to have a risk less than 'medium' under current climate conditions. In many regions and for several Level 1 and 2 categories, the level of risk is expected to rise in the future (see Table 6.1). These results can be used as a foundation for informing adaptation efforts made to improve the resilience of infrastructure assets across Ontario and help mitigate the identified climate risks and the associated cascading impacts.

Table 6.1: Summary of Climate Risks to Infrastructure (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Most at Risk Regions Abbreviations[9]	
FN - Far North	E - Eastern
NE - Northeast	C- Central
NW - Northwest	SW - Southwest

Infrastructure Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Buildings	Medium	High	High	SW, FN
Pipeline Transportation	Medium	Medium	Medium	All
Stormwater Management	High	High	High	All
Transportation	Medium	High	High	C, E, SW, NE, NW
Utilities	Medium	High	High	All
Waste Management	Medium	Medium	High	C, E, SW, NE, NW

[9] 'Most at risk regions' are those that display highest risk scores operating under RCP8.5. For more details on regional risk breakdown by Level 1 category, see Appendix 9.

In addition, the interconnectedness of Ontario's infrastructure sector with economic and social systems introduces a layer of complexity that was not quantitatively assessed or reflected in the risk profiles for infrastructure. This is crucial to consider when reviewing the results, as there are known interdependencies and numerous indirect and cascading impacts that can occur within, between and outside of Ontario's infrastructure systems that exacerbate climate risks.

6.2 Ontario's Infrastructure

Ontario's infrastructure underpins people's ability to live, work, play, and remain connected within and outside of the province. Ontario's infrastructure is significant to both Ontario and Canada. According to the Financial Accountability Office of Ontario (FAO), the Government of Ontario owns an estimated 38% of public infrastructure across the province, municipalities own 52%, and the Federal Government owns 10 % (Financial Accountability Office of Ontario, 2020). This report estimates that municipal-owned infrastructure has a current replacement value[10] of $484.2 billion, with roads, bridges, water, storm and wastewater infrastructure accounting for approximately 82%. Provincial-owned infrastructure across Ontario has a current replacement value of $265.6 billion, with highways, bridges, schools, and hospitals accounting or approximately 80% (Financial Accountability Office of Ontario, 2020)[11].

Through an evaluation of the condition of close to 90% of assets in Ontario, it is estimated that approximately 34.7% of provincial assets and 45.3 % of municipal assets are not in a good state of repair (Financial Accountability Office of Ontario, 2020; 2021a). As such, the Financial Accountability Office of Ontario (FAO) estimated the cost to bring Ontario's assets into a state of good repair (infrastructure backlog) to be $16.8 billion for provincial assets and $52.1 billion for municipal assets. However, there is uncertainty about the precise condition of many municipal assets. The FAO estimates that the municipal infrastructure backlog could range from $45 billion to $59 billion (Financial Accountability Office of Ontario, 2021a).

In 2022, Statistics Canada estimated that Ontario holds approximately 33% of all of Canada's infrastructure assets (Statistics Canada, 2022f). Of this amount, the top three largest industries in terms of asset dollars include Institutional Buildings, Transportation Infrastructure, and Electrical Power Infrastructure, together accounting for approximately 70% of the total assets (Statistics Canada, 2022f).

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[10] A measure of the cost of rebuilding assets with an equivalent capacity, functionality, and performance.

[11] It should be noted that the FAO does not include details on infrastructure assets that are not entirely owned by the Province or municipalities and as such does not include certain assets, such as energy infrastructure. Consequently, the noted report does not include all critical infrastructure systems.

Future investments in infrastructure are a key component of the Government of Ontario's 2022 Fall Economic Statement, with $159.3 billion in planned investments for the 2022-2032 Capital Plan (Government of Ontario, 2022a). Specific investments for specific infrastructure systems include:

- Transportation:
    - $25.1 billion for highway expansion and rehabilitation
    - $61.6 billion for public transportation, including subway, train, streetcar travel
- Buildings:
    - $40 billion for hospital infrastructure
    - $6 billion for postsecondary institutions (universities, colleges, Indigenous institutes)
    - $21 billion for school infrastructure and childcare facilities
- Telecommunications:
    - $4 billion for high-speed internet infrastructure

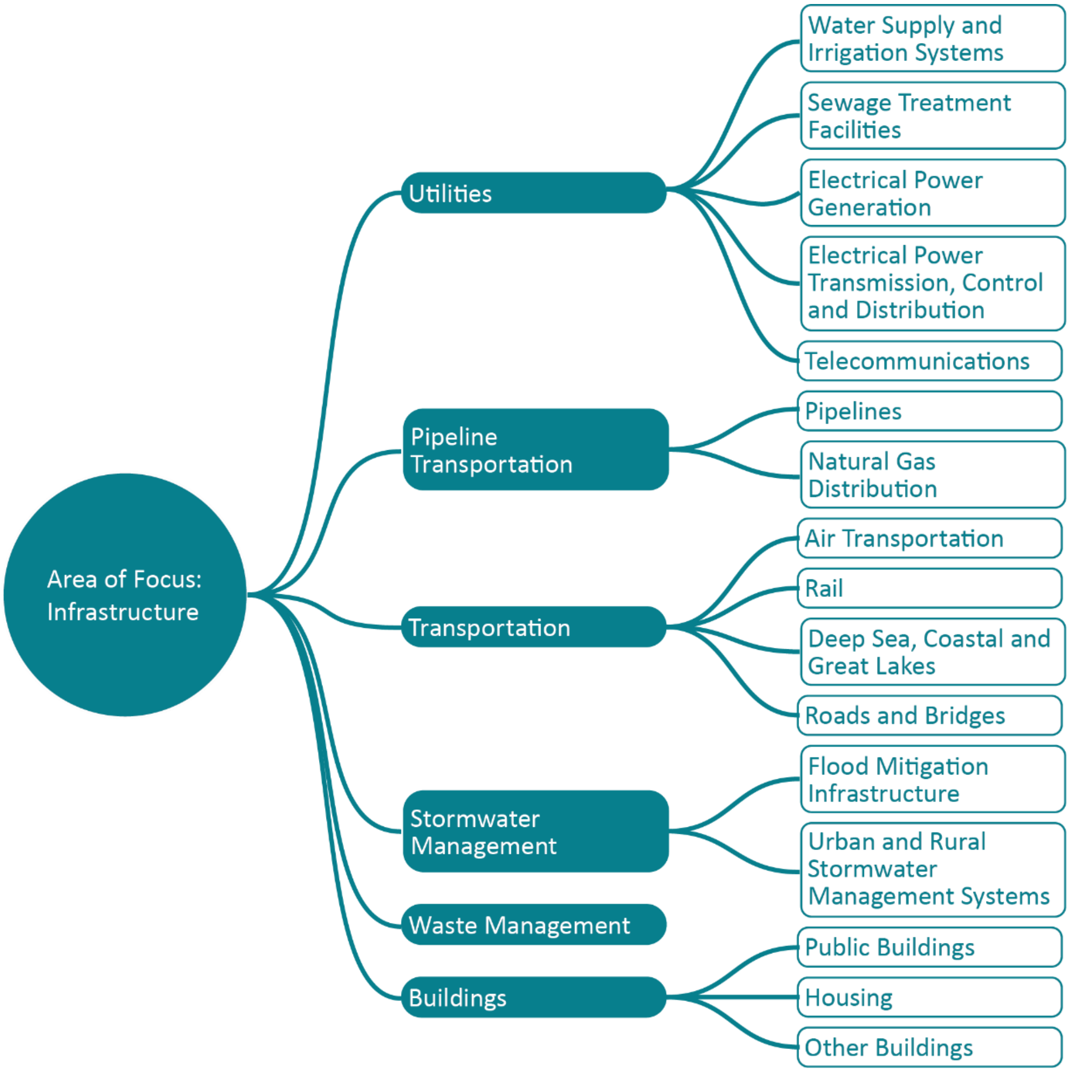
The quantity of built infrastructure in Ontario is largely driven by where Ontarians live. There are a few exceptions, such as, power generation infrastructure might be located where natural bodies of water present opportunity, rather than near a significant population. Consequently, much of Ontario's infrastructure is concentrated within the most populous regions, such as the Southwest, Central, and Eastern regions of the province, where approximately 94% of the population of Ontario lives (Statistics Canada, 2016). In general, infrastructure assets are less concentrated and connected farther north (e.g. the Far North).

6.3 Defining Infrastructure in the Context of the PCCIA

For the purposes of this assessment, Ontario's infrastructure was organized into key categories to support analysis. Level 1 and Level 2 categories were identified. A Level 1 category is defined as an overall 'sector', similar to how the North American Industrial Classification System (NAICS) defines sectors. Each Level 1 category was further broken down into 'sub-sectors' to ensure that nuances within infrastructure sectors could be properly analysed.

Figure 6.1 provides a summary of each the Level 1 and 2 categories assessed as part of the Infrastructure Area of Focus. Appendix 1 provides a full summary of the Level 1 and 2 categories assessed as part of the Infrastructure Area of Focus, including a brief description of each.

Figure 6.1: Structure of the Infrastructure Area of Focus in the Context of the PCCIA



6.4 Infrastructure Risk Snapshot across Ontario

Summary of Risks

Through this impact assessment, 690 unique risk scenarios were assessed under the Infrastructure Area of Focus and were evaluated quantitatively. At a regional level, infrastructure risk profiles are summarized in Figure 6.2, illustrating current risk, and the expected risks for the 2050s and 2080s, for each Level 1 category, operating under a high-emissions scenario (RCP8.5).

All infrastructure across Ontario faces climate risk. In fact, not a single asset included in this assessment is considered to have a risk less than 'medium' under current climate conditions. In many regions and for certain assets, this risk is expected to rise in the future. A significant portion of infrastructure across Ontario is not in a state of good repair, and the less investments made to improve assets that all Ontarian's rely upon, the greater impacts climate change will have across the province.

As an example of increasing risk profiles, several categories under Utilities increased from a current 'medium' risk profile to a 'high' risk profile in future time periods. The risk to Electrical Power Generation (Level 2 category under Utilities) is largely driven by rising temperatures which is more prevalent in the Central, Eastern and Southwest Regions, but present in all regions. High and extreme temperatures will accelerate the deterioration of equipment as it performs under higher heat conditions (United States Department of Energy, 2013). The physical risk to both Electrical Power Generation and Energy Transmission, Distribution Level 2 categories is also driven by extreme precipitation events (short- and longer-term events). For Electrical Transmission, Control and Distribution, risk is largely driven by winter precipitation (specifically Rain:Snow Ratio, which can be a proxy for freezing rain). Freezing rain or ice accumulating on distribution lines is the most notable and the greatest contributing factor to physical damage to this infrastructure category.

Under the Buildings Level 1 category, the Level 2 category of Housing in the Central, Eastern and Southwest regions exhibit the highest risk profiles. Risk to Housing is greatly driven by short-term extreme precipitation events, projected to increase over time. Risk to Waste Management is deemed to be 'medium' but increasing to 'high' for Central, Eastern and Southwest regions by mid-century (2050s). Stormwater management infrastructure across all regions of the province is evaluated as 'high' risk under current and remain 'high' across all future time periods.

From a regional perspective, some regions have risk profiles that are rising faster compared to others across the Infrastructure Area of Focus. As noted in Section 6.2, the vast majority of infrastructure is concentrated within the most populous regions of Ontario: Southwest, Central, the Eastern regions. This is reflected as climate risks in these regions are increasing at an accelerated rate, compared to the northern regions of the province.

Key Climate Drivers

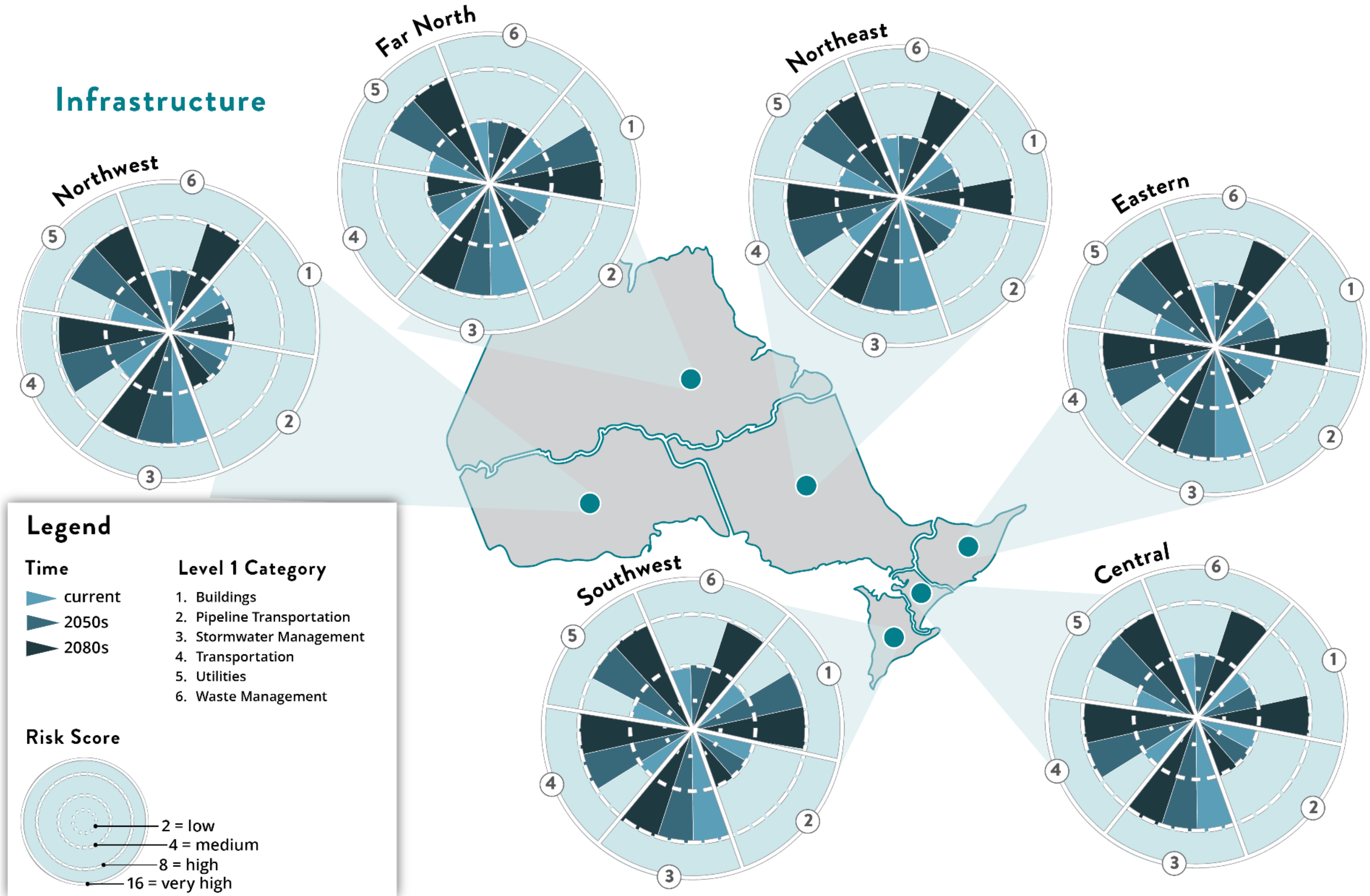
Risk scenarios assessed under the Infrastructure Area of Focus are driven by several climate variables selected for each of the Level 1 and 2 categories. Key climate drivers to the risk profiles under this Area of Focus are listed in Table 6.2 and include extreme precipitation events, Extreme Hot Days, and wildfire, which are the main drivers of 37%, 19% and 14% of all risk scenarios, respectively. A full list of all major climate variables that are driving the highest risks to Ontario's Infrastructure Area of Focus by Level 1 category and region is available in Appendix 8.

Table 6.2: Main Climate Variables Assessed for Infrastructure Area of Focus

Climate Variable	Proportion (%) of Area of Focus Risk Scenarios
Extreme Precipitation Event (shorter term)	**37%**
Extreme Hot Days	**19%**
Wildfire	**14%**
Other Variables	**30%**

While extreme precipitation, extreme heat and wildfire are driving the greatest amount of risk scenarios for this Area of Focus, other climate variables also pose threats to Ontario's infrastructure systems. Winter precipitation is another climate variable group that is particularly impactful for the Infrastructure Area of Focus. Examples of direct impacts driven by climate variables across different Level 1 and 2 categories are captured below in Section 6.7

Figure 6.2: Current and Future Risk Profiles by Region Assessed for Infrastructure (RCP8.5)[12]



[12] Appendix 13 provides an alternative visual format of the presented risk results by Level 1 category and region for this Area of Focus.

6.5 Approach to Assessing Climate Impacts on Infrastructure

Climate change impact assessment for the Infrastructure Area of Focus considered only direct impacts at the asset level. Indirect and cascading impacts of infrastructure disruption and damage are not considered in this quantitative assessment, rather they are covered under other Areas of Focus and under the Cross-Sectoral Considerations (Section 10.0).

Climate impacts on infrastructure were assessed for every region of Ontario. For each Level 2 category, various interactions of how climate variables could lead to impacts were documented and used to quantify how likely it would be to occur and how severe the consequences would be if it did. For infrastructure, the assessment of consequences was scoped to the level of damage and extent of financial loss. To evaluate the severity of impact consequence for each risk scenario, the cost of asset damage or replacement was evaluated. The extent of financial loss sustained under each risk scenario was quantified based on the ranges shown in Table 6.3. A 'very high' consequence score reflected full failure or damage to the infrastructure asset whereas a 'low' score reflected increased maintenance. 'Medium' and 'high' consequence score reflected the range between increased maintenance and full failure of the asset.

To provide additional context to how risks were quantified by Level 1 and Level 2 category. Table 6.4 presents examples of consequences and how they were assessed.

The strength of evidence for this Area of Focus was generally ranked as medium, with the exception of a handful of Level 2 categories and scenarios where research on direct climate impacts remains limited. For instance, robust climate impact research and risk assessments exists for utility and transportation infrastructure systems in Ontario, with less available for specific pipeline transportation assets. In addition, most scenarios related to wildfire impacts on all types of infrastructure was rated low, as research available on the magnitude and likelihood of the associated consequences for Ontario infrastructure is limited.

Table 6.3: Consequence Criteria Applied to the Infrastructure Area of Focus

Consequence Score	Category	Cost of Asset Damage or Replacement due to Impact by Climate Variable
16	**Very High**	**>60%** (Full failure/damage to infrastructure/infrastructure no longer operating at its intended purposes)
8	**High**	**40 – 60%** (Earlier end of life)
4	**Medium**	**20 – 40%** (Moderate damage/infrastructure still operating in some capacity at its intended purposes but at a reduced level)
2	**Low**	**10 – 20%** (Increased maintenance/ Infrastructure operating at its intended purpose)
1	**Very Low**	**<10%** (Status quo)

Table 6.4: Types of Consequences Evaluated for Infrastructure Level 2 Categories

Type of Consequence	Example	Level 2 Category
Increased maintenance and rehabilitation of assets	Increased maintenance due to extreme events causing infrastructure damage or blockages to dam structures resulting from flooding and debris. This will affect components like spillways and potentially damage the dam infrastructure itself. This will require more frequent replacement or repaired more frequently.	Flood Mitigation Infrastructure
Increased damages resulting in need for replacement of infrastructure components	Increased maintenance and rehabilitation costs to fill in cracks of concrete/asphalt; potential replacement if the damage is large to be filled. Potential damage to navigation aid instruments must be repaired.	Air Transportation; Roads and Bridges
Increased operational demands resulting in shorter asset lifespan	Increased pumping requirements or overwhelm pumps (early burn out of pumps), and blockages will increase maintenance needs and shorten the lifespan of pumps. Infrastructure failure leading to short period flooding and/or temporary inconveniences/use.	Urban and Rural Stormwater Management Systems
Increased operational costs and disruptions resulting from damaged infrastructure or reduced accessibility	Lower water levels could result in additional costs for shipping due to requiring more frequent trips to ship cargo due at lower capacity limits. Impacts from weathering and cracking from freeze-thaw cycling and flooding events may damage or cause full submersion of infrastructure.	Deep Sea, Coastal and Great Lakes
Increased costs to asset owners for replacement and costs for relocating those who occupy assets	Increase replacement and maintenance cost. Cost for property damage and repair, including the cost of losing housing and having to find somewhere to live will come with another cost as well.	Housing
Repair or replacement consequences requiring specialized expertise	Require large equipment and engineering to cover exposed pipe.	Natural Gas Distribution

The Infrastructure Area of Focus applied socio-economic projections to all future risk profiles (2050s and 2080s) to reflect projected regional population growth and increased density of physical infrastructure in certain regions of the province. Box 4 provides further details on how socio-economic indicators were used in the assessment of consequences associated with climate impacts on infrastructure.

Box 4: Socio-economic Projections Applied to Infrastructure Area of Focus

As described in Section 4.0, socio-economic projections were applied to risk evaluation based on the influence on likelihood of consequence and impact for PCCIA risk scenarios. For the Infrastructure Area of Focus, two socioeconomic indicators were applied to the likelihood of consequence across each Level 1 category, these included: population density and housing stock. To calculate the risk scores for the 2050s and 2080s, the two socio-economic indicators were assessed to determine possible influence on future consequences of impact. For example, housing stock was used to adjust the consequence scoring of future climate impacts on Housing, based on elevated regional exposure and sensitivity.

6.6 Limitations of the Infrastructure Assessment

Scope of Infrastructure Area of Focus

The inherent interdependence that exists for full functioning business and community creates complexity for specific lines of risk assessment of infrastructure. As such, the assessment of impacts is constrained to direct impacts to assets and does not include indirect impacts or assessment of the way impacts cascade through infrastructure systems and may be compounded or amplified. These impacts are described qualitatively within this section of the report.

Interconnections and Interdependencies

While there are examples of assessment of interdependent infrastructure systems (C40 Cities, 2017), robust methods for assessing complex climate risks across systems are limited and were not part of the PCCIA scope. Therefore, associated indirect and cascading impacts with infrastructure damages and failures are reported in a narrative format throughout this section, and further assessed under other Areas of Focus (e.g. People and Communities or Business and Economy) and various themes under the Cross-Sectoral Considerations (Section 10.0) of this report (see Box 5). Further methodological and general limitations that apply to the impact assessment are covered in Sections 2.6.

Box 5: Infrastructure Interdependencies in the PCCIA

Previous impacts experienced across Ontario have highlighted the important of considering infrastructure interdependencies and how they interact with climate impacts. With this in mind, it is important to note that the Infrastructure Area of Focus concentrated on assessing the direct physical impact of climate change to infrastructure (both private and public sector) within Ontario. An example of how the PCCIA was limited in assessing infrastructure interdependencies can be illustrated with the Electrical Transmission, Control and Distribution Level 2 category. Risk to this category can be largely driven by winter precipitation (specifically Rain:Snow Ratio, which can be a proxy for freezing rain). The direct impacts of freezing rain or ice accumulating on distribution lines was assessed for the physical damage to this infrastructure category. However, it is recognized that the consequence of impacted electrical infrastructure would be felt by individuals, communities and businesses who rely on that infrastructure, making the consequential risk widespread and far reaching. Dependent on the severity and context of the event, there could also be cascading impacts across other infrastructure systems (e.g. water or telecommunication infrastructure). Some of these impacts are covered in other Areas of Focus. For example, direct impacts to services are covered under People and Communities (Section 8.0) and impacts to industry and business are covered under Business and Economy (Section 9.0). More discussion on cross-sectoral impacts can be found in Section 10.0, while this Area of Focus concentrates on climate risks associated with the direct physical impacts and damages to infrastructure across Ontario.

6.7 Current and Future Climate Risks

6.7.1 Buildings

Overview

Buildings are found across Ontario and provide a space sheltered from the outside environment and climate for people, public services, and businesses to function. In the Province, buildings are designed and constructed based on the Ontario Building Code, regulated under the Building Code Act (Government of Ontario, 2022b). Buildings were categorized into three sub-categories and evaluated as part of this assessment: 1) Housing, 2) Public buildings, and 3) Other buildings.

The Housing Level 2 category refers to all privately owned residential buildings and public housing. When assessing Housing, the distribution of building types (e.g. single detached houses, and mid- and high-density buildings) for each geographic region was considered. In 2018, Ontario owned 8,403 social and affordable housing assets, totaling 122,764 units were publicly owned across Ontario (total of provincial, regional, and municipal ownership) (Statistics Canada, 2020b, 2020d). Municipal ownership of social and affordable housing units represents the largest share, owning 68% of total structures (76% of units) (Statistics Canada, 2020b, 2020d).

Public Buildings as a Level 2 category are considered those owned or operated by a government entity and primarily engaged in providing educational services, community services, and activities of a government nature. Examples of Public Buildings included during the assessment period are City Halls, public office buildings and buildings at transportation hubs.

The Other Buildings Level 2 category includes commercial, institutional and industrial properties such as hospitals, warehouses, factory buildings, office spaces and stores. In Ontario, buildings account for approximately a quarter of the province's total emissions, making this area an important focus for climate action (Office of the Auditor General of Ontario, 2020a). The Government of Canada is investing in energy efficiency retrofits and net-zero new builds, taking climate change risks into consideration and making investments to reduce emissions from buildings (Natural Resources Canada, 2022b).

Direct Impacts

Climate change can impact buildings in many ways. Four climate variable groups were identified as being particularly impactful to Buildings: Extreme Precipitation Event (shorter term), High and Extreme Temperature (Extreme Hot Days), Low Temperature (Extreme Cold Days), and Wildfire (Eastern, Northeast, Northwest and Far North Regions only).

In all three of the Building Level 2 categories, Extreme Precipitation and Wildfire resulted in the highest consequence scores. Both hazards have the potential to damage building foundations/frames, shortening the service life of the structure. For example, a short-duration high-intensity precipitation event can result in water damage to buildings and lead to concrete corrosion to foundations that can weaken the structure and reduce the building's service life.

Table 6.5 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 6.6, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 6.5: Illustrative Risk Scenario Examples for Buildings Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Housing	A short-term high-intensity precipitation event can result in water damage to buildings. This includes concrete corrosion to foundations that will weaken the structure and reduce the building's service life.	**High**
Other Buildings	Low temperatures resulting in an increase of Cooling Degree Days can result in the settlement of permafrost (Far North) or heaving under buildings which would result in damage to the building structure (e.g. cracks in the foundation or walls) and may result in the temporary closure of services. Damage to infrastructure will reduce the service life of the building.	**Low**
Public Buildings	High temperatures can cause increased cooling loads on building cooling infrastructure, which may impact performance and strain equipment. This can shorten the life expectancy and require additional maintenance for buildings that are impacted.	**Low**

The risk profile for all three types of buildings (housing, public buildings and other buildings) is similar. It was determined to be currently 'medium' but rising to 'high' risk by the 2080s in most regions. Risks are rising faster in the Far North where the rate of climatic change is accelerated and where improvements to and additions of buildings face a more significant backlog. For instance, changes in low temperature for buildings in the Far North, can cause heaving under buildings resulting in damage to the building structure (e.g. cracks in the foundation or walls), and may result in the temporary closure of services.

Table 6.6 provides the risk scores for each Level 2 category under Buildings, by region and timeframe. Risks to housing in Southwest Ontario are rising faster than in other regions, being largely driven by existing vulnerability to flooding (e.g. short-term extreme precipitation events).

Table 6.6: Risk Scores for Building Level 2 Categories (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Buildings	Housing	Central Region	**Medium**	**Medium**	**High**
Buildings	Housing	Eastern Region	**Medium**	**Medium**	**High**
Buildings	Housing	Far North Region	**Medium**	**High**	**High**
Buildings	Housing	Northeast Region	**Medium**	**Medium**	**High**
Buildings	Housing	Northwest Region	**Medium**	**Medium**	**Medium**
Buildings	Housing	Southwest Region	**Medium**	**High**	**High**
Buildings	Other Buildings	Central Region	**Medium**	**Medium**	**High**
Buildings	Other Buildings	Eastern Region	**Medium**	**Medium**	**High**
Buildings	Other Buildings	Far North Region	**Medium**	**High**	**High**
Buildings	Other Buildings	Northeast Region	**Medium**	**Medium**	**Medium**
Buildings	Other Buildings	Northwest Region	**Medium**	**Medium**	**Medium**
Buildings	Other Buildings	Southwest Region	**Medium**	**Medium**	**High**
Buildings	Public Buildings	Central Region	**Medium**	**Medium**	**High**
Buildings	Public Buildings	Eastern Region	**Medium**	**Medium**	**High**
Buildings	Public Buildings	Far North Region	**Medium**	**High**	**High**
Buildings	Public Buildings	Northeast Region	**Medium**	**Medium**	**Medium**
Buildings	Public Buildings	Northwest Region	**Medium**	**Medium**	**Medium**
Buildings	Public Buildings	Southwest Region	**Medium**	**Medium**	**High**

Indirect Impacts

Indirect impacts associated with building damage and failures (e.g. inability to occupy or use a building) were not quantitatively evaluated as part of the risk profiles but were noted throughout the assessment.

One such example relates to the combination of poor drainage in the building footprint and building damage that would lead to water infiltration. Buildings can be indirectly impacted during extreme precipitation events if the environment around them has a decrease in permeability that may lead to increased infiltration of water into buildings causing physical damage to interior parts of a building. The trickle-down impact is reflected in damp conditions on the inside of the building and the potential for mould (Lacasse et al., 2020; Hallegatte & Corfee-Morlot, 2010; Chinowsky et al., 2014).

Buildings may also be impacted indirectly through increased urban growth and housing development. This pressure can lead to development in high-risk areas such as floodplains and wetlands and in the context of climate change, lead to increased flood risk into the future (Lacasse et al., 2020; Hallegatte & Corfee-Morlot, 2010; Chinowsky et al., 2014).

6.7.2 Pipeline Transportation

Overview

Pipelines and natural gas distribution form an essential component of Ontario's energy distribution network, contributing $7.7B to the province's GDP in 2017(Canadian Energy Centre, 2021). For the purposes of this climate impact assessment, two Level 2 categories were evaluated within pipeline transportation: 1) natural gas distribution and 2) other pipelines. Natural gas distribution refers to the distribution of natural or synthetic gas to residents and businesses through mains. Pipelines refer to various types of pipelines and integrated systems that include pumping stations, storage facilities and other facilities. Table 6.7 illustrates the value of this infrastructure, by summarizing key pipeline infrastructure in Ontario.

Table 6.7: Pipeline Infrastructure in Ontario (Source: Enbridge, 2022)

Pipeline Infrastructure	Description in Ontario Context
TC Energy Mainline	TC Energy Mainline crosses Ontario, connecting Alberta and Quebec, carrying 445 million cubic metres of natural gas per day.
Dawn to Parkway Transmission Pipeline	Dawn to Parkway Transmission Pipeline is 257 km in length, and transports natural gas from Sarnia to Mississauga, with peak capacity of 6.5 bcf per day.
2193914 Canada Ltd.	2193914 Canada Ltd. is a 43.3 km natural gas pipeline located along the TransCanada Corridor, connecting Mississauga to Vaughan. The Pipeline carries 0.32 billion cubic feet of natural gas per day (9.06 million cubic meters per day).
Line 9	Line 9 originates in Sarnia and terminates in Montreal, Quebec, carrying crude oil over 832 km at an average capacity of 300,000 barrels per day.
Line 7 and Line 8	Line 7 and Line 8 originate in Sarnia and terminate near Hamilton, measuring 193 km and 210 km in distance respectively. Both carry crude oil products.

Pipeline Infrastructure	Description in Ontario Context
Line 5	A small section of the total 1,038 km length of Line 5 crosses Ontario. Line 5 originates in Superior, Wisconsin, and terminates in Sarnia, Ontario. Line 5 carries light crude and natural gas liquids with 540,000 barrels per day average annual capacity.
Vector Pipeline	Fifteen miles (24 km) of the Vector Pipeline's total 348-mile (560 km) length are located in Ontario. The Pipeline connects Joliet, Illinois to Dawn, Ontario, approximately 30 km southeast of Sarnia. The Pipeline has a capacity of 1.745 billion cubic feet of natural gas per day (49.9 million cubic meters per day).
Line 11	Line 11 transports 117,000 barrels of crude oil per day over 76 km from Hamilton to Nanticoke.
Niagara Gas Transmission Ltd. Pipelines	Four natural gas distribution pipelines are operated by Niagara Gas Transmission Ltd.: the Link Pipeline (9.9 km in length; 0.02 Bcf/d average annual capacity); the Rockcliffe Pipeline (1.0 km; 0.05 Bcf/d); the Orleans Pipeline (10.0 km; 0.06 Bcf/d); and the Cornwall Pipeline (4.3 km; 0.04 Bcf/d). These pipelines connect Ontario, Quebec, and New York State (US).
St. Clair Pipelines L.P.	St. Clair Pipelines L.P. operates two natural gas pipelines in Lambton County, the St. Clair River Crossing (0.9 km length; 0.2 Bcf/d average annual capacity) and the Bluewater Pipeline (2.9 km; 0.1 Bcf/d).

Direct Impacts

Climate change can impact natural gas distribution and pipelines in many ways. Extreme precipitation may lead to soil saturation, movement or undermining of pipes and buried assets, and increased maintenance requirements to ensure operational safety. Shifting seasonal precipitation and/or flooding could increase the exposure of infrastructure to hazardous conditions, leading to damage of assets. Increasing air temperature and extreme heat could shift soil conditions, leading to a higher likelihood of erosion, and instability, causing indirect impacts associated with sun exposure. The direct impacts identified have the potential to trigger geotechnical hazards such as landslides and river scouring, which may result in slope instability causing pipeline dislodgement and rupture.

Table 6.8 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Table 6.8: Illustrative Risk Scenario Examples for Pipelines Transportation Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Natural Gas Distribution	Extreme precipitation may cause pipelines to be exposed to the elements, this may include debris which can cause damage to the infrastructure.	**Low**
Pipelines	Extreme precipitation causing advanced scouring of bed material above buried pipe in a water course.	**Low**

The risk profile for both natural gas distribution and pipelines were found to be similar across all regions of Ontario. Risks are considered to be 'medium' under current climate conditions and remain relatively similar in the future. This unchanging risk profile reflects, to an extent, the fact that large portions of these assets are buried, actively managed and monitored, and not directly exposed to extreme weather events.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 6.9. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 6.9: Risk Scores for Pipeline Transportation Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Pipeline Transportation	Natural Gas Distribution	Central Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Natural Gas Distribution	Eastern Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Natural Gas Distribution	Far North Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Natural Gas Distribution	Northeast Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Natural Gas Distribution	Northwest Region	**Medium**	**Medium**	**Medium**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Pipeline Transportation	Natural Gas Distribution	Southwest Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Pipelines	Central Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Pipelines	Eastern Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Pipelines	Far North Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Pipelines	Northeast Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Pipelines	Northwest Region	**Medium**	**Medium**	**Medium**
Pipeline Transportation	Pipelines	Southwest Region	**Medium**	**Medium**	**Medium**

Indirect Impacts

While assessing direct impacts on physical infrastructure through risk scoring, some indirect impacts to Pipeline Transportation were identified. For example, extreme precipitation events coupled with high and extreme temperature events could lead to the long-term deterioration of soil conditions leading to erosion, instability, or increased exposure of pipes to atmospheric conditions. More generally, where climate-related impacts exist for pipeline transportation, cascading impacts can result in reputational issues for infrastructure owners and operators, increase the financial costs of managing assets safely, and reduce the serviceable lifespan of assets before they need replacement.

6.7.3 Stormwater Management

Overview

Stormwater management broadly refers to reducing runoff of precipitation across surfaces and managing water systems to maintain the natural hydrologic cycle. The objective of stormwater management is to prevent increased risks from flooding and stream erosion, and improve water quality. Ontario owns and manages a significant amount of stormwater management infrastructure; however, it is aging, which presents an additional risk for climate change and flood risk.

Flooding represents the costliest natural hazard in Ontario, exemplified by Hurricane Hazel in 1954 with restoration costs estimated to be around $1 billion in current dollars, and more recent flooding disasters across Ontario, including the 2018 flood in Toronto with an $80 million in insured damage, and flooding of the Albany River in 2019 causing the evacuation of 2,500 members of Kashechewan First Nation (Public Safety Canada, 2019). Flash flooding events, like the one in Toronto in 2018, occur during heavy rainstorms or may be caused by dam failure or the sudden release of significant ice jams, and can be exacerbated when stormwater management (SWM) infrastructure is not maintained (e.g. storm drains clogged by debris). Seasonal flooding is caused by accumulated spring melt, ice jams, and consistent rainfall.

Based on the persistent risks from flooding, and significant flooding events in the spring of 2019, a special advisory report, titled An Independent Review of the 2019 Flood Events in Ontario (Government of Ontario, 2021b) was prepared, detailing 66 recommendations to improve existing flood policy and pursue flood mitigation infrastructure investments and improvements (Government of Ontario, 2021b). *Protecting People and Property: Ontario's Flooding Strategy* (Government of Ontario, 2020e) was built around many of the Special Advisor recommendations and provides further provincial policy directives in handling the risks from floods within the province.

Ontario has 1,678 medium- and large-size dams on record, with the majority of dam infrastructure located in Southwestern, Central, and Eastern regions (Ontario GeoHub, 2022). Ontario Power Generation (OPG) operates 66 hydroelectric stations, generating one third of OPG's total electricity production (Ontario Power Generation, 2022). Aging dam infrastructure presents additional vulnerability to climate change and increases flood risk. The Canadian Dam Association records indicate that there are 118 large dams[13] in Ontario, all over 30 years old, and of which 105 (89%) are over 50 years old (Canadian Dam Association, 2019).

Smaller scale, but still significant, SWM infrastructure is in place throughout municipalities, rural communities, and agricultural areas, contributing to water quality management and capacity management. Not to be neglected are conveyance systems including channels, ditches, culverts, and storm sewers, which convey water to larger holding and treatment areas.

Pervious surfaces are those which allow water to infiltrate (softscape, parkland, permeable pavers, etc.), which reduce water volume from rainfall and flooding events, and also act as water filtration systems. Impervious surfaces do not allow for infiltration (asphalt, concrete, buildings, etc.), and contribute to higher runoff and flooding as water. The Ontario Ministry of Environment, Conservation and Parks considers impervious cover in the Stormwater

[13] A large dam is defined as a dam with a height of 15 m or more, or a dam between five and 15 meters in height which impounds (accumulates/retains) more than three million cubic meters of water.

Management Planning and Design Manual, specifying water storage requirements based on the conversion of land from pervious to impervious surface (Ontario Ministry of the Environment, Conservation and Parks, 2019). The Greater Toronto Area (in the Central region) is heavily urbanized, with 73% impervious surface coverage (Monica, 2019). Dense urban areas with high levels of impervious surfaces experience ‘flashier’ runoff, characterized by rapidly accumulating water that increases river discharge over a short period of time. This leads to an increase in flooding conditions, as river systems are overwhelmed by the rapid influx of water.

Wetlands provide natural flood and erosion control, among other benefits to water quality and habitat. Ontario is home to approximately 25% of Canada’s wetlands, with over 35 million hectares. The majority of Ontario wetlands are located in northern regions (Northeast, Northwest, Far North) (Government of Ontario, 2021e). Wetlands in southern regions (e.g. Southwest and Central) are being lost to alternative land uses (primarily urban development and agriculture). For example, over 13,000 hectares of wetland were lost at an increasing annual rate over the fifteen-year period of 2000 to 2015 (Government of Ontario, 2021e) (see Box 6 for further details on green infrastructure).

Box 6: Green Infrastructure in the PCCIA

Accelerating the implementation of green infrastructure (e.g. low-impact developments) can help to slow runoff, store water, and increase infiltration. While green infrastructure was not included as a distinct category in this Area of Focus, it is highlighted as an adaptation solution, to improve stormwater management by increasing the resilience of infrastructure in Ontario’s communities.

In order to assess the impacts of climate change on stormwater management, three Level 2 categories were used: 1) flood mitigation infrastructure, such as berms, dams, dikes, and wetlands; 2) urban stormwater management systems (SWM) such as storm sewers, culverts, storage structures and pump stations; and 3) rural stormwater management systems, such as tile drains, municipal drains and ditches.

Direct Impacts

Climate change is expected to have significant impacts on stormwater management (SWM) in Ontario. Extreme precipitation events, both accumulated precipitation over the longer term, and short-term events are found to be some of the most impactful conditions on SWM infrastructure in Ontario. Table 6.10 provides example risk scenarios for this Level 1 category.

Extreme flooding presents risks related to dam washout and failure, or physical damage to dams and pump stations, which could be exacerbated by increased levels of debris in floodwater. Increases in damage incidents result in increased maintenance or replacement/reconstruction of this infrastructure, as well as required downtime or reduced capacity in the system while damage is being addressed. A full dam washout causing a release of water would result in infrastructure impacts beyond the SWM infrastructure itself and include damage to transportation infrastructure and to public and private property. Debris can block or impede the efficiency of urban and rural SWM infrastructure, reducing infiltration and flow capacity, and contributing to flooding and worsening water quality and environmental conditions. Flooding which exceeds design flows may result in sewer overflows with undersized systems for the scale of the flooding event, and residents may experience sewage backup in basements.

Table 6.10: Illustrative Risk Scenario Examples for Stormwater Management Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Flood Mitigation Infrastructure	Long-term, accumulated precipitation can cause infrastructure damage or blockages to dam structures resulting from flooding and debris. This will affect components like spillways, and potentially damage the dam infrastructure itself. This may require more frequent replacement or repair.	**Medium**
Urban and Rural Stormwater Management Systems	Short-term, extreme precipitation may increase pumping requirements or overwhelm pumps (early burn out of pumps), and blockages which will increase maintenance needs and shorten the useful life of pumps. Infrastructure failure leading to short-period flooding and/or temporary inconveniences/use.	**High**

The risk profiles of flood mitigation Infrastructure, as well as rural and urban stormwater management systems, are considered to be 'high' under current climate conditions and remains 'high' in the future (see Table 6.11 at the end of this section). This risk may be higher if development occurs in high-risk areas or where water is infiltrated or stored, like wetlands. Socio-economic indicators were used to reflect the changing density of populations and infrastructure needs in the future. However, the way in which Ontario develops and builds moving into the future may not be entirely reflected in future risk profiles especially if future climate conditions are not considered in infrastructure planning and design. If infrastructure is not properly planned, developed, maintained or replaced with future climate conditions in mind, the risk may be even greater for future time periods.

Summarized in Table 6.11, all Level 2 categories considered under stormwater management are deemed to have 'high' risk profiles now and moving into the future. Risks were found to already be 'high' for both urban and rural stormwater management systems and flood mitigation infrastructure. Current risks are considered 'high' considering the extent and severity of consequences that can occur when stormwater management systems and flood mitigation infrastructure are impacted. Two main considerations for why risks may not be increasing in future time periods include:

- Risks for these particular Level 2 categories are largely driven by extreme precipitation events (e.g. short and longer duration). The future frequency of these variables is projected to increase across Ontario, though not substantially until the end of century. Climate variable frequency scores reflect this and remain unchanging until the 2080s. This could imply that the extent of the likelihood increase may not be sufficient to elevate risks to 'very high' for both Level 2 categories in relation to all other risks across Ontario.
- To calculate future risk scores, socio-economic indicators were applied to determine if there was an influence on the consequences of the impact. In some cases, consequence scoring was increased (e.g. housing stock is expected to increase the impermeable surfaces and increase surface runoff/water entering flood mitigation infrastructure). However, the degree of influence these projections had on future consequences scoring may not entirely reflect the influence that urban growth and development will have on future risk profiles for this Level 1 category.

More broadly, to evaluate the extent of risk more locally, additional climate variables and/or public floodplain maps would be important to refine results.

Table 6.11: Risk Scores for Stormwater Management Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Stormwater Management	Flood Mitigation Infrastructure	Central Region	**High**	**High**	**High**
Stormwater Management	Flood Mitigation Infrastructure	Eastern Region	**High**	**High**	**High**
Stormwater Management	Flood Mitigation Infrastructure	Far North Region	**High**	**High**	**High**
Stormwater Management	Flood Mitigation Infrastructure	Northeast Region	**High**	**High**	**High**
Stormwater Management	Flood Mitigation Infrastructure	Northwest Region	**High**	**High**	**High**
Stormwater Management	Flood Mitigation Infrastructure	Southwest Region	**High**	**High**	**High**
Stormwater Management	Urban and Rural Stormwater Management Systems	Central Region	**High**	**High**	**High**
Stormwater Management	Urban and Rural Stormwater Management Systems	Eastern Region	**High**	**High**	**High**
Stormwater Management	Urban and Rural Stormwater Management Systems	Far North Region	**High**	**High**	**High**
Stormwater Management	Urban and Rural Stormwater Management Systems	Northeast Region	**High**	**High**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Stormwater Management	Urban and Rural Stormwater Management Systems	Northwest Region	**High**	**High**	**High**
Stormwater Management	Urban and Rural Stormwater Management Systems	Southwest Region	**High**	**High**	**High**

Indirect Impacts

Generally, the indirect impacts to stormwater management are widespread and far-reaching across other Areas of Focus. For example, when stormwater management infrastructure is sized inadequately to handle storm conveyance during extreme precipitation events, widespread flooding impacts occur. These capacity constraints may not cause physical damage to stormwater infrastructure (e.g. pipe damage) however the associated risks may be widespread and underrepresented under this Level 1 category.

6.7.4 Waste Management

Overview

Waste management refers to infrastructure and establishments that provide waste management services, such as waste collection, treatment and disposal services; environmental remediation services; and septic tank pumping services. Material recovery facilities (recycling, composting) are also included in this category.

Ontario's population of 14.57 million people generated approximately 12 million tonnes of landfilled waste in 2019 (Ontario Waste Management Association, 2021). Ontario relies primarily on local landfills with 73% of waste landfilled within the province (8.7 million tonnes), while 27% is transported to the United States for disposal. Of the over 800 landfills within the province, Ontario depends heavily on seven primary landfills which accommodate 60% of landfilled waste in the province. Major landfills are located primarily in Southwest, Central, and Eastern Ontario, centered around major population centers and where consolidation and transportation of waste between municipal jurisdictions is facilitated by major highways. Northern regions of Ontario have a greater number of smaller landfills, dedicated to communities due to transportation limitations and the dispersed nature of the communities. With such an important percentage of waste managed at a limited number of landfill sites, climate-related impacts to these sites presents significant risks for waste management operations.

In 2021, the waste management sector in Ontario employed 3,231 full-time and part-time employees in the public sector, with an estimated 17,393 full-time equivalent jobs inclusive of the private sector (Statistics Canada, 2021a; The Conference Board of Canada, 2021a). Well-managed landfills are an essential component of the safety of workers, citizens, and the environment. Improperly managed landfills may cause unsafe environmental conditions and nuisance conditions (odour).

Direct Impacts

This impact assessment identified several ways that climate change can impact waste management. Extreme precipitation and extreme temperatures are anticipated to have the most significant impacts on waste management. Table 6.12 provides an example risk scenario for this category. Extreme precipitation events may cause increased leachate generation and ponding or flooding within a landfill. This may lead to slope instability of the waste at a landfill, with slope failure resulting in waste displacement and potential contamination of the surrounding environment. Extreme heat and high temperatures increase the likelihood of landfill fires under dry conditions.

Table 6.12: Illustrative Risk Scenario Example for Waste Management Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Waste Management	Extreme precipitation can cause slope instability of the waste piled at a landfill. Slope failure could result in displacing waste on-site into the surrounding environment. Shorter, more intense storms will have a greater effect on slope stability.	**Medium**

As demonstrated in Table 6.13, the risk profile of waste management was determined to be ‘medium’ under current climate conditions. This is expected to remain similar by mid-century and increase by the end of century. The increase in the latter half of the century is reflective of the increased frequency expected for extreme precipitation and temperatures by end of century. These risks are consistent across every region of Ontario except the Far North, reflecting less demand, density of landfills and waste management services. To calculate future risk profiles, socio-economic indicators had an influence on the consequences of the impact. For example, population density was used to adjust the scoring for Waste Management based on the required infrastructure to meet increased capacity needs.

Table 6.13: Risk Scores for Waste Management Level 1 Category

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Region	Climate Risk Scores		
		Current	2050s (RCP8.5)	2080s (RCP8.5)
Waste Management	Central Region	**Medium**	**Medium**	**High**
Waste Management	Eastern Region	**Medium**	**Medium**	**High**
Waste Management	Far North Region	**Medium**	**Medium**	**Medium**
Waste Management	Northeast Region	**Medium**	**Medium**	**High**
Waste Management	Northwest Region	**Medium**	**Medium**	**High**
Waste Management	Southwest Region	**Medium**	**Medium**	**High**

Indirect Impacts

Changing climate conditions can also indirectly impact waste management operations in various ways.

- Warming climate conditions may lead to increased odour generation, thereby decreasing air quality.
- Shifting species changes and temperature regimes can increase vermin, disease vectors and small animals, leading to higher risk to public health.
- Impacts to water infrastructure and operations may include leachate generation causing soil and water contamination and exacerbate the likelihood of landfill fires.
- Climate-related impacts could result in unsafe conditions for workers through unstable slope conditions within the work areas.
- General increased landfill management requirements and associated costs with increased maintenance.

6.7.5 Transportation

Overview

Ontario's transportation network is significant, and connects residents and businesses within, across and external to the province, with important road, rail, water, and air transportation routes. There are over 4,300 km of 400-series highways in Ontario, serving as the primary road transportation network, connecting east-to-west and north-to-south (Government of Ontario, 2020b; 2020c; 2022d). The 400-series highways are critical infrastructure supporting Ontario, Canadian, and international business with over 416,000 vehicles per day (including 41,000 transport trucks transporting over $600 million in goods). Rail lines in Ontario are operated by Canadian National Railway (CN), Canadian Pacific Railroad (CP), and VIA Rail, providing freight and passenger transportation services. Additional operators such as GO Train service from Metrolinx are also provided on the rail infrastructure and represent an important element of passenger transportation across southern Ontario. Canada's busiest airport, the Lester B. Pearson International Airport in Mississauga saw almost 50 million passengers in 2019 (Statistics Canada, 2021b).

Direct Impacts

Strongly linked with results from the transportation economy assessment under Business and Economy (Section 9.7.10), this Level 1 category focuses on the assets themselves. Climate impacts were evaluated across several sub-categories: 1) air transportation, 2) deep sea, coastal and great lakes transportation, 3) rail transportation and 4) roads and bridges. Climate risks posed to each of these transportation systems vary significantly.

Table 6.14 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 6.15, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 6.14: Illustrative Risk Scenario Examples for each Transportation Level 2 Category

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Air Transportation	High and extreme temperatures can cause bleeding of asphalt runways or buckling of concrete runways that can lead to the temporary closure of the lane due to the safety concerns.	**High**
Deep Sea, Coastal and Great Lakes	Extreme precipitation may lead to the formation of cracks due to weathering or the degradation of infrastructure. Locks may be closed for longer due to the increase in the maintenance required, and docks may periodically be submerged.	**Low**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Rail	Buckling and damage due to Extreme Hot Days will affect infrastructure life expectancy and stability and increase maintenance needs.	**High**
Roads and Bridges	The expected life expectancy of infrastructure will decrease due to cycles of freeze-thaw (low temperature, degree days below 0°C).	**Medium**

Air Transportation

Air transportation includes airfields (runways, taxiways, aprons, and de-icing operations), terminals and landside infrastructure (buildings, parking lots, and groundside paving), and communications equipment. Risks associated with air transportation are deemed to be 'medium' under existing conditions and increasing to 'high' for all future time periods. The increase in risk reflects the significant impacts anticipated from extreme heat. Extreme heat and high temperatures can lead to the bleeding of asphalt or buckling of concrete runways that can lead to closures of airport lanes due to the safety concerns. Extreme precipitation is also a key driver of risk for air transportation, causing localized standing water and flooding and associated physical damages and disruptions. The 2013 storm in the Toronto area caused significant flooding and led to considerable erosion and gravel spilling onto runways (Public Safety Canada, 2019).

Deep Sea, Coastal and Great Lakes Infrastructure

The deep sea, coastal and Great Lakes Level 2 category includes infrastructure associated with deep sea, coastal, and Great Lakes (Lakes Superior, Michigan, Huron, Erie, and Ontario) water transportation of freight and passengers; including ports, marinas, harbours, canals, and waterways. The risks to deep sea, coastal and great lakes infrastructure were determined to be 'medium' under the current timeframe and remain at this score in future time periods. This does not indicate that climate change will not impact this type of infrastructure. Instead, it may indicate that the scope of this impact assessment did not facilitate a comprehensive evaluation of impacts on deep sea, coastal and Great Lakes infrastructure. Through this assessment several impacts were identified that would cause physical damage and impacts on this type of infrastructure. For example, increased frequency of extreme precipitation events (short-term and longer-term) may lead to the formation of cracks due to weathering or the degradation of infrastructure. Flooding conditions may also cause locks to be closed for longer due to damages and the associated increase in maintenance. With anticipated greater year-to-year and multi-year variability in water levels, docks may periodically be submerged or stranded due to higher and lower water levels compared to historical observations.

Rail Transportation

Rail transportation includes all rail lines, rail yards, as well as associated land, structures (culverts, tunnels, bridges, etc.), and buildings supporting rail operations Risks associated with rail transportation are considered 'medium' now and increase to 'high' for all future time periods. Extreme heat and precipitation are anticipated to be the most impactful on rail infrastructure. Extreme heat can lead to heat kinks or buckling during Extreme Hot Days of railways, resulting in increased maintenance, repairs and/or the need for complete replacement. Impacts are particularly pronounced when the rail infrastructure has exceeded its lifespan. In addition, extreme precipitation events may lead to washouts, damage to rail lines, and increased maintenance, repairs and/or complete replacement needs.

Roads and Bridges

The roads and bridges Level 2 category encompasses all roads (including ice and winter roads but excluding forestry roads) as well as associated earthwork, drainage, and structures incorporated into roadways (culverts, bridges, tunnels, etc.). The risks to roads and bridges across Ontario are considered to be 'medium' under current and mid-century (2050s) timeframes but increase to 'high' by the end of century. High temperatures and extreme precipitation events have a high likelihood of leading to weathering and premature deterioration of roadway infrastructure, increasing maintenance and repair requirements. In addition, a shortened asset life is expected due to increasing freeze-thaw cycles from warming winter temperatures and frequent washouts due to extreme precipitation. Regionally, risks are relatively higher in Central and Eastern Ontario. Wildfires have the potential to impact the Eastern, Northwest, Northeast, and Far North Regions, with the potential to destroy or damage wooden infrastructure (minor bridges), and otherwise degrade road surfaces and bridge cabling.

Winter roads have a unique context and provide critical connections to many communities across the Far North of Ontario. As part of this assessment, winter roads were included within the roads and bridges Level 2 category. Due to increasing variability in conditions throughout shoulder seasons, and rapidly increasing air temperatures in the winter season, risks should be considered particularly elevated for these types of road systems (Hori et al, 2018a; 2018b).

Summarized in Table 6.15, the Level 2 categories under Transportation are anticipated to experience varying levels of risk associated with climate change. All Level 2 categories had a risk score of 'medium' in the current timeframe. Air Transportation and Rail are deemed to have a 'high' risk score in the 2050s and 2080s, while Roads and Bridges have a 'medium' risk score in the 2050s, increasing to 'high' by the 2080s. The only Level 2 category that does not increase in risk is deep sea, coastal and Great Lakes infrastructure.

While socio-economic indicators related to population and infrastructure density play a role in the risk scores under the Infrastructure Area of Focus, the risk profiles for transportation are largely driven by changes in climate conditions.

Table 6.15: Risk Scores for Transportation Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Transportation	Air Transportation	Central Region	**Medium**	**High**	**High**
Transportation	Air Transportation	Eastern Region	**Medium**	**High**	**High**
Transportation	Air Transportation	Far North Region	**Medium**	**Medium**	**Medium**
Transportation	Air Transportation	Northeast Region	**Medium**	**High**	**High**
Transportation	Air Transportation	Northwest Region	**Medium**	**High**	**High**
Transportation	Air Transportation	Southwest Region	**Medium**	**High**	**High**
Transportation	Deep Sea, Coastal and Great Lakes	Central Region	**Medium**	**Medium**	**Medium**
Transportation	Deep Sea, Coastal and Great Lakes	Eastern Region	**Medium**	**Medium**	**Medium**
Transportation	Deep Sea, Coastal and Great Lakes	Far North Region	**Medium**	**Medium**	**Medium**
Transportation	Deep Sea, Coastal and Great Lakes	Northeast Region	**Medium**	**Medium**	**Medium**
Transportation	Deep Sea, Coastal and Great Lakes	Northwest Region	**Medium**	**Medium**	**Medium**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Transportation	Deep Sea, Coastal and Great Lakes	Southwest Region	**Medium**	**Medium**	**Medium**
Transportation	Rail	Central Region	**Medium**	**High**	**High**
Transportation	Rail	Eastern Region	**Medium**	**High**	**High**
Transportation	Rail	Far North Region	**Medium**	**High**	**High**
Transportation	Rail	Northeast Region	**Medium**	**High**	**High**
Transportation	Rail	Northwest Region	**Medium**	**High**	**High**
Transportation	Rail	Southwest Region	**Medium**	**High**	**High**
Transportation	Roads and Bridges	Central Region	**Medium**	**Medium**	**High**
Transportation	Roads and Bridges	Eastern Region	**Medium**	**Medium**	**High**
Transportation	Roads and Bridges	Far North Region	**Medium**	**Medium**	**Medium**
Transportation	Roads and Bridges	Northeast Region	**Medium**	**Medium**	**Medium**
Transportation	Roads and Bridges	Northwest Region	**Medium**	**Medium**	**Medium**
Transportation	Roads and Bridges	Southwest Region	**Medium**	**Medium**	**Medium**

Indirect Impacts

For this Level 1 category particularly, it should be noted that indirect impacts associated with transportation infrastructure failure and disruptions were not quantitatively evaluated as part of the described risk profiles. The Business and Economy Area of Focus characterizes and evaluates climate risks for the transportation economy in Ontario (Section 9.7.10). In addition, the People and Communities Area of Focus covers impacts related to critical services and emergency response as they relate to transportation failure and disruptions.

6.7.6 Utilities

Overview

Utilities as a Level 1 category includes infrastructure assets that are primarily engaged in operating electric, gas, and water utilities. Strongly linked with results from the utility services assessment under Business and Economy (Section 9.7.11), this category focused on the assets themselves and the direct impact of climate change on utility infrastructure systems. Climate impacts were evaluated across several sub-categories: 1) water supply and irrigation systems, 2) sewage treatment facilities, 3) electrical power generation, 4) electrical transmission, control and distribution, and 5) telecommunications.

Direct Impacts

Table 6.16 provides example risk scenarios for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 6.17, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 6.16: Illustrative Risk Scenario Examples for Utility Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Electrical Power Generation	As high and extreme temperatures are experienced, there will be an increased use of water for cooling purposes as baseline temperature in cooling water (lakes, rivers) will increase. As cooling water will be warmer, its effects will require a larger volume of water and/or more time to cool, there may be an Accelerated deterioration of equipment as it performs under higher heat conditions (mechanical equipment, heat stress).	**High**
Electrical Transmission, Control and Distribution	Increased maintenance due to heavy/intense precipitation events causing debris to travel (infrastructure damage or blockages), backups or leaves can clog and erode sump pumps, structures near riverbanks can wash out and may require	**High**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
	reinforcements, damage to equipment that will need to be replaced or repaired more frequently.	
Sewage Treatment Facilities	Flooding and property damage from flooding conditions. The integrity of underground tanks will weaken and may result in cracking and infiltration due to the change in pressure in the soil from oversaturation, which will lead to the failure of infrastructure.	**Medium**
Telecommunications	Extreme flooding may cause ground movement due to erosion, resulting in the severing of fibre optic lines, leading to the disruption of internet and cable services for entire communities.	**Low**
Water Supply and Irrigation Systems	Property damage due to flooding and landslide events which would require more frequent maintenance.	**Low**

The risk to utility services was assessed by Level 2 category across all regions of Ontario. There was variability in the Level 2 risk profiles under Utilities. All Level 2 categories have a risk score of ‘medium’ in the current timeframe, except Electrical power generation which has a current risk score of ‘high’. Risks to electrical transmission, control and distribution are anticipated to increase from a ‘medium’ to a ‘high’ risk score in the 2050s and maintained this score in the 2080s. Level 2 categories including sewage treatment facilities, telecommunications and water supply and irrigation systems, remain at a ‘medium’ risk score throughout the 2050s and 2080s.

Housing stock is a major socio-economic driver affecting future risk scores through utility Level 2 categories. Housing stock projections influenced the scoring of sewage treatment facilities, based on the assumption of increased capacity requirements across each assessed region. Again, it is critical to recall that these scores only indicate direct impacts to the physical infrastructure, and do not reflect cascading impacts or failures to or from utility infrastructure systems.

Electrical Power Generation

Electrical Power Generation includes facilities primarily engaged in the generation of electric power, by hydraulic energy, fossil fuels, nuclear energy, or other processes (e.g. wind turbines). In Ontario, nuclear generated power was responsible for 56.8% of electricity generation in 2020 and is produced at three facilities located in the Southwest and Central regions (OEB, 2021; Government of Ontario, 2022e). Natural gas and wind production are predominantly located in the Southwest region (producing 6.3% and 8.7% respectively), and hydroelectric power production (24.4%) is predominant in the remaining regions (IESO, 2022a; Canadian Nuclear Safety Commission, 2022; OEB, 2021). Solar electricity is a minimal contributor to Ontario's grid, at 2.4% (OEB, 2021).

Electrical power generation can be impacted by climate change in a variety of ways, and in part depends on energy sources. For example, low water flows due to drought conditions can reduce hydroelectricity generation. This Level 2 category was evaluated against high and extreme temperatures (e.g. Extreme Hot Days and Cooling Degree Days) and extreme precipitation events (e.g. longer term accumulated precipitation). Extreme precipitation was found to be the greatest driver of risk for this Level 2 category. Water damage and impacts from overland flows and flooding may cause severe damage to equipment and shorten the useful life of electrical power generation infrastructure.

Electrical Transmission, Control and Distribution

Electrical power, once generated, requires transmission and distribution to consumers and for end use. The Ontario electricity grid is made up of transmission lines delivering electricity from generators to communities. The Independent Electricity System Operator (IESO) directs the flow of electricity over these lines, while transmission companies (e.g. Hydro One) own, operate, and maintain the lines and towers (IESO, 2022a). The Electrical transmission, control and distribution Level 2 category includes the transmission, distribution and control of electric power. Natural gas distribution is included in the Pipeline Transportation Level 1 category.

Electrical transmission, control and distribution were evaluated against four climate variable groups: high and extreme temperatures (Extreme Hot Days), extreme precipitation events (short term), winter precipitation (Rain:Snow Ratio), and wildfire. Winter precipitation (Rain:Snow Ratio) is the greatest driver of risk for this Level 2 category. An increase in exposure (duration and intensity) or a shift to freezing rain or wet snow can have negative impacts on transmission and distribution infrastructure and cause significant equipment damage. Heavy loading on transmission lines or on adjacent tree branches can lead to contacts and outages.

Impacts from extreme heat are also associated with some of the highest risk interactions for this Level 2 category. Extreme heat can reduce the carrying capacity of transmission and distribution lines and damage substations and transformers.

Sewage Treatment Facilities

Sewage treatment facilities include sewer systems and sewage treatment facilities that collect, treat, and dispose of wastewater. Combined sewer overflows were captured in this Level 2 category instead of storm collection systems due to their primary purpose being low-flow sanitary loads. Sewage treatment facilities can be affected by several different climate variables, with extreme precipitation events (accumulated precipitation, longer-term), being particularly impactful. Extreme precipitation events may cause infiltration and leaks in sewage treatment infrastructure, like piping systems. This may result in significant physical damages to the infrastructure over time, with associated maintenance and replacement costs expected to increase.

Telecommunications

Telecommunications includes infrastructure primarily engaged in providing telecommunications (cell) and/or video entertainment services. Telecommunications infrastructure consists of both wired and wireless technologies as well as satellites, all of which are integral to supporting public, emergency, retail and commercial services.

Telecommunications as a Level 2 category was evaluated against high and extreme precipitation events (accumulated precipitation, longer term), winter precipitation (Rain:Snow Ratio), and wildfire. The risk interactions related to wildfire (in Far North and Northeast regions) have the greatest level of consequence under this Level 2 category. In addition to the physical damage that fire can have on telecommunication infrastructure, heat from wildfire can cause damage to above-ground telecommunication lines causing loss/interruption of communication systems for entire communities. Flooding conditions caused by changes in precipitation patterns (e.g. rain in the winter season) and increased frequency of extreme precipitation events, may also cause ground movement due to erosion, resulting in the severing of fibre optic lines, leading to the disruption of internet and cable services for entire communities. Increases in precipitation, coupled with rising air temperatures (or humidity), may affect the radio spectrum which wireless communications rely upon. Extreme precipitation events may also disrupt transmitted signals or require increased transmission power to withstand challenging weather conditions. As a result, this may restrict the ability of customers who are supported within a given region or spectrum band (Adams and Steeves, 2014).

Under this assessment, the risk profile for telecommunications was deemed as ‘medium’ under the current timeframe, did not increase into the future across most regions. The risk profile increases for Eastern Ontario by the end of century, reflecting increased likelihood of impact and severity of consequences. The relatively stable risk scores for telecommunication indicate the nature of physical damage to this type of infrastructure, as impacts tend to be contained and isolated to local areas. However, it should be noted that only direct physical impacts and damages are included in the quantitative risk scores and the indirect or cascading impacts of climate change are not reflected.

Water Supply and Irrigation Systems

Water supply and irrigation systems as a Level 2 category include potable and non-potable water supply sources and the distribution infrastructure of the water such as irrigation systems. Potable water systems also include surface and groundwater treatment facilities, and distribution includes buried pipes, disinfection & booster stations, reservoirs. In this assessment, truck fill and cistern, or fill up at a treatment plant are not included. Irrigation systems include sprinklers for agriculture, groundwater pumps, piping, and focused mostly on agricultural applications instead of urban irrigation (e.g. for lawns, golf courses, etc.).

Several climate variables can impact the physical infrastructure of water supply and irrigation systems. Extreme precipitation events (accumulated precipitation, shorter term) can cause flooding which carries debris and, in some events, may cause slope failure. The risk profile for water supply and irrigation systems was assessed at a 'medium' and was not found to increase over time, considering only direct damage to the infrastructure assets.

Table 6.17: Risk Scores for Utility Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	**Level 2 Category**	**Region**	**Climate Risk Scores**		
			Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Utilities	Electrical Power Generation	Central Region	**High**	**High**	**High**
Utilities	Electrical Power Generation	Eastern Region	**High**	**High**	**High**
Utilities	Electrical Power Generation	Far North Region	**High**	**High**	**High**
Utilities	Electrical Power Generation	Northeast Region	**High**	**High**	**High**
Utilities	Electrical Power Generation	Northwest Region	**High**	**High**	**High**
Utilities	Electrical Power Generation	Southwest Region	**High**	**High**	**High**
Utilities	Electrical Transmission, Control and Distribution	Central Region	**Medium**	**High**	**High**
Utilities	Electrical Transmission, Control and Distribution	Eastern Region	**Medium**	**High**	**High**
Utilities	Electrical Transmission, Control and Distribution	Far North Region	**Medium**	**High**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Utilities	Electrical Transmission, Control and Distribution	Northeast Region	**Medium**	**High**	**High**
Utilities	Electrical Transmission, Control and Distribution	Northwest Region	**Medium**	**High**	**High**
Utilities	Electrical Transmission, Control and Distribution	Southwest Region	**Medium**	**High**	**High**
Utilities	Sewage Treatment Facilities	Central Region	**Medium**	**Medium**	**High**
Utilities	Sewage Treatment Facilities	Eastern Region	**Medium**	**Medium**	**High**
Utilities	Sewage Treatment Facilities	Far North Region	**Medium**	**Medium**	**Medium**
Utilities	Sewage Treatment Facilities	Northeast Region	**Medium**	**Medium**	**Medium**
Utilities	Sewage Treatment Facilities	Northwest Region	**Medium**	**Medium**	**Medium**
Utilities	Sewage Treatment Facilities	Southwest Region	**Medium**	**Medium**	**High**
Utilities	Telecommunications	Central Region	**Medium**	**Medium**	**Medium**
Utilities	Telecommunications	Eastern Region	**Medium**	**Medium**	**High**
Utilities	Telecommunications	Far North Region	**Medium**	**Medium**	**Medium**
Utilities	Telecommunications	Northeast Region	**Medium**	**Medium**	**Medium**
Utilities	Telecommunications	Northwest Region	**Medium**	**Medium**	**Medium**
Utilities	Telecommunications	Southwest Region	**Medium**	**Medium**	**Medium**
Utilities	Water Supply and Irrigation Systems	Central Region	**Medium**	**Medium**	**Medium**
Utilities	Water Supply and Irrigation Systems	Eastern Region	**Medium**	**Medium**	**Medium**
Utilities	Water Supply and Irrigation Systems	Far North Region	**Medium**	**Medium**	**Medium**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Utilities	Water Supply and Irrigation Systems	Northeast Region	**Medium**	**Medium**	**Medium**
Utilities	Water Supply and Irrigation Systems	Northwest Region	**Medium**	**Medium**	**Medium**
Utilities	Water Supply and Irrigation Systems	Southwest Region	**Medium**	**Medium**	**Medium**

Indirect Impacts

Due to the interconnected nature of utilities, indirect and cascading impacts from climate change are anticipated to be significant. Cascading impacts related to failures and disruptions of utility infrastructure are covered under other Areas of Focus, and Cross-Sectoral Considerations section (Section 10.0). Examples of other indirect impacts posed by climate change include:

- Extreme precipitation events may lead to electrical power generation station or station equipment breakdown or physical damage. This may lead to downtime or reduced capacity in the system and may result in increased O&M needs (Golder Associates, 2015).
- Areas impacted by wildfire may experience "flashy" runoff after a fire resulting in low ground absorption capacity and higher than average runoff. This can drastically affect the hydrology of a drainage basin and may impact hydroelectric plants storage and function (Fant et al., 2020; Sunrise Powerwalk Project, 2008; Smith, 2014).
- Prolonged exposure to suboptimal temperature conditions may reduce the efficiency and function of wastewater treatment facilities, for example frozen service lines, frozen sewage lagoons, and microbial health and function. This could lead to partially treated or untreated water discharging to receiving water bodies (US EPA, 2022).
- Regions where nuclear power generation occurs, will be impacted by high and extreme temperatures which may result in an increase to the baseline temperature in cooling water (lakes, rivers). As the cooling water temperature increases, it will require a larger volume of water or more time to cool.

6.8 Climate Change Opportunities

Opportunities resulting from direct physical climate change impacts on infrastructure are limited. As demonstrated throughout this assessment, changing climate conditions across different regions of the province can affect infrastructure in a variety of ways. Overall, the impact assessment found the risks that climate change has on Ontario's infrastructure, outweigh any potential positive impacts. However, there are a select number of interactions that indicate a potential for minor positive impacts for areas of transportation infrastructure in Ontario. The interactions that exhibited the potential for positive impacts related to warming winter temperatures (Degree Days <0C°) and the Roads and Bridge Level 2 categories:

- In the long term (e.g. 2080s), warmer winter temperatures may lead to a reduction of thermal cycling and cold weather-related damages, resulting in extended road lifespan and reduced costs.
- Less ice accretion on roadways due to warmer winter temperatures may result in a reduced need for de-icing compounds, which may be beneficial for road and bridge surface longevity.

6.9 Adaptive Capacity

6.9.1 Adaptive Capacity Summary

Adaptive Capacity within the Infrastructure Area of Focus was determined for each Level 1 category and was based on the following components: Technology, Resource Availability, Governance and Sector Complexity. Select Level 1 categories, including Utilities, were more inherently complex when assigning Adaptive Capacity because there were multiple Level 2 categories, spanning across diverse sectors (e.g. electrical power generation and transmission, telecommunications, water supply and irrigation, and sewage treatment). An Adaptive Capacity rating of 'low', 'medium' or 'high' is assigned for each Level 1 category assessed under the Infrastructure Area of Focus. A description and supporting rationale for the rating of each Adaptive Capacity component is provided below.

The results from the Adaptive Capacity analysis are provided in Table 6.18. A regional analysis of Adaptive Capacity can be found in Appendix 11.

Table 6.18: Infrastructure Adaptive Capacity Rating for Level 1 Categories[14]

Level 1 Category	Technology	Resource Availability	Governance	Sector Complexity	Level 1 Adaptive Capacity Rating
Transportation	Medium	Low	Medium	Medium	**Medium**
Waste Management	Medium	Medium	Low	Medium	**Medium**
Utilities	Medium	Medium	Medium	Low	**Medium**
Pipeline Transportation	High	Medium	Medium	Medium	**Medium**
Stormwater Management	High	Medium	Medium	Medium	**Medium**
Buildings	Medium	Low	Medium	Medium	**Medium**

The results of the overall Adaptive Capacity ratings are ‘medium’ for all Level 1 categories. This is reflective of the individual components, which scored ‘medium’ for the majority of the Level 1 categories. Note that a ‘high’ Technology rating does not reflect the state of the current infrastructure.

Infrastructure impacts other Areas of Focus functionality and improvements to Adaptive Capacity would reduce climate risks for numerous indirect impacts identified throughout this assessment. A few examples of how higher Adaptive Capacity ratings would impact Infrastructure include:

- Reduced downtime and less frequent maintenance
- Longer useful life of infrastructure (less frequent replacement)
- Reduced impacts on critical services that rely on infrastructure
- Reduced environmental impacts in the event of a severe weather event

One example of an improvement to Adaptive Capacity in this Area of Focus is the update and use of flood plain maps and associated mapping tools. This information and these tools are used by utility companies, Conservation Authorities and others to help determine areas under elevated flood risk. Where not already in place, updating these maps to include future climate

[14] Note these scores do not consider geographic location within the province. Please see Appendix 11 for regional Adaptive Capacity ratings.

change would enable climate-sensitive growth and development, and protect people, infrastructure, and communities.

6.9.2 Technology

A 'high' Adaptive Capacity rating for technology reflects existing technologies or evolving design parameter considerations that limit disturbances to infrastructure performance during extreme weather events or in response to changing climate conditions. Pipeline Transportation is considered to have a 'high' technology rating. This is reflective of the majority of pipeline transportation infrastructure being underground in Ontario which offers protection from many climate hazards (Swanson et al., 2021). Underground construction, paired with design code requirements that capture extreme events and low temperatures (> -40 °C), resulted in a 'high' technology rating (Bruschi et al., 2014; Canada's Oil and Natural gas Producers, 2022). Stormwater management also has a 'high' technology rating, as stormwater infrastructure has advanced technology to support changing conditions and has several pilot projects underway to incorporate future climate conditions (Berggren, 2007; Andrey et al., 2014). The remaining Level 1 categories have a 'medium' technology rating, reflecting some evidence of technological advancements but the adoption of best practices could improve across all regions and sub-components of the sector.

6.9.3 Resource Availability

Resource availability reflects the funding, capital, workforce and other tools available for each Level 1 category. Resource availability was rated 'low' for transportation due to limited funding available to build climate resilience into existing infrastructure (much of which is aging) (OCCIAR, 2019; Lemmen and Warren, 2014; Chattha, 2021). This category was also ranked 'low' for buildings which reflects a lack of funding required to build climate resilience into existing (and aging) physical infrastructure. Land development and land use legislation can accomplish large-scale change (geographically and sector-wide) to support flood risk management which is one of the most significant risk factors for this category (Lacasse et al., 2020; Government of Ontario, 2020e; Chattha, 2021). The remaining Level 1 categories have a 'medium' rating, to reflect more available funding opportunities and tools (e.g. floodplain mapping) to manage and build resilient infrastructure, but are not yet widely shared or require more resources to complete. No Level 1 categories were assigned a 'high' rating under this Adaptive Capacity category.

6.9.4 Governance

Governance reflects any regulation or targets related to the climate impacts on infrastructure. Waste Management has a 'low' rating for Governance, indicative of the focus of governance on climate change mitigation, but little on climate change adaptation at this point (Government of

Ontario, 2020e; 2021a). The remaining Level 1 categories have a ‘medium’ rating, reflecting a combination of governance support (including updating design guidelines). No Level 1 categories were assigned a ‘high’ rating under this component of Adaptive Capacity.

6.9.5 Sector Complexity

High sector complexity is indicative of lower scores for Adaptive Capacity. Since utilities have a wide range of infrastructure included in this Level 1 category, it was considered to have high sector complexity and thus has a ‘low’ rating under Sector Complexity. This is driven by the numerous decision-makers and stakeholders that have roles to play in a complex decision-making environment (Ontario Waste Management Association, 2021; CSA Group, 2019b). A ‘high’ rating under this component reflects low complexity and a higher capacity to adapt. No Level 1 categories were assigned a ‘high’ rating under this component of Adaptive Capacity.

6.10 Climate Adaptation Priorities

The results of the PCCIA can shed light on current and emerging adaptation priorities for the province, based on the anticipated magnitude of risk, and associated capacity levels to respond and cope with climate change impacts. As described in Section 2.4.5, an adaptation priority is defined as any Level 1 or 2 category in a given region that has an Adaptive Capacity of ‘medium’ or lower and a risk score of ‘high’ or greater (see Appendix 12 for combined Level 1 and regional Adaptive Capacity ratings).

Using the categories of Adaptive Capacity (technology, resource availability, governance, and sector complexity), each of the six Level 1 categories score a ‘medium’ Adaptive Capacity. When combining this with the regional Adaptive Capacity ratings, Central, Northeast and Northwest regions are found to have the lowest capacity rating. This section provides further detail on current and emerging adaptation priorities for the Infrastructure Area of Focus, considering existing levels of capacity and current and future risk scores.

Current Adaptation Priorities

There are a number of adaptation priorities that emerged for the current timeframe that correspond to Level 1 and 2 categories of ‘high risk’ with corresponding ‘medium’ levels of Adaptive Capacity. The current adaptation priorities are summarized in Table 6.19.

Table 6.19: Current Infrastructure Adaptation Priorities

Current Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[15]
Flood Mitigation Infrastructure	Central, Northeast, Northwest, Far North	High	Medium
Urban and Rural Stormwater Management Systems	Central, Northeast, Northwest, Far North	High	Medium
Electrical Power Generation	Central, Northeast, Northwest, Far North	High	Medium

Priority themes for adaptation include electrical power generation, flood mitigation infrastructure, and urban and rural stormwater management systems across all Central, Northeast, Northwest and Far North regions. Note that infrastructure systems ranking as 'high' risk in Southwest and Eastern Ontario are not identified as current priorities based on the associated regional capacity (see Appendix 12).

Emerging Adaptation Priorities

By the mid-century, several additional 'high' risk categories will emerge for Ontario's infrastructure, adding to those already identified for the current timeframe, all of which continue to persist. Emerging adaptation priorities for infrastructure by mid-century are summarized in Table 6.20.

Table 6.20: Emerging Infrastructure Adaptation Priorities by Mid-Century 2050s (RCP8.5)

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[16]
Housing	Far North	High	Medium
Other Buildings	Far North	High	Medium
Public Buildings	Far North	High	Medium
Air Transportation	Central, Northeast, Northwest	High	Medium
Rail	Central, Northeast, Northwest, Far North	High	Medium

[15] See Appendix 12 for combined Adaptive Capacity ratings and associated scoring matrix.
[16] See Appendix 12 for combined Adaptive Capacity ratings and associated scoring matrix.

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[16]
Electrical Power Transmission, Control and Distribution	Central, Northeast, Northwest, Far North	**High**	**Medium**

Based on the results from Table 6.20, infrastructure themes that warrant priority for future (timeframe) adaptation include air transportation, electrical transmission, control and distribution, housing, other buildings, public buildings, and rail Level 2 categories. As the mid-century approaches, the focus will remain in the same regions but with greater concentration on northern regions. For example, the Far North has more adaptation priorities for select categories, based on the accelerated rate of change in climate conditions and significant backlogs for building improvements.

Extreme precipitation is the greatest driver of climate risk presented in all the identified priority areas, with high and extreme temperatures (Extreme Hot Days) being the second greatest. This commonality, along with the heightened vulnerability of northern regions, can be used to inform measures for building Adaptive Capacity across Ontario's infrastructure systems.

Advancing Adaptation

Several adaptation measures can help to build resiliency and reduce risk to Ontario's complex infrastructure systems. For example, integrating climate considerations into asset management is a cross-cutting adaptation option that builds climate resilience into infrastructure planning, design and maintenance (Lemmen and Warren, 2014).

Climate change risk assessments at the infrastructure system or asset level are key for understanding vulnerability and identifying targeted options to enhance resilience. For example, the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol, can be applied to different sizes and types of infrastructure systems and assets. The Protocol supports users in identifying and assessing how different climate drivers affect infrastructure performance and life expectancy (Climate Risk Institute and Institute for Catastrophic Loss Reduction 2021).

Infrastructure resiliency can also be improved through investments in proven and emerging technologies, integrating climate hazards into emergency response plan development, considering climate-focused recommendations in decision-making, and implementing updated climate-resilient design codes (Infrastructure Canada, 2022). Specific adaptation actions can include, improving tracking and monitoring technology, increasing the frequency of maintenance and inspections of infrastructure, locating new buildings outside of high-risk flood zones, increasing transmission tower height, burying distribution lines, increasing the temperature standard for the performance of railways, developing and practicing climate event (emergency) response plans, and valuing and protecting natural assets such as wetlands (OECD, 2018; ONEIA, 2022; Nodelman et al., 2015; Fausto et al., 2016; Golder, 2021; TRCA, 2019; RVCA, 2022). In addition, updating design standards regularly to meet future climate conditions can increase the climate resiliency of new infrastructure builds and developments (e.g. updating intensity-duration-frequency (IDF) parameters to reflect the change in duration and amount of rainfall of an extreme precipitation event) (Genivar, 2011; Chiotti, 2019; Fausto et al., 2016).

Another opportunity for building climate resilience throughout Ontario's infrastructure system is the development and posting of climate change datasets and associated tools for assessing climate impacts and risks. Natural Resources Canada's Flood Hazard Identification Mapping Program (FHIMP) is designed to inform climate-smart land use decisions by making available floodplain mapping and related modeling and datasets (Natural Resources Canada, 2022a). Such tools and data that explicitly consider future climate conditions will support climate resilient infrastructure across Ontario.

The PCCIA Adaptation Best Practices (ABP) Report (External Resource – 2) further references adaptation options for the Infrastructure Area of Focus. Ontario is equipped with adequate knowledge and existing practices to lessen and avoid many of the climate risks posed to infrastructure. A high-level summary is provided in Table 6.21, with asset-specific adaptation options are available in the ABP Report.

Table 6.21: Adaptation Options for the Infrastructure Area of Focus

Adaptation Category	Examples of Adaptation Measures
Projects or Programs	- Incorporate climate change into asset management, and specifically develop technical guidance on how to do so and at what level of detail. - Develop programs to support communities of practice focused on each of the major infrastructure asset categories. - Fast-track the deployment of green infrastructure by incorporating green infrastructure into designs and renewed development.
Research and Development	- Support and encourage the release of quantitative datasets that can be used to assess risk and inform infrastructure design. - Require that new research and modeling should factor in climate change scenarios where they inform infrastructure planning and design, such as floodplain mapping. - Develop climate resiliency design guidelines with technical specificity.
Investment and Incentives	- Increase and mobilize funding for partnership research among industry, institutions, governments, and Indigenous Communities. - Increase funding to support infrastructure upgrades that explicitly factor in future climate conditions and enhance climate change adaptation.
Policy and Regulation	- Increase the frequency of maintenance and monitoring and develop extreme weather response plans. - Require climate change risk assessments for new, rehabilitated and replaced infrastructure. - Develop policies to adopt climate risk frameworks to build sustainability and resilience principles into infrastructure projects.

7.0 Natural Environment Area of Focus

7.1 Overview

Climate change is already a threat to Ontario's natural environment, and is expected to drive risks to species, habitats, and ecosystem services even higher in the future. PCCIA climate change risk profiles are rising to 'high' by mid-century for almost all natural systems and species. By end of century, one quarter of risks under this Area of Focus are expected to be 'very high' (see Table 7.1).

Regional differences are important to recognize, with human development compounding climate risks in regions further south. In northern regions, accelerated rates of climatic change are driving risks. Sustaining and amplifying existing natural features to be resilient to climate change provides support for ecosystem structure and function, contributes to carbon management in support of GHG reduction, provides core elements for cultural benefit and provides subsequent health benefits for the human population.

Table 7.1: Summary of Climate Risks to Natural Environment (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Most at Risk Regions Abbreviations[17]	
FN - Far North	E - Eastern
NE - Northeast	C- Central
NW - Northwest	SW - Southwest

Natural Environment Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Fauna				SW, C
Flora				SW
Aquatic Ecosystems				NE, NW, FN, C
Terrestrial Ecosystems				All
Regulating Services				C, NE, FN
Provisioning Services				C, E, SW
Ecosystem Cultural Services				NE, NW

[17] Most at risk regions' are those that display highest risk scores operating under RCP8.5 (Appendix 9).

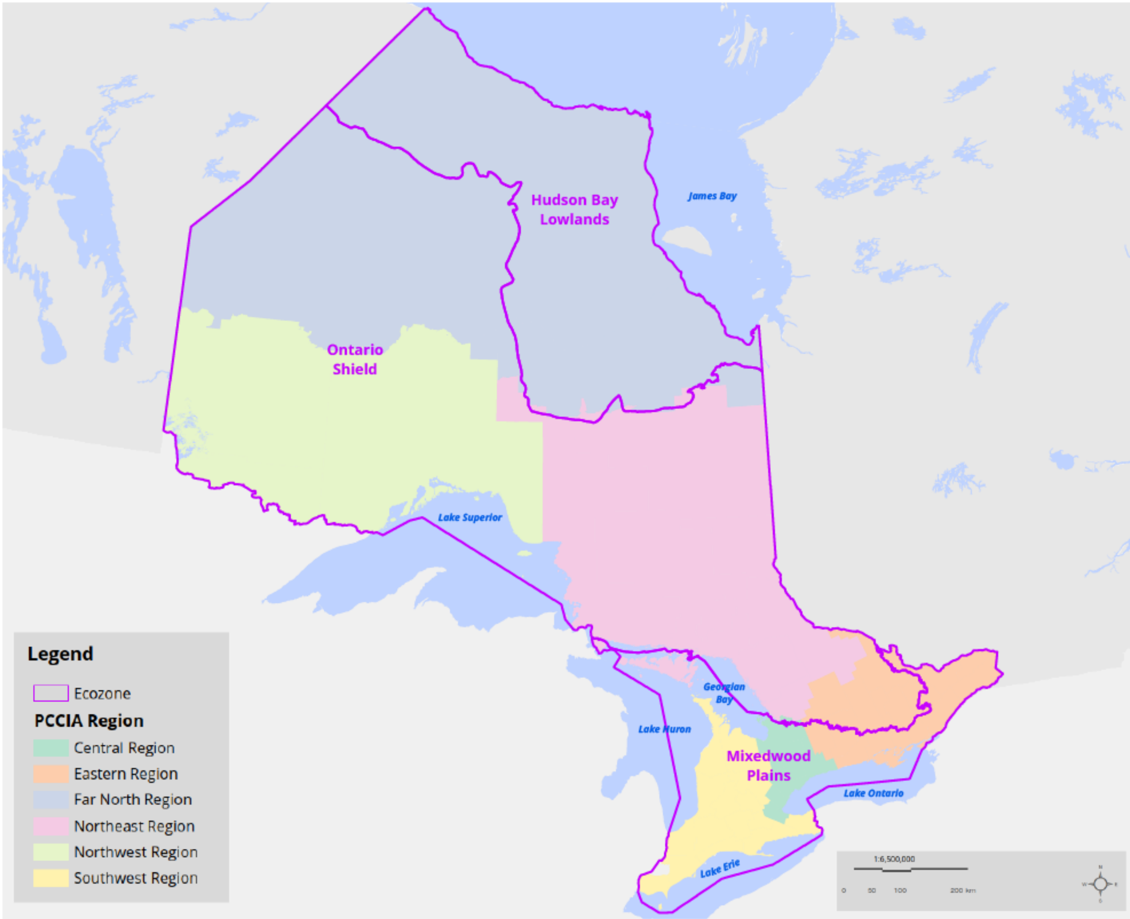
7.2 Ontario's Natural Environment

Ontario's natural environment is comprised of a diversity of species, forests, wetlands, lakes, streams, and other natural features, with intrinsic, socio-economic, and cultural value due to the essential goods and services that it provides to Ontarians (Pascual et al., 2010; Office of the Auditor General of Ontario, 2021b). Ontario's natural environment, including more than 30,000 species, sustains the province's biodiversity (Ontario Biodiversity Council, 2021). A healthy natural environment also sustains ecosystem functions and cycles that are essential lifelines, including the distribution of water, climate regulation and air filtration, and provide services like access to water, medicines, natural resources, and space for recreation (Haines-Young and Potschin, 2017). Recognizing the inherent value of the natural environment and of Ontarians' right to a healthful environment, Ontario's Environmental Bill of Rights (1993) outlines the shared goal and responsibility to protect, conserve and restore the natural environment for the benefit of current and future generations. Efforts to monetize the annual flows of ecosystem services in Ontario demonstrate the economic merits of protecting nature (Green Analytics, 2017).

Ontario's natural environment consists of three distinct ecozones that are based on ecology, climate and geology: Hudson Bay Lowlands, Ontario Shield, and Mixedwood Plains. The six Ontario regions used in the PCCIA relate to these ecozones in various ways (see Figure 7.1).

The Far North region encompasses the entirety of the Hudson Bay Lowlands and carries global significance for carbon storage. The vast peatland ecosystems also hold immense cultural value to 31 First Nations communities that inhabit the area (Harris et al, 2022; McLaughlin and Webster, 2014; Wilkinson and Shulz, 2012). A significant portion of the Far North is within the Ontario Shield ecozone comprised of the northwestern range of Ontario's boreal forest which is home to northern species at risk such as wolverine (*Gulo gulo*) and boreal woodland caribou (*Rangifer tarandus caribou*). The significance of this region is encoded in the *Far North Act* which describes the region's cultural value, ecological systems, and capacity for carbon storage and sequestration (Far North Act, 2010, S.O. 2010, c. 18, amended 2021).

Figure 7.1: Map of PCCIA Regions and Ontario Ecozones (Hudson Bay Lowlands, Ontario Shield and Mixedwood Plains)



The Northwest and Northeast PCCIA regions divide the Ontario Shield into two regions which are characterized by the presence of the boreal forest and mixed forests in the south, with forest fires as common natural disturbances (Crins et al., 2009). Black spruce and tamarack dominate in conifer swamps and peatlands in low-lying areas in the Northwest and Northeast regions, whereas mixed and deciduous forests dominate in southern part of the Ontario Shield.

The Eastern region consists of the lower part of the Ontario Shield and the eastern portion of the Mixedwood Plains ecozone. The Central region is in the Mixedwood Plains ecozone and contains Lake Simcoe, an ecologically important body of water, significant for its lucrative recreational fishing industry, fresh drinking water provision, agricultural irrigation, and proximity to high-density human populations (North et al., 2013). The Southwest and Central regions are in the Mixedwood Plains ecozone and contain most of Carolinian forest zone in Canada. These two regions have the highest human population density in Ontario, yet contain one-third of the rare, threatened, and endangered species found in all of Canada (Centre for Land and Water Stewardship, 1994).

Each of these regions face unique threats and challenges from the effects of climate change, including considerations of non-climatic pressures (e.g. human development) (Kraus and Hebb, 2020).

7.3 Defining Natural Environment in the Context of the PCCIA

To assess the impacts of climate change on the natural environment, this Area of Focus was divided into seven Level 1 categories in such a way that it covered the intrinsic value of nature and biodiversity, natural resources, and values important to humans. This structure included Flora, Fauna, Aquatic Ecosystems, Terrestrial Ecosystems, Regulating Services, Provisioning Services, and Ecosystem Cultural Services. Flora and Fauna Level 1 categories comprised species illustrating climate change impacts on various taxonomic groups. Ecosystems are assemblages of living and non-living components of the environment linked together through nutrient cycles and energy flows and are represented in this assessment as land cover types. Ecosystem services are the benefits people derive from nature. Regulating services are required for the maintenance of Earth's systems and comprise of ecosystem processes that moderate natural phenomena. These natural phenomena can affect human health, safety, and comfort. Provisioning services are flows of nutritional, non-nutritional, and energetic outputs from living and natural abiotic systems; cultural ecological services are non-material and generally non-consumptive outputs of ecosystems that affect physical and mental states of people (Haines-Young and Potschin, 2017).

Each Level 1 category was broken down into multiple Level 2 categories, which were the focus of the impact assessment (see Figure 7.2). Specific species or species groupings, land cover types, and ecosystem services were selected for quantitative risk assessment based on their ecological significance and climate sensitivity, their distribution and abundance, importance to Ontario communities and information availability. The selection of Level 2 categories and associated details was also based on advice from environmental professionals working in Ontario, to represent a mix of species and systems that could reflect the effects of climate change on the broader level, to provide a clear picture of climate risks to the Natural Environment Area of Focus. The Level 2 categories for Flora, Fauna, and Ecosystems are supported by many indicator species defined in Ontario's Significant Wildlife Habitat Mitigation Support Tool (Ontario Ministry of Natural Resources and Forestry, 2014c). Figure 7.2 below, lists the Level 1 and Level 2 categories that were assessed and further information on each Level 2 component appears in Appendix 1.

Examining climate change impacts at the species level was not possible due to the vast number of plants, animals, and lichen in Ontario. Instead, taxonomic groups include select, illustrative species which allows consideration of a mix of species with wide and limited distribution, varying levels of sensitivity to climate change, diversity in conservation status, information availability, and the inclusion of a few species of human interest (e.g. managed species). This ranking system indicates the relative rarity of a species sub-nationally and relative risk of disappearing from the province due to threats such as habitat loss, invasive species, pollution, and unsustainable use (Ontario Biodiversity Council, 2021). Values range from SH (possibly extirpated), S1 (critically imperilled), S2 (imperiled), S3 (vulnerable), S4 (apparently secure) to S5 (secure) (NatureServe, nd). Figure 7.3 shows the breakout of species included in the assessment by the numbers.

Figure 7.2: Structure of the Natural Environment Area of Focus in the Context of the PCCIA

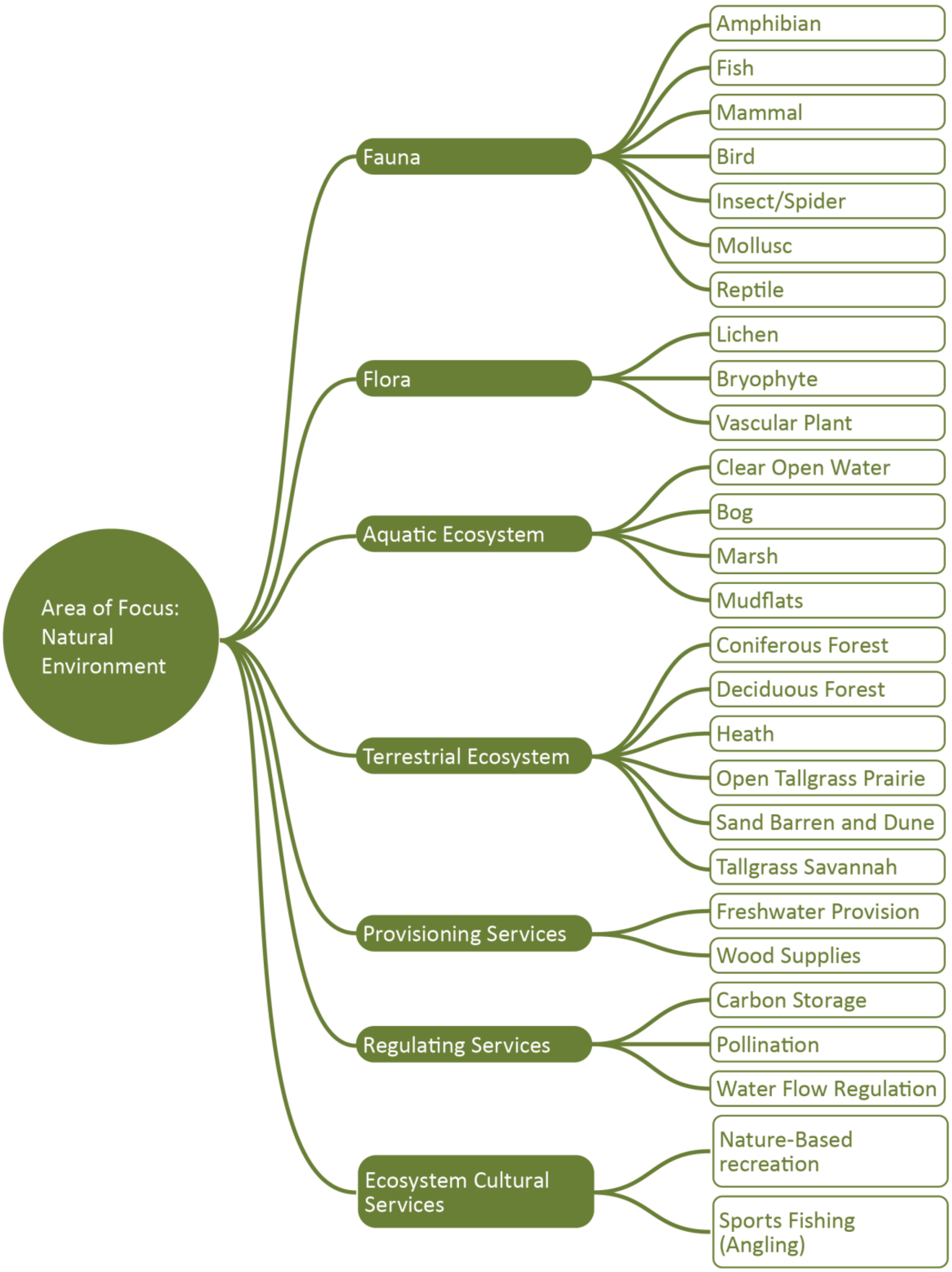
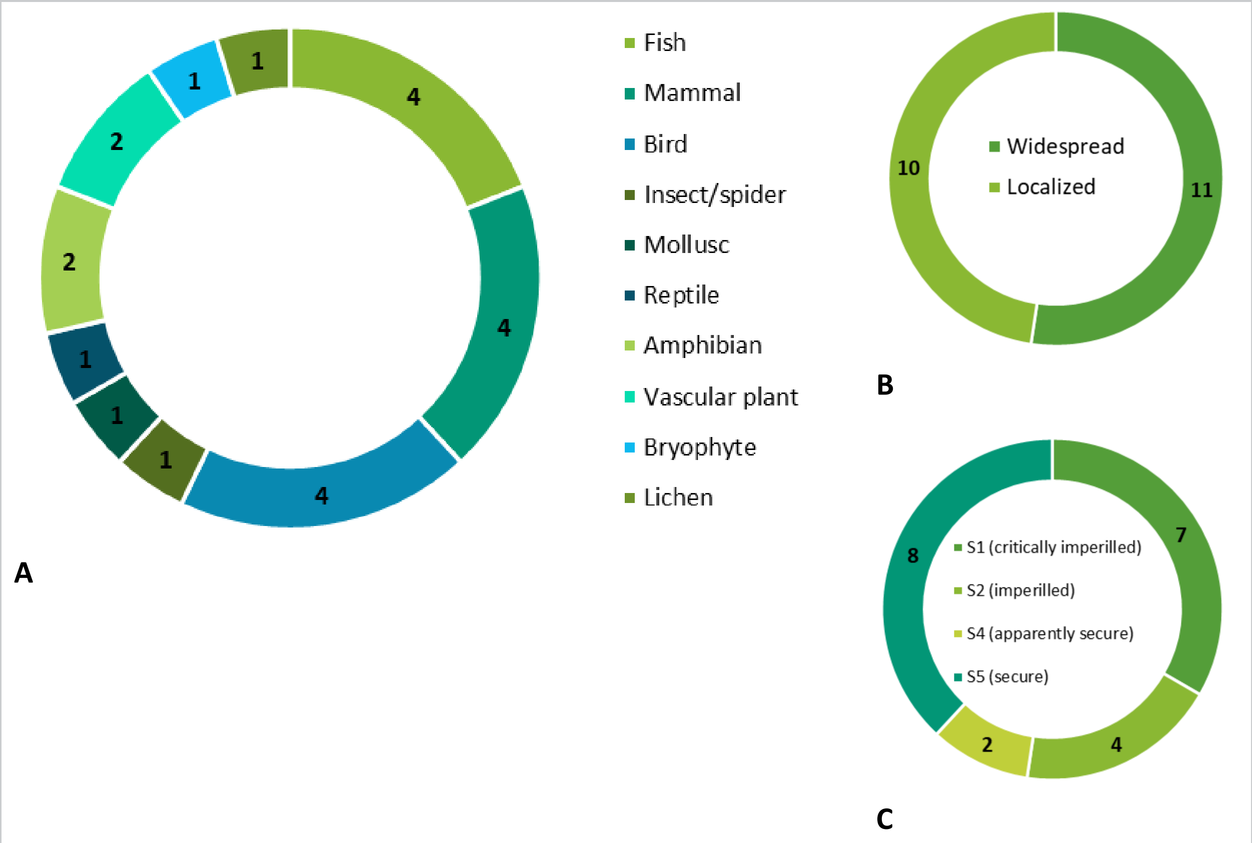


Figure 7.3: Scope of Illustrative Species of Fauna and Flora Assessed Quantitatively in the PCCIA under the Natural Environment Area of Focus.



Caption: Panel A is the distribution of illustrative species by taxonomic group (number), Panel B is the breakout of species occurring throughout the province (widespread) and those of geographically restricted occurrence, Panel C is the breakout of species by conservation staCtus (S-rank).

For ease of assessment, the Ontario Land Cover Compilation (2014a) was used to consider individual habitat types (e.g. land cover), as opposed to a mix that would be present in each ecozone. The nomenclature from the Ontario Land Cover Compilation was retained (e.g. using mudflats instead of coastal wetlands). The final selection comprised ten of 27 land cover types, including a mix of localized and widespread habitats, and considering the potential amount of literature on each habitat type and climate change in our selection. Land cover data from the NALCMS (North American Land Change Monitoring System) 2015 Land Cover project (Natural Resources Canada, 2015) was used to determine the extent of coniferous forest and deciduous forest in each PCCIA region and included these ecosystem types where land cover comprises two percent of land cover or more.

For the assessment of ecosystem services, the Common International Classification for Ecosystem Services (CICES) was used as a point of departure. We selected seven ecosystem services, based on the potential amount of literature available and importance for the province, with a roughly even distribution among regulating services, provisioning, and cultural ecological services.

Natural environments within Ontario's regions are diverse and not all Level 2 categories of ecosystems were assessed for each PCCIA region, nor are all illustrative of Flora and Fauna present across PCCIA regions (as shown in Table 7.2). By design, a mixture of species and ecosystems were included that are localized and of specific significance to regions where they occur and those with a widespread distribution.

Table 7.2: Overview of Natural Environment Level 1 and Level 2 Categories Assessed within the PCCIA

Level 1 Category	Level 2 Category	Illustrative component	Southwest Region	Central Region	Eastern Region	Northeast Region	Northwest Region	Far North Region	Key attributes (including S-rank[18])
Fauna	Fish	*Sander vitreus* (Walleye)							Managed/harvested species, moderate climate sensitivity, widespread, common. S5
		Micropterus dolomieu (Smallmouth bass)							Managed/harvested species, widespread, common, high climate sensitivity (extensive range expansion with climate change), S5
		Clinostomus elongatus (Redside dace)							Climate change vulnerable species with localized distribution. S2
		Salvelinus fontinalis (Brook Trout)							Managed/harvested species, high climate sensitivity, widespread, common, but extensive range contraction and population loss particularly in central and southwest PCCIA regions, S5
	Mammal	*Alces americanus* (Moose)							Managed/harvested species, moderate climate sensitivity, widespread, common, relies on specialized aquatic feeding habitat, S5
		Odocolieus virginianus (White-tailed deer)							Managed/harvested species, widespread, charismatic, common, rely on seasonal concentration areas. S5
		Rangifer tarandus (Caribou, boreal pop.)							Climate change vulnerable species with localized distribution, habitat along migration corridors important. S4
		Myotis septentrionalis (Northern myotis)							Widespread distribution, reliance on seasonal concentration areas (winter roost). S1S2
	Birds	*Meleagris gallopavo* (Wild Turkey)							Managed/harvested species, fairly widespread, common. S5
		Protonotoria citrea (Prothonotary warbler)							Moderate climate sensitivity, migratory, forest associated, localized, charismatic, endangered. S1b
		Charadrius melodus (Piping Plover)							High climate sensitivity, migratory, aquatic, widespread but patchy distribution, endangered. S1b
		Fulica americana (American Coot)							Widespread, charismatic, potential climate sensitivity, relies on marsh breeding habitat. S4
	Insect/Spider	*Trimerotropis huroniana* (Lake Huron grasshopper)							Localized distribution, tied to dune habitats, S2
	Mollusc	*Simpsonaias ambigua* (Salamander mussel)							Climate change vulnerable species with localized distribution. S1
	Reptile	*Plestiodon fasciatus pop. 1* (Common five-lined skink, Carolinian population)							Climate change vulnerable species with localized distribution, reliance on seasonal concentration area. S2
	Amphibian	*Desmognathus fuscus* (Northern dusky salamander)							Climate change vulnerable species with localized distribution, reliance on woodland ponds. S1

[18] S-rank = Provincial conservation ranking: SH (possibly extirpated), S1 (critically imperilled), S2 (imperilled), S3 (vulnerable), S4 (apparently secure), S5 (secure)

Level 1 Category	Level 2 Category	Illustrative component	Southwest Region	Central Region	Eastern Region	Northeast Region	Northwest Region	Far North Region	Key attributes (including S-rank[18])
		Pseudacris crucifer (Spring peeper)							Widespread distribution, common, charismatic, potential climate sensitivity, reliance on woodland ponds. S5
Flora	Vascular plant	*Pinus strobus* (Eastern White Pine)							Commercial coniferous species, widespread; it is Ontario's provincial tree. S5
		Eleocharis equisetoides (Horsetail spikerush)							Climate change vulnerable species with localized distribution. S1
	Bryophyte	*Mielichhoferia mielichhoferiana* (Alpine copper moss)							Climate change vulnerable species with localized distribution. S1
	Lichen	*Arthrorhaphis alpina* (Alpine dot lichen)							Climate change vulnerable species with localized distribution. S1
Aquatic ecosystems	Clear open water (lakes, rivers, and streams)								Includes Great Lakes, widespread occurrence, habitat for multiple and diverse communities and species, supports species at risk, and Indigenous, recreational and commercial interests.
	Bog								Widespread occurrence, considered as rare or specialized wetland communities, along with fens constitute peatlands.
	Marsh								Widespread occurrence, preferred habitat of many of the province's birds.
	Mudflats								Localized occurrence, important habitat for waterfowl stopover or staging areas.
Terrestrial ecosystems	Tundra heath								Localized occurrence, inhabitants include arctic fox and willow ptarmigan
	Coniferous forest								Widespread ecosystem type, providing habitat to diverse species, of commercial interest.
	Deciduous forest								Widespread ecosystem type providing habitat to diverse species, of commercial interest.
	Sand barren and dune								Sand barrens sustain rare vegetation communities and associated wildlife. Dune habitat supports imperiled species and human recreation.
	Open tallgrass prairie								Sustains a rare vegetation community, provincially and globally significant. Fire adapted.
	Tallgrass savannah								Sustains a rare vegetation community, provincially and globally significant. Fire adapted.
Regulating services	Natural carbon storage								Also known as biogenic carbon storage, it is an important aspect of global climate regulation provided by Ontario's natural systems (forests, wetlands, soils), contributing to reduced atmospheric carbon levels or limiting further carbon dioxide accumulation.

Level 1 Category	Level 2 Category	Illustrative component	Southwest Region	Central Region	Eastern Region	Northeast Region	Northwest Region	Far North Region	Key attributes (including S-rank[18])
	Pollination								Fertilization of crops by plants or animals, which maintain or increase the abundance and/or diversity of other species that people use or enjoy. Bumble bee distribution and abundance as a proxy.
	Water flow regulation								Regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems. Includes the capacity of vegetation to retain water and release it slowly.
Provisioning services	Freshwater								Water for drinking (by humans) and non-drinking purposes (e.g. cooling, safe navigation) from natural surface and groundwater sources
	Wood supplies								Biomass from forests, harvested and sold. Focuses on timber products.
Ecosystem cultural services	Recreational fishing								Fishing regulated by the province through licensing.
	Nature-based recreation								Warm-season (hiking, camping) and winter season (skiing, snowmobiling) activities are included, in parks and protected spaces and elsewhere.

7.4 Natural Environment Risk Snapshot across Ontario

Summary of Risks

A changing climate is affecting and will continue to affect Ontario's natural environment in multi-faceted ways (Douglas and Pearson, 2022). Climate change presents direct stressors to species, influences the timing of life stages and population dynamics, species distribution and abundance, as well as water quantity and quality, and frequencies and intensities of disturbances (e.g. wildfires and pest outbreaks). In turn, these changes influence each other causing cascading effects that can reduce or magnify the initial response. Climate change impacts exacerbate threats to biodiversity and ecosystem health caused by human-created stressors, such as habitat loss and fragmentation and pollution. The cascading interactions make isolating distinct risk scenarios driven by individual climate variables challenging. In addition, species and ecosystems have an inherent ability to adjust to or cope with biophysical change, although natural Adaptive Capacity is the least understood of the three dimensions of climate change vulnerability (Thurman et al., 2020).

Changing climate is already a stressor or threat to Ontario's natural systems and the benefits humans derive from them. The current risk profile indicates that about one in ten risks evaluated are currently "high", with the majority rated as 'medium'. Only a small number of specific risk scenarios are scored 'low' (at current) and all pertain to regulating services (carbon storage in southern Ontario). By mid-century, the risk profile shifts substantially, with most risks rated as 'high'. By the end of the century about 25% of the risk scenarios are 'very high'. At this aggregate level results are presented for a high-emissions scenario (RCP8.5). Differences in risk profiles between RCP4.5 and RCP8.5 are presented in Appendix 7.

Risk levels differ by natural element (Level 1 and 2 categories) and across Ontario's regions. Risks to fauna reach the highest levels by the end of century in the Eastern, Central, Southwest regions, with levels of expected development, economic and (human) population growth exacerbating climate stresses to individuals and populations in regions with high biodiversity (Kraus and Hebb, 2020) (see Figure 7.4). When considering risks to aquatic and terrestrial ecosystems, Ontario's Central region and three northern regions stand out as having highest risk levels by the end of the century, with much of the risk driven by the impacts of climate change on northern wetlands ecosystems, including changes in community structure and matter and nutrient cycling, as well as risks from impacts to lake ecology (e.g. mixing and oxygenation).

Key Climate Drivers

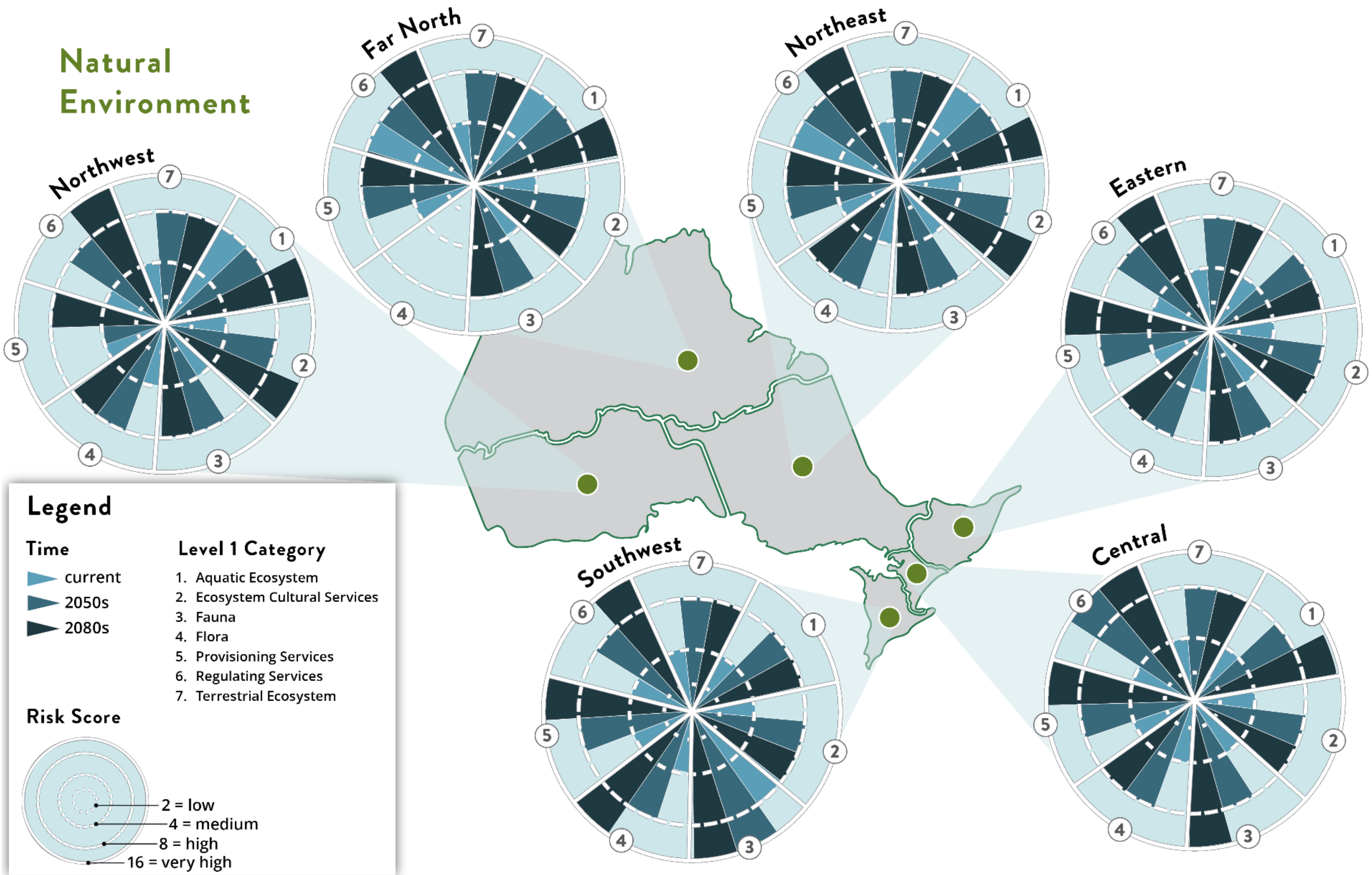
Annual and seasonal increases in temperature represent the broadest climate variable group affecting elements of the natural environment. Mean annual temperature or mean seasonal temperature change were not among the main climate variables in the PCCIA (see Section 3.0), therefore Growing Degree Days generally is used as a proxy. Just over 40% of all natural environment risk scenarios relate to changes in Growing Degree Days (see Table 7.3). Examples of impacts in such risk scenarios include temperature-driven changes in species life-cycle events, mismatches in food web dynamics, habitat-related stress to species (e.g. climate suitability), redistribution of plants and animals, and changes to ecosystem processes (e.g. carbon and nutrient cycling).

Changes in the nature and timing of precipitation also present significant stressors to elements of the natural environment, and are driven by species' reliance on specific hydroperiods, community and ecosystem attributes adapted to specific hydrological conditions, snow, and ice regimes, among others. For example, Moisture Deficits causing fluctuations in water levels have the potential to change vegetation and nesting habitat in wetlands. Reduced snow cover can promote overwintering and expanded ranges among species with deep snow as a limiting factor on survival. A large portion of natural environment risk scenarios involve a precipitation-related variable as a dominant driver of risk. A full list of all major climate variables that are driving the highest risks to Ontario's Natural Environment Area of Focus by Level 1 category and region is available in Appendix 8.

Table 7.3: Main Climate Variables Assessed for the Natural Environment Area of Focus

Climate Variable	Proportion (%) of Area of Focus Risk Scenarios
Growing Degree Days	**41%**
Moisture Deficit/Drought	**20%**
Rain:Snow Ratio	**8%**
Other Variables	**31%**

Figure 7.4: Current and Future Risk Profiles by Region Assessed for Natural Environment (RCP8.5)[19][20]



[19] Appendix 13 provides an alternative visual format of the presented risk results by Level 1 category and region for this Area of Focus.

[20] Note: Proxy species of Flora selected for quantitative assessment occur in all regions but the Far North, which explains why this Level 1 appears empty for that region.

Regional variation also exists for the concentration of risks evaluated as ‘very high’ and their relative change in number from mid-century to end of century. In the 2050s, Southwest and Central regions have the highest number of ‘very high’ risks, and this number doubles by the 2080s. The number of ‘very high’ risks in the Far North also doubled from 2050s to 2080s. ‘Very high’ risks increase six-fold in Eastern Ontario. In southern Ontario, socio-economic factors prominently magnify risk levels, notably for the flow of ecosystem services and in relation to the fate of species at risk. The Far North contains vast swathes of ecosystems and related ecosystem processes of global significance (e.g. peatlands as natural carbon stores), with climate threats combined with potential development representing risks that are not only extensive, but also irreversible.

7.5 Approach to Assessing Climate Impacts on the Natural Environment

A total of 921 unique climate risk scenarios were identified across the seven Level 1 categories under this Area of Focus and were part of the quantitative assessment. Although the overall PCCIA methodology focused on assessing direct impacts (see Section 2.0), this restricted approach for the natural environment was not always appropriate. Climate change risks to flows of ecosystem services are mediated by the health and integrity of biotic and abiotic systems and their vulnerability to climate variables, therefore the assessment of climate risk to provisioning, regulating, and ecosystem cultural services require an understanding of climate-driven impairments or enhancements of underlying natural assets.

Climate risk was defined for each Natural Environment Level 1 category by assessing risk at the scale of selected Level 2 species, ecosystem, or ecosystem service present within regions. Thus, Level 1 category scores are representative of the selected proxies associated with each. For Level 2 categories pertaining to Flora and Fauna, illustrative species were selected based on information on climate change impact and vulnerability, regional relevance, and diversity in representation in conservation status, range, and human interest at the for each Level 1 category. In other words, certain Level 2 risk scores do not depict overall risk for components within the category, but rather present an illustration of risk for the category and inform a fuller picture for the Level 1 categories.

The total number of climate variables assessed in scenarios for different Level 1 categories ranged from four (for Flora, Aquatic Ecosystems, Provisioning Services, and Regulating Services) to seven (for Fauna). The types of climate variables assessed for Level 2 categories depended on evidence of an ecosystem or physical response in the literature (e.g. documented sensitivity), geographic location/distribution, and advice from expert stakeholders received through the PCCIA engagement process. Growing Degree Days, Degree Days <0˚C, and Cooling

Degree Days all act as proxy climate variables for a warming climate or overall change in annual average temperature (see Section 3.0 for further information on the definition of climate variables used in the PCCIA).

Within this Area of Focus, climate variables that can jointly influence impact pathways (e.g. interactive effects) and impact pathways unique to certain regions of Ontario are included. For example, the combined effect of changes in temperature, precipitation and frequency or intensity of extreme conditions is notable for freshwater fish. Warmer water temperatures affect the health, abundance, and persistence of species, with drought exacerbating vulnerability if species are forced into isolated pools and floods (and related sedimentation), causing negative or positive impacts depending on the timing of species reproductive cycle. Changes in temperature, precipitation, and intensity or frequency of drought conditions also shape wildfire (a natural disturbance), leading to complex impact pathways on terrestrial landscapes. Ontario's Far North is underlain by continuous, discontinuous, and sporadic permafrost and contains marine coast, which are unique traits compared to other provincial regions, and highlight the interconnected nature of abiotic and biotic systems. For example, warming temperatures are accelerating permafrost degradation, which may lower the water table, cause slumping, and degrade water quality. In turn, these impacts can lead to loss of coastal wetlands including marshes and shoreline erosion, with cascading impacts on the region's biodiversity, such as through degradation of habitat for several species at risk.

As described in Section 2.0, a single risk scenario was selected for each unique risk interaction. The likelihood of a risk scenario occurrence and associated severity of consequence(s) for each selected component of the natural environment were assessed and combined to form a risk score. Subsequently, risk scores for individual scenarios were compiled to provide an overall risk score for each Level 1 and 2 category.

Consequences for this Area of Focus were evaluated based on two sets of criteria pertaining to environmental damage:

- Environmental loss and damage/ability to recover from impact (modified from Murray et al., 2016)
- Disruption / enhancements to flows of ecosystem services

The first criterion was applied to climate risks associated with species and ecosystems and the second was applied to climate risks for ecosystem services. Literature and expert judgment were used to support consequence scoring. Consequences in relation to environmental loss and damage were assessed qualitatively based on the magnitude of impact in space and time. Consequences in relation to service disruptions were assessed qualitatively based on the geographic reach of the impact, population affected and / or required human response. The consequence criteria applied to this Area of Focus can be found in Table 7.4. The first set of criteria focuses on the ability to recover from climate impacts and the other focuses on the ability of natural assets, such as wetlands and forests, to deliver ecosystem services despite climate threats. The first set of criteria was applied to climate change risks associated with species and ecosystems and the second for climate change risks for ecosystem services.

Examples of consequences related to direct and indirect impacts on species and ecosystems include:

- Change in abiotic conditions (e.g. freshwater hydrological regimes)
- Direct stresses to individuals and populations (e.g. physiology and behaviour of individuals, population dynamics)
- Habitat-related stresses to individuals and populations (e.g. change in habitat quality, loss of suitable habitat)
- Change in synecological relations, specifically change in food web interactions
- Change in community structure (e.g. relative abundances within a community, community composition)
- Change in ecosystem processes and dynamics (e.g. energy flow and nutrient or matter cycle-related ecosystem processes)

Examples of consequences related to direct and indirect impacts on ecosystem services include:

- Change in abiotic conditions (e.g. freshwater hydrological regimes)
- Direct stresses to individuals and populations (e.g. physiology and behaviour of individuals)
- Change in community structure (e.g. relative abundances within a community)
- Change in ecosystem processes and dynamics (e.g. energy flow and nutrient or matter cycle-related ecosystem processes)
- Change in access to services
- Change in availability of services
- Change in quality of services

Table 7.4: Consequence Score Categories and Rubrics Used to Determine Severity of Impact for Natural Environment Area of Focus

Score	Category	Ability to Recover from Impact by Climate hazard	Ability of Natural Asset to Deliver Services Due to Climate Hazard Impact
16	**Very High**	Very serious, widespread, and potentially permanent/irreversible damage or loss to populations demographics and/or habitats (e.g. local extinctions) occurring due to deterioration in habitat conditions, reduced food availability, and/or other factors.	Catastrophic disruptions affecting the entire province or beyond and leading to permanent changes in systems.
8	**High**	Serious impacts on populations and/or habitats from large changes in habitat quality and/or population demographics (e.g. serious decline in reproduction limiting population increase) due to deterioration in habitat conditions, reduced food availability, and/or other factors that will be very difficult (but not impossible) to reverse/mitigate, with a long period likely needed to restore to an acceptable level.	Widespread and long-term disruptions in flows of services, impacting large numbers of people.
4	**Medium**	Wider and longer-term impacts on populations and/or habitats from changes in habitat quality and/or population demographics due to deterioration in habitat conditions, reduced food availability, and/or other factors that will be difficult to reverse/mitigate	Frequent and numerous disruptions within the capacity of the system to recuperate and recover over the medium to short term.
2	**Low**	Minimal impacts on population and/or habitats from small, generally reversible/mitigatable changes.	Many localized disruptions that are easily accommodated by normal system protocols for repair and maintenance, or changes in people's attitudes or behaviour.
1	**Very Low**	Negligible impacts on population and/or habitat structure or dynamics.	Very few localized disruptions that are easily accommodated by normal system protocols for repair and maintenance, or changes in people's attitudes or behaviour.

To update risk consequence scores for the 2050s and 2080s time periods, socio-economic projections were considered along with specific assumptions for natural environment elements in different regions across Ontario (see Box 7).

Box 7: Socio-economic Projections Applied to Natural Environment Area of Focus

As noted, a changing climate is one stressor or type of threat facing Ontario's natural environment. Impacts from other anthropogenic stressors linked to the loss of biodiversity and ecosystem services from development, economic and population growth include: habitat loss, loss of permeable surfaces, habitat fragmentation, increased pollution waste and pollution streams, and the introduction and movement of invasive species, among others.

As described in Section 4.0, socio-economic projections were applied to risk evaluation based on the influence on likelihood of consequence and impact for future risk scenarios. This enabled the consideration of non-climate stressors in our calculation of natural environment risks. For the Natural Environment Area of Focus, we used projections of three socio-economic indices to "uprate" likelihood of impact or consequence scores as part of the risk calculation. The three indices include: Ontario Population Density Index by Region (Population / km^2); Ontario Housing Stock Index by Region and Type of Housing; and Ontario GDP Index by Region and Industry (CDN $2020) (all industries). These three indices (and related sub-indicators) are proxies for non-climate drivers and stressors affecting water, land and resources, and wildlife. For species and ecosystems, it was assumed that significant increases in socio-economic factors from one period to another justified raising the likelihood of consequence score by one level due to exacerbated vulnerability associated with population growth and development. In addition, for ecosystem services, the consequences of impact scores were raised by one level, reflecting an increase in the demand for ecosystem services and, therefore, more severe consequences if service flows become impaired.

7.6 Limitations of the Natural Environment Assessment

The impacts of climate change on the natural environment are widespread, multi-faceted and inextricably linked to the well-being of human communities and regional economies. Additionally, impacts of climate change on living things (species and ecosystems) trigger adaptive responses that can be difficult to predict. These and other complexities limit the utility of generic climate change impact assessment methodologies at broad geographic scales.

Specific Area of Focus limitations within the PCCIA are related to the 1) scope and data inputs, 2) mechanisms of climate impact, and 3) interdependencies and cascading impacts.

Scope and Data Inputs

Ontario's natural environment is incredibly complex and diverse. Within the Ontario PCCIA, risks were evaluated based on illustrative species, habitats and ecosystem services. The assessment was necessarily constrained due to the magnitude and diversity of species and features. Local data, such as monitoring and GIS information that characterizes habitat or species-specific tolerance and response thresholds support the data-driven approach to this impact assessment. However, robust, spatially-explicit information on ecological or physical responses was not always available to complete an internally-focused (Area of Focus-specific) assessment. More detailed species or habitat-specific case studies could inform how climate impacts could change ecosystems in specific areas of Ontario. The final impact assessment scores are reliant on a combination of qualitative considerations from literature reviews and expert judgement of the consulting team and stakeholders.

Mechanisms of Impact

The interaction between climate variables and Level 2 categories are captured via the formulation and analysis of risk scenarios. Formulation of risk scenarios involved desk-based research and application of expert judgement. In developing the risk interactions and scenarios, several assumptions were made about the mechanisms of climate impact. Importantly, the scope of the PCCIA engagement process (see Appendix 3 for engagement details) precluded reviewing detailed interim products, such as the full list of risk interactions and scenarios. Future assessments should consider steps to bring together knowledge holders to conceptually map impact pathways and validate and adjust risk scenarios through a participatory process.

Complex and Cascading Impacts

The application of the 'Most Probable Worst-Case Event' for risk scenarios and assessment is a particularly challenging concept to apply to the Natural Environment Area of Focus. Many of the impacts to natural environment may be gradual and/or complex, rather than one single worst-case event causing significant impacts. Further, the indirect and cascading impacts of climate change defy quantitative and semi-quantitative impact assessments of the scope typically desired at the provincial level (e.g. breadth of climate variables, Level 1 and 2 categories included). Raising the visibility of indirect and cascading impacts stemming from impairments to the natural environment is particularly important given, a) the heightened recognition of strategies to address the twin crises of climate change and biodiversity loss and b) the fundamental role played by ecosystem resilience in supporting resilience of other systems like natural resource industries, agriculture, human health, and wellness (CCA, 2019). This PCCIA demonstrates five broad types of cross-sectoral impacts that merit consideration in

Ontario's adaptation planning (see Section 10.0). In future assessments, further scenarios of cascading impacts should be explored and discussed, tailored to different environments and ecoregions.

7.7 Current and Future Risks

7.7.1 Fauna

Overview

Fauna refers to the animal life in a particular region. Fauna are the fish, mammals, birds, insects/spiders and other organisms that are present throughout all regions of Ontario, with their range depending on features such as climate, land-use patterns, physiographic regions, and forest types (Dobbyn, 1994). Ontario has high species diversity relative to other jurisdictions in Canada (Ontario Biodiversity Council, 2021), with Southwest, Central and Eastern regions ranking among the most biodiverse ecoregions in Canada (Kraus and Hebb, 2020). Within the categories of fauna assessed for this report (fishes, mammals, birds, insects/spiders, molluscs, reptiles and amphibians), insects/spiders make up about 90% of the list of Ontario species maintained by the Natural Heritage Information Centre. Although most of these fauna species are secure, about one percent are species at risk – that is – species that are in danger of disappearing (Office of the Auditor General of Ontario, 2021a). Globally, key threats to species diversity include habitat loss/degradation, overexploitation, invasive species, climate change, and pollution (IPBES, 2019). Threats to biodiversity are similar for fauna in Ontario overall but differ by region and extent of development pressures.

Fauna provides numerous social, economic, and cross-sectoral benefits to people and their well-being (Nantel et al., 2014). Important ecosystem services such as pollination, food provision, and nature-based recreation depend on healthy fauna, and the broader ecological communities and functions they support. Species, including fauna, have diverse value beyond their usefulness to humans as a resource or natural asset, including intrinsic values and intangible values tied to culture (e.g. Indigenous views of boreal woodland caribou as sacred gifts from the Creator) (Anderson et al., 2022; Assembly of First Nations and David Suzuki Foundation, 2013).

The impacts of climate change on fauna occur at different levels, affecting individual species, populations, or communities of species (Geyer et al., 2011), with vulnerability to these impacts depending on capacity for dispersal or movement, sensitivity to temperature and precipitation change, reliance on particular physical features, synchrony with other species on which they depend, and genetic factors (NatureServe, 2016). Species' vulnerability to climate change is often due to more than one of these factors. For example, species may be unable to shift their range to accommodate rising temperature because of natural or anthropogenic barriers, limited dispersal ability, or their reliance on a specialized habitat niche (Brinker et al., 2018). Further, one single climate variable, such as temperature rise can cause direct and cascading impacts for fauna. Temperatures exceeding species' thermal tolerance force a shift to their ranges toward cooler environments (Brinker et al., 2018; Soroye et al., 2020; Dove-Thompson et al., 2011). Changing annual and seasonal temperatures provide additional challenges to native fauna by accommodating the spread of invasive and predatory species whose ranges may also shift to new environments favorable to their niches (Brinker et al., 2018, Mortsch et al., 2006). All of these stresses, combined with non-climate stresses, can lead to local or widespread declines in species populations and a loss of biodiversity.

For the purposes of the PCCIA, seven Level 2 categories were used to assess the risks associated with the direct impacts to fauna: fishes, mammals, birds, insects/spiders, molluscs, reptiles, and amphibians. To make the assessment tractable, illustrative species were selected for quantitative risk assessment, but it is critical to recognize the regional diversity of fauna and the unique climate sensitivities of species (including conservation status) in extrapolating or generalizing risk results to the level of taxonomic groups. Nevertheless, patterns of climate change vulnerability across taxonomic groups have been illustrated by previous research. Most recently, a landmark Ontario study on the climate change vulnerability of species in the Great Lakes Basin shed light on high-level patterns of vulnerabilities across taxonomic groups. Brinker et al., (2018) found that birds, insects/spiders, and reptiles are generally found to be more resilient to climate change impact while species that depend heavily on water (e.g. fishes, amphibians, and molluscs) tend to be more vulnerable. Support for comprehensive and broad-scale studies such as Brinker et al., (2018) is necessary to continue building Ontario's knowledge base on climate change risks to the natural environment.

Direct Impacts

The following sections provide brief characterizations of each Level 2 category assessed for fauna across Ontario and related risk results. Risk scenarios for fauna were driven by climate variables related to temperature and precipitation, including average temperature, high and extreme temperature, Moisture Deficit, extreme precipitation events and winter precipitation. Changes in severity and occurrence of assessed climate variables could lead to environmental consequences of the following types:

- Changes in the physiology and behaviour of individuals
- Changes in population dynamics
- Increases in habitat-related stresses
- Changes in food web interactions
- Changes in relative abundance of a species within a community

Examples of climate risk scenarios for each Level 2 category appear in Table 7.5. Table 7.6 provides the risk profiles for each Level 2 category assessed under fauna, by region and timeframe (operating under RCP8.5), at the end of this section.

Table 7.5: Illustrative Risk Scenarios for Fauna

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Fishes (Brook trout)	Suitable thermal habitat is significantly reduced in the summer for the cold-water fish brook trout, requiring the species to seek refuge. A lack of habitat connectivity prevents this and causes local extirpations and a loss in indigenous brook trout biodiversity.	**High**
Mammals (Moose)	Growing Degree Days will exceed the upper temperature threshold for moose, causing regional extirpation as their range shifts northward.	**Medium**
Birds (Prothonotary warbler)	Drought conditions reduce the suitable breeding habitat for the prothonotary warbler, potentially to the point of extirpating the species from Ontario.	**Medium**
Insects/ Spiders (Lake Huron grasshopper)	Lake Huron grasshoppers may undergo loss of suitable habitat from lower water levels that favour vegetation succession over the building of dune habitat along the lake coast.	**Low**
Mollusc (Salamander mussel)	Water temperatures could exceed the salamander mussel's upper thermal limit. Extreme weather events resulting in the stranding (low flow scenario) or scouring (high flow scenario) of the species would also put it at high likelihood of extirpation.	**Low**
Reptile (Common five lined skink)	Warming temperatures may facilitate a range expansion of the common five-lined skink, increasing genetic diversity.	**Medium**
Amphibian (Spring peeper)	Earlier onset of Spring Peeper breeding increases competition for food and creates mismatches in food webs (predator-prey systems) ultimately affecting the health of local populations.	**Medium**

Amphibians

According to the Natural Heritage Information Centre, 34 species of amphibians are present in Ontario, with under 20% of those species threatened or of special conservation concern (Office of the Auditor General of Ontario, 2021a). Exposure to warmer seasonal air temperatures, spring temperatures in particular, is one mechanism of potential climate change impact for amphibians, with effects including changes in the rate and timing of lifecycle events (e.g. earlier breeding) and related implications on synecological relations (Blaustein et al., 2001). Due to their semi-permeable skin and high reliance on aquatic resources throughout their lifecycle, amphibians are also highly sensitive to climate-change induced shifts in aquatic resources and environments (Parmesan, 2007).

Changing length in hydroperiods, seasonal shifts in freeze-thaw periods, and drought-prone summers pose significant threats to amphibian habitat and breeding grounds (Luymes and Chow-Fraser, 2022). Amphibians typically reproduce in ephemeral pools, which are influenced by the phenology of a wetland's hydroperiod (Brinker et al., 2018). Forested ephemeral pools among unimpacted forest networks are thus integral to amphibian recruitment, but increasing habitat fragmentation and alterations from encroaching urban and agricultural sectors, particularly in Southwest and Central Ontario, have contributed to greater canopy openness and declines in wetland habitat (Luymes and Chow-Fraser, 2022).

Projected changes in rates of precipitation and evaporation owing to higher temperatures can further decline their accessibility to these pools, resulting in cascading impacts on reproductive success, population sizes and overall health (Brinker et al., 2018). Among amphibian habitat types, large permanent wetlands are afforded more protection, while temporary wetlands such as ephemeral pools are underrepresented among management and conservation efforts (Luymes and Chow-Fraser, 2022).

Climate risks to amphibians were assessed across the six PCCIA regions, with risk scenarios driven by a range of climate variables including, temperature changes (Growing Degree Days) and drought conditions (Moisture Deficit). Northern dusky salamander (Desmognathus fuscus) and spring peeper (Pseudacris crucifer) are the illustrative species used to highlight climate risks to both localized and endangered species as well as widespread and secure species, respectively (Box 8).

Box 8: Species Used to Characterize Climate Risks to Ontario's Amphibians

Northern dusky salamander (Credit: K. Ueda, CC BY NC 2.0)

Northern dusky salamander is an amphibian with distribution in Ontario that is restricted to a single stream site in the Niagara Gorge (e.g. Southwest region) (COSEWIC,, 2012). Although globally listed as a secure species, it extremely rare and especially vulnerable to extirpation from the province, listed as an endangered species both provincially and federally (Brinker et al., 2018, COSEWIC, 2012). Aside from limitations on suitable habitats, major threats to this salamander include environmental and demographic stochasticity, disruption or contamination of groundwater discharge sources, and streambank erosion.

Spring peeper (Credit: P. Paplanus, CC BY 2.0)

Spring peeper is a tiny frog with widespread distribution and abundance in Ontario. It is found in a wide range of non-urban habitats across Ontario's regions, tending to breed in temporary woodland ponds, summer under leaf litter and hibernate under logs and loose bark. The spring peeper's breeding call in the spring –a loud, high-pitched peep repeated over and over – is widely recognized by Ontarians and is one of the earliest frog breeding calls. Its blood chemistry allows it to withstand temperatures a few degrees below zero (Ontario Nature, nd).

The current climate risk profile associated with the environmental consequences from climate change impacts to amphibians is rated as 'medium' in all regions, except in the Southwest region where current risk levels are 'high', influenced by the high vulnerability of the Northern dusky salamander. By mid-century risk levels are 'high' across southern Ontario (Central, Eastern and Southwest), whereas in northern Ontario risk levels stay at 'medium'. By late century (2080s) risk levels are 'high' across the province. The risk results are consistent regardless of whether emissions follow a high emissions scenario (RCP8.5) or a moderate emissions scenario (RCP4.5), with socio-economic projections of population growth, urban and industrial development exacerbating risk in southern Ontario. Current risk levels are consistent with observed impacts of warming temperatures on reproductive processes within amphibian communities (Walpole et al., 2012; Klaus and Lougheed, 2013).

Warmer springs alter breeding behaviour of amphibians, reducing the risks from reproductive failure but increasing the level of niche overlaps among species. Spring peepers demonstrate advancing phenology (e.g. earlier reproduction) in correlation with warmer spring temperatures (Blaustein et al., 2001; Klaus and Lougheed 2013; Gibbs and Breisch, 2001). Since spring peepers require ephemeral pools to reproduce successfully, breeding earlier in the spring reduces the risk from reproductive failure when vernal pools dry out later in the season (Walpole et al., 2012). However, if rising temperatures lead to ephemeral pool evaporation before breeding can occur, reproductive success could decline. Because amphibians are key components of many ecosystems, changing reproductive timing for spring breeding anurans (frogs and toads) like spring peepers has potential to affect other species within their communities, creating mismatches in food webs, and ultimately affecting population health (Walpole et al., 2012; Blaustein et al., 2001).

More intense or frequent dry conditions have potentially profound implications for amphibian population and species persistence. For example, northern dusky salamanders rely on their moist skin for respiration (Markle et al., 2013), making drought a particularly impactful climate variable. Adult northern dusky salamanders require suitably moist habitat to ensure that they can effectively absorb oxygen through their skin and mucous membranes (Markle et al., 2013; CESCC, 2016). Larvae are reliant on access to slow-moving streams or seeps for eight months of the year before they metamorphose (Markle et al., 2013). A supraseasonal drought (hydrologic drought) of one year or more, results in quite a low probability of persistence of the species. Droughts would reduce water flow in the stream sites where northern dusky salamanders are found in Ontario. No other suitable habitat develops near their stream sites to serve as a refuge for temporary emigration during a drought. The probability of persistence after a four-year drought is almost zero (Price et al., 2012). Given that the northern dusky salamander is restricted to one site in Ontario, such climate conditions may cause extirpation from the province.

Birds

According to the Natural Heritage Information Centre, 511 species of birds inhabit Ontario's forests, grasslands, fields, and shores, possessing diverse habitat requirements, diets, and periods of activity (González-Salazar et al., 2014; OMNR, 2011). Birds are less vulnerable to climate change relative to other assessed groups of Ontario fauna, due to their ability to disperse (Brinker et al., 2018). Nevertheless, risk factors to birds from climate change include gains or losses in habitat (for breeding, migration, and other purposes), degree of dependence on ecological synchronicities, degree of habitat specialization, and migration distances in the case of non-resident birds (Galbraith et al., 2014).

Migratory birds are vulnerable to climate-induced changes in phenology, with large-scale shifts in spring migration times already observed in the range of two days per decade, or one day per degree Celsius of warming (Hurlbert and Liang, 2012; Usui et al., 2016). The long-term consequences of temperature-related shifts in migration timing on species and whole populations, such as range expansions along poleward margins (Coristine and Kerr, 2015), are uncertain but examples of shorter-term responses are available. For example, extended breeding seasons due to earlier spring arrivals of species can disrupt synchronicities in food or habitat resource availability and abundance (Hoover and Schelsky, 2020). Longer distance migratory birds, whose migration timing is primarily influenced by the length of daylight (e.g. photo period), face additional challenges with local changes along their migratory path, as they may be unable to adjust departure dates to conditions at stopover sites and in their arrival breeding grounds (Zaifman et al., 2017, Hoover and Schelsky, 2020).

For waterfowl, local air temperatures and the amount of snow cover are influential factors in migration timing, and in general, northward shifts in wintering range have been observed (Thurber et al., 2020).

Birds are sensitive to climate change impacts on breeding, wintering, and migration habitat. For waterfowl, spring-time water levels and wetland habitat are critical to breeding success, including pair density and quality of breeding (Dove-Thompson et al., 2011). Habitat quality, as determined by the network and permanence of wetland complexes, is important to waterfowl and shorebird breeding and influences annual population sizes. Periods of drought and variability in rainfall, combined with land-use/land-cover changes pose significant threats to populations in Ontario (Dove-Thompson et al., 2011, Galbraith et al., 2014). For coastal shorebirds, sea level rise and more intense storms will reduce wintering habitat, especially in areas affected by land surface subsidence (Galbraith et al., 2014). Climate change-induced losses in terrestrial ecosystems (see Section 7.7.4) will impact bird species associated with forested and vegetated habitats for breeding, food sources, and migratory stopover habitat, including migratory, perching songbirds and ground-dwelling birds.

Climate risks to birds were assessed across the six PCCIA regions, with risk scenarios driven by a range of climate variables, including temperature changes (Growing Degree Days and Growing Season Length as proxies for changes in average annual temperatures), low temperature (Degree Days < 0˚C), winter precipitation (Rain to Snow Ratio), extreme precipitation, and drought (Moisture Deficit).

Wild turkey (Meleagris gallopavo), prothonotary warbler (Protonotoria citrea), piping plover (Charadrius melodus), and American coot (Fulica americana) are the illustrative species used to highlight climate risks to land-based game birds, migratory songbirds, shorebirds, and waterfowl, respectively (Box 9). In addition, risk results include the generic assessment of climate risk to “migratory songbirds” and “waterfowl” overall.

Box 9: Species Used to Characterize Climate Risks to Ontario's Birds

Wild turkey (Credit: St. Maslowski, USFWS, public domain image)

Wild turkey is a large, gregarious, and omnivorous ground-dwelling bird with distribution across Ontario, excluding the Northwest and Far North regions. It uses a mix of forest and open areas (e.g. agricultural fields). Unregulated hunting and habitat degradation led to its extirpation for almost a century, but the species was reintroduced and populations restored (OMNR, 2011). Wild turkey is harvested in the province as game and is growing in popularity (Tonelli, 2021).

Prothonotary warbler (Credit: H. Mays, CC BY-NC-SA 2.0)

Prothonotary warbler is an endangered passerine bird species with a distribution in Ontario restricted to the Southwest region. The species is a charismatic, migratory, habitat specialist that nests in tree cavities in flooded woodlands and eats spiders and other small invertebrates (OMNR, 2011). Habitat loss and degradation, including in its wintering grounds, have driven population declines.

Piping plover (Credit: G. Nieminen, USFWS, public domain image)

Piping plover is a small, endangered migratory shorebird, found to breed along the shores of the Great Lakes and northwestern Ontario. It eats insects and small crustaceans and nests on sandy or gravelly beaches above the high-water mark. Human disturbance to beaches, storm surges and severe weather are main threats to the species.

American coot (Credit: C. Klebba, CC SA)

American coot is a common waterfowl species found across the Northwest, Northeast, Eastern, Central, and Southwest provincial regions. It requires shallow freshwater and marsh vegetation for breeding. In non-breeding seasons the species can occupy diverse aquatic habitats, including ponds in city parks. Its diet is omnivorous.

The current climate risk profile associated with the environmental consequences from climate change impacts to birds is rated as 'medium' across all regions of Ontario, with risk levels increasing to 'high' by mid-century and stabilizing at that level across the province by late century.

Current and future risk levels for waterfowl specifically, are 'high' and 'very high' in Southwest and Central Ontario, with the effect of exposure to climate conditions exacerbated by anthropogenic threats to species' habitats. Current risk levels are consistent with observed bird responses to warming temperatures (Hurlbert and Liang, 2012; Usui et al., 2016), in some cases leading to northward range expansions due to milder winters (Nguyen et al., 2003, MacDonald, 2018). Assessing climate change risks for migratory birds, both land and water-based, is complex due to the possibility of exposure to climate and non-climate related stressors to birds along their migratory routes. It is important to note that this assessment is limited to assessing climate impacts experienced only within Ontario.

Warmer temperatures and extended growing seasons present direct stresses to the health of individuals and populations by creating mismatches in the timing of life cycle events and requirements for survival. For example, the migration and nesting timing of many songbirds is aligned to ensure maximum food availability for their young (Stanley et al., 2012). Changes to the growing season length in Ontario will result in a mismatch between the arrival of migratory songbirds and availability of foods such as insects. This de-synchronization threatens the survival and reproduction of migratory songbirds, which can lead to declining populations (King and Finch, 2013). A similar risk exists for waterfowl species, where an extended growing season in Ontario may create mismatches between the hatching of waterfowl chicks and availability of foods for some waterfowl species, in turn reducing waterfowl survival rates and abundance (Adde et al., 2020).

Conversely, warmer winters and decreased snow depth creates favourable conditions for improved survival and range expansion of ground-dwelling species currently limited by low temperatures. Deep powdered snow and severe winter conditions are associated with reduced survival of wild turkey populations due to increasing food requirements to meet thermoregulatory demands (Haroldson et al., 1998), reduced availability of food and cover, and increased vulnerability to predation (Niedzielski and Bowman, 2014). Studies show that deep snow forces wild turkeys to travel further to find food when local resources are covered (Nguyen et al, 2003), delays nest establishment and poult development with a snow depth of greater than 30 cm for more than 10 days drastically decreasing odds of survival (Lavoie et al., 2017). Therefore, interactions associated with milder winters and reduced snow cover (e.g. low temperature) revealed potential opportunities related to improved winter survival and northward range expansion. This expansion is already occurring in Ontario (Brinker et al., 2018).

Climate-change induced fluctuations in water levels can degrade habitat quality and availability, influencing bird population dynamics. For example, the prothonotary warbler is vulnerable to extreme precipitation events, such as intense storms. More frequent and intense storms that cause loss or damage to the species' wintering and breeding habitat pose a serious threat to the species due to its clumped and restricted distribution in Canada (Ontario Ministry of Natural Resources and Forestry, 2012). Similarly, fluctuations in water levels linked to extreme flooding events (Ontario Ministry of Natural Resources and Forestry, 2012) can submerge or erode dunes and render this habitat insufficient for the piping plover to breed successfully (Gratto-Trevor and Abbott, 2011). Despite several Ontario populations of piping plovers being found in a provincially protected areas (Ontario Ministry of the Environment, Conservation and Parks, 2019), events causing nesting habitat to become unreliable, increase the likelihood of extirpation (Ontario Ministry of Natural Resources and Forestry, 2012).

Marsh nesting obligate species, such as the American coot, are vulnerable to hydrological variability (Mortsch et al., 2006). Unless offset by increasing precipitation, increasing temperatures may lead to higher rates of evaporation thereby reducing water levels (Dove-Thompson et al., 2011). Suboptimal water levels, decreasing wetland coverage for reasons unrelated to climate change, and temperature-induced expansions in invasive and predatory species taken together reduce habitat suitability for the American coot, with the potential of population declines and local extirpations (Mortsch et al., 2006). Climate vulnerability assessments for inland waters in the Great Lakes basin indicate that habitat suitability for the American Coot is likely to decrease by mid- and end of century in multiple climate scenarios (Chu, 2015).

Fish

145 species of fishes inhabit Ontario's lakes and streams, distributed regionally following latitudinal gradients in climate, land use patterns and fish species richness (Smith et al., 2021). Cold-, cool-, and warm- water fishes – thermal guilds to study and manage fishes – are adapted to specific thermal niches. Thermal niches are influenced by channel flow rates and morphology, riparian vegetation, adjacent land use and land cover, ground water discharge, and air temperatures, that are likely to fluctuate in Ontario under climate change (Chu et al., 2005). Timing of the spring freshet, groundwater discharge and temperature variability in particular can lead to thermal stratification and changes in fish habitat use, with potential habitat overlaps among previously niche-differentiated species (Chu et al., 2005; Brinker et al., 2018). Habitat overlaps may lead to competition over resource use and space that can be further exacerbated by the introduction and expansions of invasive and predatory species (De Stasio Jr. et al., 1996, Chu et al., 2005).

Cold-water species may be most vulnerable to changing air temperatures and water temperatures, particularly determined by water depth since shallow water bodies (e.g. small lakes) may lose habitat space more quickly with increased warming (Brinker et al., 2018; Smith et al., 2021). Fish range dispersal is already limited to aquatic networks, which may be fragmented by the addition of anthropogenic barriers that restrict movement, including dams and culverts (Brinker et al., 2018).

Climate risks to fishes were assessed across all six PCCIA regions, focusing on risk scenarios driven by temperature changes, specifically Growing Degree Days, which have been increasingly used to explain variation in fish growth and development, since air temperature was first used as a surrogate for water temperatures. Brook trout (Salvelinus fontinalis), walleye (Sander vitreus) and smallmouth bass (Micropterus dolomieu) are the illustrative species used to highlight climate risks to cold water, cool water, and warm water fishes, respectively. In addition, risk results include the assessment of climate risks to redside dace (Clinostomus elongatus), a species at risk (see Box 10).

The current climate risk profile associated with the environmental consequences from climate change impacts to fish is rated as 'high' in southern Ontario (Central, Eastern and Southwest) and 'medium' in northern Ontario (Northeast, Northwest and Far North), increasing to 'high' for future time periods. Current risk levels are consistent with observed impacts of warming temperatures on fish distributions, phenology, among other traits (Lynch et al., 2016, Krabbenhoft et al., 2020), as well as studies simulating changes in volumes of thermal lake habitat available to fishes (Smith et al., 2021).

Risk profiles differ among cold-water, cool-water and warm-water fish species. Increases in average annual temperature (Growing Degree Days) in Ontario will alter the amount of suitable habitat for fishes, influencing their growth rate, abundance, and distribution. One simulation study based on long-term monitoring of lakes reported that the extent of thermal habitat available to cold-water fishes like brook trout, will decline by over 50% by the 2080s (under high emissions scenario, RCP 8.5) compared to current habitat, with larger habitat losses expected in Northwest and Northeast regions (Smith et al., 2021). Cool-water fishes like walleye may gain suitable habitat toward mid-century, but then suffer declines by the 2080s in a high emissions scenario (RCP8.5). The same study projects sizeable gains in suitable habitat for warm-water fishes like smallmouth bass under moderate and high emissions scenarios (RCP4.5 and RCP8.5).

Box 10: Species Used to Characterize Climate Risks to Ontario's Fishes

Brook trout (Credit: R. Hagerty, USFWS, public domain image)

Brook trout is a cold-water fish species found in lakes and streams of Southwest, Eastern, Central, Northwest, and Northeast regions. They are indicative of healthy aquatic ecosystems and are adapted to cold, clean, well oxygenated waters, and require groundwater upwellings for spawning and thermal refuge. The species is commonly targeted for recreational fisheries.

Walleye (Credit: E. Engbretson, USFWS, public domain image)

Walleye is a cool-water fish native to Ontario, with distribution across the province. Walleye are a preferred recreational fish for anglers in Ontario and are targeted in summer, fall, and winter. The popularity of fishing for walleye is on the rise (McGuigan, 2022).

Redside dace (Credit: H. Zell, CC BY-SA 3.0)

Redside dace a cool-water fish occurring in much of Ontario, except the Northwest and Far North. Most populations in Ontario are from streams in the Greater Toronto Area. The species is endangered in Ontario, with habitat loss and degradation from urbanization and agriculture as its most significant threats.

Smallmouth bass (Credit: S. Stukel, USFWS, public domain image)

Smallmouth bass is a common species of warm-water fish occurring throughout Ontario. The species is commonly targeted for recreational fisheries.

As a cold-water fish, brook trout's optimal water temperature range is between 13-17°C (Smith and Ridgway, 2019). Water temperatures exceeding 20°C cause stress and adverse physiological impacts (Dove-Thompson et al., 2011; Mackey et al., 2021). These impacts translate to a reduced ability to compete with other fish species like the non-native Brown trout, avoid predators, and capture prey (Di Rocco et al., 2015; Chetkiewicz et al., 2018). A response to significant reductions in suitable thermal habitat leads is to seek refuge, often in headwaters. However, this may be prevented by lack of habitat connectivity, which causes mortality, local extinctions, and loss of brook-trout biodiversity (Di Rocco et al., 2015). Die-offs are anticipated without adequate thermal refuge (Gunn and Snucins, 2010; Robinson et al., 2010).

In contrast, walleye's thermal tolerance presents a mixed picture when comparing across regions. In southern regions of Ontario, warmer temperatures in summer and fall could well exceed the optimum performance range for walleye (24˚C), offsetting any benefits from increased recruitment due to warming temperatures in the spring. (Shuter et al., 2002). Warming in Northeast Ontario create more favourable conditions for walleye recruitment, growth, and survival, increasing the species' abundance in this region (Shuter et al., 2002). Although walleye's range is expected to expand northward, their overall occurrence in the province is likely to decline.

As an endangered, small-bodied fish drawing attention to climate risks posed to redside dace is important. This fish prefers water temperatures below 20°C and spawn when temperatures reach ~18°C (COSEWIC, 2017). Laboratory studies suggest that this species is not currently at its thermal limit but is most sensitive to local temperature pulses in the summer (Leclair et al., 2020). Growing Degree Days exceeding the optimal range may result in year-round fitness consequences as well. In combination with anthropogenic stressors (e.g. riparian vegetation removal), redside dace populations are likely to experience acute temperature increases that exceed their survival ability (Brinker et al., 2018).

Warm-water fishes are likely to benefit from climate change. For example, the smallmouth bass can withstand temperatures between 15 and 27°C (Smith et al., 2021). Warmer temperatures will increase habitat for warm-water fishes in the Central, Northeast, Northwest, and Far North regions of Ontario. Assuming habitat connectivity or introductions by humans, new thermal habitats for warm-water fishes have resulted in range shifts of approximately 13 to 17.5 km per decade in the last 30 years in Ontario lakes (Alofs et al., 2014), and expanding northern range limits anticipated due to climate change (Chetkiewicz et al., 2018; Chu et al., 2005).

The expansion of other warm-water fish species such as smallmouth bass into cold- and cool-water fish habitat is a concern for some populations due to competition for food and space and predation on juveniles (Kerr and Grant 2000; Weidel et. al. 2000, Lynch et al., 2016). Increasing overlap in occurrence of smallmouth bass and walleye is anticipated for Ontario lakes, with this overlap happening despite shifting walleye distribution because smallmouth bass are invading lakes more quickly than walleye are becoming extirpated (Van Zuiden et al., 2016). This co-occurrence of species may result in predation by smallmouth bass and competition for space and prey resources, leading to extirpations in southern and south-central lakes (e.g. Southwest and Central regions).

Insects / Spiders

According to the Natural Heritage Information Centre, 11,621 insect and spider species are present in Ontario, with less than 1% of species threatened or of special concern (Office of the Auditor General of Ontario, 2021a). In general, information is lacking on the distribution, life histories, diets, habitat requirements and dispersal capabilities of insects/spiders to determine species responses to climate change and shifts in range distributions, as most studies focus on Lepidoptera (butterflies and moths) and Odonata (dragonflies and damselflies) (Brinker et al., 2018). Nevertheless, the climate change vulnerability assessment by Brinker et al., (2018) on Ontario species present in the Great Lakes Basin suggests that insect and spider species show climate resilience. Warming temperatures and corresponding decreases in frost period have already facilitated range expansions of several insect species within Ontario (Finkbeiner et al., 2011). Other possible mechanisms of impact include physiological and behavioural responses as well as losses in climatically-suitable habitat. Physiological responses to shifting climate conditions by individuals include changes to reproduction cycles (e.g. diapause), and/or metabolism (Sgrò et al., 2016). Landscape level threats to habitat suitability include changes in hydrology and flow rates related to climate changes, as many aquatic insects have a narrow hydrologic niche (Brinker et al., 2018).

Climate risks to insects and spiders were assessed across all six PCCIA regions, with risk scenarios driven temperature changes (Growing Degree Days) and dry conditions (Drought/Moisture Deficit). Lake Huron grasshopper (*Trimerotropis huroniana*) is the illustrative species used to highlight climate risks to insect/spiders. Endemic to the Great Lakes Basin, the Lake Huron grasshopper is a threatened species found in the Southwest, Central, and Northeast regions, its distribution restricted to the availability of dune habitats in which it lives (Brinker et al., 2018). In addition, risk results include the generic assessment of climate risk to insects/spiders overall, based on information in Brinker et al., (2018).

The current climate risk profile associated with the environmental consequences from climate change impacts to insects/spiders is rated as 'medium' in all regions of Ontario. Risk levels remain 'medium' to the end of the century for the Northwest and Far North regions. Risk levels escalate to 'high' by mid-century for Southwest, Central, and Northeast regions, with scores driven by a combination of elevated risk for the Lake Huron grasshopper (e.g. a species at risk) and anthropogenic pressures that exacerbate climate change vulnerability, especially in southern Ontario. By late century risk levels reach 'very high' for Southwest and Central regions of Ontario and 'high' for Northeast and Eastern regions.

Climate risks to insects/spiders stem from habitat-related stresses. In general terms, dryer and warmer conditions have the potential to reduce suitable habitat for native insects and spiders. Species with specialized habitats are most vulnerable. For example, species with narrow hydrological niches, such as those reliant on headwater streams, ephemeral ponds, or seepage slopes, are vulnerable to fluctuations in moisture levels and seasonal drying. Species reliant on specialized wetlands (e.g. mineral wetlands) are vulnerable to changes in plant communities, such as through temperature-driven increases in evapotranspiration and related effects on groundwater levels. Species with narrow thermal niches, such as those restricted to cool environments, could lose suitable habitat as temperatures rise.

Warmer temperatures can amplify habitat-related impacts of stressors to insect/spider species that are already imperiled. For example, rising temperatures and increased evapotranspiration could lower lake water levels and favour vegetation succession over the creation of dune habitat, which is critical for the endangered Lake Huron grasshopper (COSEWIC, 2015). Mechanisms of impact in this case are complex, as other climatic variables aside from temperature, such as total precipitation and wind speed, affect the rate of vegetation succession and dune building. The variables would have to favour vegetation encroachment into dune habitats, and lake water levels would have to remain low for a long enough for dune habitat to be lost. Anthropogenic disturbances and temperature-induced expansions in invasive and predatory species further affect the Lake Huron grasshopper by limiting available habitat and displacing preferred food sources.

Mammals

According to the Natural Heritage Information Centre, 96 mammal species inhabit Ontario's landscapes and waterscapes, with physiographic regions and forest types key in shaping mammal distribution (Dobbyn, 1994). The considerable variability and habitat requirements exhibited by mammal species, including the survival, distribution, and abundance of hibernating mammals, all likely to be influenced by climate-related changes (Rodenhouse et al., 2009, Brinker et al., 2018).

Limited thermal tolerances, food availability, habitat structure, expanding range and populations of invasive species, parasites and diseases, and weather-related changes in snow depth/ice and heat stress pose significant threats to mammals overall (Rodenhouse et al., 2009, Brinker et al., 2018). Smaller-sized mammals such as bats have high energy demands to survive their hibernation period, which is threatened by changes in food supply (e.g. flying insects who are vulnerable to changes in stream flow and precipitation), resulting in changes to their hibernation periods (Rodenhouse et al., 2009). Larger mammals such as moose may be intolerant to increasing temperatures, pushing their ranges to higher latitudes (Rodenhouse et al., 2009, Brinker et al., 2018). Species with ability to disperse and generalist habitat and food requirements are more adaptable to changing conditions, than species with limited dispersal and specialist habitat requirements; these former species types have broader thermal thresholds and can colonize new areas and diversify food sources (Douglas and Pearson, 2022).

Climate-driven movements and other physiological, behavioural, and demographic responses have a range of ecological implications. Several mammals are keystone species in the environments where they occur, meaning that their presence keeps a balance on the ecosystem. For example, herbivorous mammals like voles, deer, and moose are important food web components in their terrestrial communities; large carnivores are top predators; and other mammals help sustain plant communities that are their food sources through seed dispersal and other mechanisms (Dobbyn, 1994).

Climate risks to mammals were assessed across all six PCCIA regions, focusing on risk scenarios driven by temperature, specifically Growing Degree Days and Degree Days below 0˚C, and winter precipitation, specifically Rain:Snow Ratio.

Moose (*Alces americanus*), white-tailed deer (*Odocolieus virginianus*), caribou – boreal population (*Rangifer tarandus*) and northern myotis (*Myotis septentrionalis*) are the illustrative species used to highlight climate risks to mammals (Box 11).

The current climate risk profile associated with the environmental consequences from climate change impacts to mammals is rated as ‘medium’ in all regions, with risk levels increasing to ‘high’ by mid-century. Risk scores are anticipated to stabilize at ‘high’ in northern regions (Northeast, Northwest and Far North) by late century, but increase further to ‘very high’ in southern regions (Central, Eastern and Southwest).

Current risk levels are consistent with observed impacts of warming temperatures and changes in precipitation on mammal distribution (e.g. northward shift of white-tailed deer), demographic responses, and changes in species interactions (Dawe and Boutin, 2016; Priadka et al., 2022; Kennedy-Slaney et al., 2018; Nituch and Bowman, 2013).

Warmer temperatures cause physiological stress that limits species’ reproductive success, threatening population health. Moose, for example, thrive under temperature thresholds between 14 and 24˚C, experiencing heat stress if those temperatures are exceeded (McCann et al., 2013). Heat stress alters their metabolic, heart, respiration rates, and their movement patterns; heat stress reduces their food intake and creates mismatches in the timing of winter coat growth. All these factors ultimately lead to lower body condition with negative effects on calf production (McCann et al., 2013; Broders et al., 2012; Weiskopf et al., 2019).

Box 11: Species Used to Characterize Climate Risks to Ontario's Mammals

Moose (Credit: R. Hodnett, CC BY-SA-4.0)

Moose is a large mammal with a wide distribution across Ontario. Moose hold substantial social, economic, and ecological value to the people of Ontario (Ontario Ministry of Natural Resources and Forestry, 2009). Moose is an important source of wild food for First Nations in northern Ontario regions (Douglas and Pearson, 2022).

White-tailed deer (Credit: Hodnett, CC BY-SA-4.0)

White-tailed deer is a large herbivorous mammal with a wide distribution in Ontario. It is an iconic game species with economic, cultural, and biodiversity importance (Ontario Ministry of Natural Resources and Forestry, 2017; 2022).

Caribou (Credit: NPS Photo/Lian Law, CC BY-SA 2.0)

Boreal caribou are an iconic, medium-sized forest-dwelling species with significant cultural and ecological importance in Canada (Assembly of First Nations and David Suzuki Foundation, 2013). The boreal population of caribou lives in the boreal forest all year, with its range restricted to the Far North and Northeast regions of Ontario. This species has suffered range-wide declines despite conservation efforts.

Northern myotis (Credit: D. Thomas, CC BY-NC 2.0)

Northern myotis commonly known as the northern long-eared bat, is an endangered species of bat found throughout the boreal forest. This species roosts under loose bark, in the cavities of trees and in caves (Ontario Ministry of Natural Resources and Forestry, 2014c).

Warmer temperatures can amplify the impacts of stressors to species that are already imperiled. Bats (particularly lactating females) are more susceptible to evaporative water loss than other mammals, with evidence indicating that little brown bats (*Myotis lucifugus*), a species analogous to northern myotis, experience significant reproductive declines in years of reduced water availability linked to warmer winters and summers (Frick et al., 2010). Variations in climate leading to poor spring and summer foraging conditions reduce opportunities for juvenile bats to gain mass before hibernation and affect overwinter success, especially with the pressures of white-nose syndrome, an emergent disease in hibernating bats resulting in dehydration, starvation and often death (Balzer et al., 2022).

Warming temperatures can also degrade habitat quality, influencing population dynamics. Increasing temperatures put boreal caribou at a high risk of extirpation under conservative emission scenarios. Climatically-suitable habitat for boreal caribou could decrease between 57 and 99%with an increase in mean minimum winter temperature between 0.9 and 5.5˚C over pre-industrial temperatures (Masood et al., 2017). Increasing winter temperatures are linked to reduced ice thickness over water bodies, resulting in limited ability to browse for food and an increased risk of drowning (Masood et al., 2017). Regularly warmer winters and summers also present risks for poor body condition and population declines and local extirpation of the Boreal population of caribou due to lack of high-quality forage availability (Festa-Bianchet et al., 2011).

Warmer temperatures, shorter winters and decreased snow depth creates favourable conditions for range expansion and increased abundance of species currently limited by low temperatures. The northern distribution of white-tailed deer is in part limited by winter temperatures colder than -7˚ C, as cold temperatures increase metabolic costs for thermoregulation (Weiskopf et al., 2019). Deep snow is another limiting factor, since it increases movement costs, reduces forage availability, increases predation, and forces deer in some areas to be obligate migrators, which, taken together, decrease reproductive success (Kennedy-Slaney et al., 2018; Weiskopf et al., 2019). Reduced snow cover and warmer winters may mitigate some adverse climate impacts affecting deer condition and reproductive success. However, fluctuations in the severity of winter months may lead to pulses of expanding and contracting distribution of white-tailed deer (Kennedy-Slaney et al., 2018). Ultimately, it is expected that white-tailed deer will increase in abundance, retain their existing range, and expand northward, potentially as far as the modern-day treeline (Jenkins et al., 2007).

Warming temperatures will change species interactions, including impacts from diseases, pests, and invasive species, and shifts in and predation (Douglas and Pearson, 2022). Regularly warmer winters and summers presents population risks to boreal caribou due to increasing frequency of interactions with parasites (e.g. meningeal worm carried by white-tailed deer) and predators (Vors and Boyce, 2009; Environment and Climate Change Canada, 2020; Masood et al., 2017). The earlier onset of spring is shifting the timing of vegetation green up and insect emergence, but caribou lag behind this phenological shift, resulting in higher disturbance by insect pests when females and calves are in their most vulnerable condition (Vors and Boyce, 2009). Warming temperatures, manifested through later frost and earlier onset of spring, in combination with contractions in forest canopy, may result in increased spread of fatal parasites from white-tailed deer to moose, as well as increased rates of predation on moose (Weiskopf et al., 2019, Priadka et al., 2022).

Molluscs

According to the Natural Heritage Information Centre 312 mollusc species are present in Ontario, with close to 6% of species threatened or of special concern (Office of the Auditor General of Ontario, 2021a). Molluscs are aquatic bivalves that are sedentary in adult life stages, relying on other species to disperse larvae to new areas (Brinker et al., 2018). Therefore, climate change-induced shifts in species composition influence molluscs' reproductive success (Brinker et al., 2018). Survival rates may be further impacted by changes to habitat quality (Brinker et al., 2018). Changes to aquatic habitats, including changes to water depths, current velocities, and increased turbidity, combined with their limited mobility, have the potential to detrimentally affect mollusc populations. Molluscs' already restricted dispersal potential is further limited by anthropogenic barriers (e.g. dams), and existing habitat space and use may be threatened by invasive species who may colonize previously unsuitable habitat (Brinker et al., 2018). Losses in biodiversity of mollusc species, in turn, affect food webs and nutrient recycling (Spooner et al., 2011).

Climate risk to molluscs was assessed in the Southwest region – with risk scenarios driven by temperature changes (Growing Degree Days) and extreme precipitation events. Salamander mussel (*Simpsonaias ambigua*) is the illustrative species used to highlight climate risks to mussels. This endangered freshwater mussel has a localized distribution and is found burrowed in sand or silt in the Sydenham River; it uses the Mudpuppy, a salamander, as its host (COSEWIC, 2001). Habitat quality for the Salamader mussel continues to decline from intense agriculture, urban development, and pollution from point and non-point sources. Although information on specific threats to this freshwater species is scarce, limiting factors likely include impoundments, siltation, channel modification and pollution (COSEWIC, 2011). Because of its localized occurrence and conservation status, risk results from the assessment of this illustrative species may be applicable to other endangered mollusc species in Ontario.

The current climate risk profile associated with the environmental consequences from climate change impacts to endangered molluscs in Southwest Ontario is rated as 'high', with risk levels increasing to 'very high' by mid and end-of-century, regardless of emissions scenario. Impacts on the mollusc due to exposure to climate change are exacerbated by anthropogenic pressures in Southwest Ontario linked to projected population growth, urban and industrial development (e.g. road run off, pollution).

Exposure to climate change, combined with pressures from human activities, put the salamander mussel at high risk of extirpation in Ontario. Rising temperatures and increased evapotranspiration can result in low water levels in streams (Spooner et al., 2011), which is problematic for the species due to its lack of mobility and niche habitat requirements (Lee et al., 2011). The species is indirectly vulnerable to extreme precipitation events, such as intense storms, since high flow scenarios can cause scouring and siltation, posing serious threats to species persistence (Spooner et al., 2011; COSEWIC, 2011). The loss of this species would result in decreased nutrient recycling efficiency in the river environment.

Reptiles

According to the Natural Heritage Information Centre, 50 reptile species are present in Ontario, with over 40% of species threatened or of special conservation concern (Office of the Auditor General of Ontario, 2021a). Relative to amphibians, reptiles may be more resilient to climate change on account of their preference for heat and a generalist diet (Winter et al., 2016, Brinker et al., 2018). However, reptile populations in Ontario may still be affected by climate change-induced habitat losses and expansions of invasive species. Reptiles reliant on freshwater habitats are vulnerable to hydrologic changes resulting from climatic shifts habitat may be more vulnerable to (Brinker et al., 2018).

Climate risk to reptiles was assessed in four of the PCCIA regions – Southwest, Central, Eastern and Northeast Regions –with risk scenarios driven by temperature changes (Growing Degree Days). The common five lined skink (*Plestiodon fasciatus*) is the illustrative species used to highlight climate risks to reptiles (Box 12).

Box 12: Ontario's Common Five Lined Skink, Illustrative Species of Climate Risks to Reptiles

Common five lined skink (Credit: W.L. Farr, CC-SA-4.0)

Common five lined skink is a small lizard species common in North American, although in Canada on occurring in the Southwest, Central, Eastern, and the Northeast provincial regions (Seburn, 2010). It occurs in openings or edges of deciduous forests, in rocky (shield population) and sandy areas (Carolinian population). The Carolinian population is endangered, with major threats including habitat loss, fragmentation, and degradation from development. Information on the skink's distribution and movements is limited, as are accurate population estimates.

The current climate risk profile associated with the environmental consequences from climate change impacts to reptiles (as illustrated by the common five lined skink) in Southwest, Central, Eastern, and the Northeast regions is rated as 'medium', with risk levels staying at 'medium' levels by mid and end-of-century for Southwest and Central regions. For Eastern and the Northeast regions, risk levels are anticipated to rise to 'high' by mid-century and then fall again to 'medium' by late century. These counterintuitive results illustrate the challenges of analyzing potentially positive effects of climate change, with heightened risk in Eastern and Northeast regions in mid-century denoting a potential upside for the lizard. The potential advantages of warming temperatures for populations of common-five lined skinks counteract with anthropogenic pressures linked to projected population growth, urban and industrial development (e.g. road run off, pollution).

Warmer temperatures can facilitate a range expansion of the common five-lined skink, increasing populations' genetic diversity; however, the species' occurrence in heavily modified landscapes and as small, localized populations counteract gains in thermally suitable habitat. As an ectotherm, the common five-lined skink relies on ambient air temperature to maintain its internal body temperature (Vincer, 2009). Evidence suggests that the species' distribution in Ontario is limited by thermal energy accumulation during the growing season, as cool environments limit embryo development and the ability of juveniles to reach adult stages (Ziebarth, 2021).

Warming temperatures may be net-advantageous for the common five lined skink and may shift the peripheral population northward, potentially increasing genetic diversity in Ontario (Howes and Lougheed 2008; Feltham, 2020). However, changes in moisture availability, natural and anthropogenic barriers, as well as continued habitat loss and degradation unrelated to climate change render the species vulnerable and act to limit populations' prevalence and expansion (Brinker et al., 2018). Populations of this species in protected areas (e.g. Point Pelee National Park, Rondeau Provincial Park, and Pinery Provincial Park) may be better able take advantage of the boost in Adaptive Capacity conferred by warming temperatures.

Table 7.6: Risk Scores for Fauna Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Fauna	Amphibian	Central Region	**Medium**	**High**	**High**
Fauna	Amphibian	Eastern Region	**Medium**	**High**	**High**
Fauna	Amphibian	Far North Region	**Medium**	**Medium**	**High**
Fauna	Amphibian	Northeast Region	**Medium**	**Medium**	**High**
Fauna	Amphibian	Northwest Region	**Medium**	**Medium**	**High**
Fauna	Amphibian	Southwest Region	**High**	**High**	**High**
Fauna	Bird	Central Region	**Medium**	**High**	**High**
Fauna	Bird	Eastern Region	**Medium**	**High**	**High**
Fauna	Bird	Northeast Region	**Medium**	**High**	**High**
Fauna	Bird	Northwest Region	**Medium**	**High**	**High**
Fauna	Bird	Southwest Region	**Medium**	**High**	**High**
Fauna	Migratory songbirds	Central Region	**Medium**	**High**	**High**
Fauna	Migratory songbirds	Eastern Region	**Medium**	**High**	**High**
Fauna	Migratory songbirds	Far North Region	**Medium**	**High**	**High**
Fauna	Migratory songbirds	Northeast Region	**Medium**	**High**	**High**
Fauna	Migratory songbirds	Northwest Region	**Medium**	**High**	**High**
Fauna	Migratory songbirds	Southwest Region	**Medium**	**High**	**High**
Fauna	Waterfowl	Central Region	**High**	**Very High**	**Very High**
Fauna	Waterfowl	Eastern Region	**Medium**	**High**	**High**
Fauna	Waterfowl	Far North Region	**Medium**	**High**	**High**
Fauna	Waterfowl	Northeast Region	**Medium**	**High**	**High**
Fauna	Waterfowl	Northwest Region	**Medium**	**High**	**High**
Fauna	Waterfowl	Southwest Region	**High**	**Very High**	**Very High**
Fauna	Fish	Central Region	**High**	**Very High**	**Very High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Fauna	Fish	Eastern Region	High	Very High	Very High
Fauna	Fish	Far North Region	Medium	High	High
Fauna	Fish	Northeast Region	Medium	High	High
Fauna	Fish	Northwest Region	Medium	High	High
Fauna	Fish	Southwest Region	High	Very High	Very High
Fauna	Insect/Spider	Central Region	Medium	High	Very High
Fauna	Insect/Spider	Eastern Region	Medium	Medium	High
Fauna	Insect/Spider	Far North Region	Medium	Medium	Medium
Fauna	Insect/Spider	Northeast Region	Medium	High	High
Fauna	Insect/Spider	Northwest Region	Medium	Medium	Medium
Fauna	Insect/Spider	Southwest Region	Medium	High	Very High
Fauna	Mammal	Central Region	Medium	High	Very High
Fauna	Mammal	Eastern Region	Medium	High	Very High
Fauna	Mammal	Far North Region	Medium	High	High
Fauna	Mammal	Northeast Region	Medium	High	High
Fauna	Mammal	Northwest Region	Medium	High	High
Fauna	Mammal	Southwest Region	Medium	High	Very High
Fauna	Mollusc	Southwest Region	High	Very High	Very High
Fauna	Reptile	Central Region	Medium	Medium	Medium
Fauna	Reptile	Eastern Region	Medium	High	Medium
Fauna	Reptile	Northeast Region	Medium	High	Medium
Fauna	Reptile	Southwest Region	Medium	Medium	Medium

Indirect Impacts

Warming temperature will indirectly impact fauna in Ontario by altering habitat and species' ranges, encouraging the expansion of species, including invasive species that can outcompete native species, and increase the abundance of forest pests and/or pathogens.

For certain species, such as brook trout, habitat is expected to become increasingly disconnected. This will indirectly impact gene flow by leading to genetically isolated populations (Argent and Kimmel, 2013). For other species, changes to historic weather patterns will modify habitat. One example is where changing weather patterns will negatively affect sand barren and dune habitats via increased erosion. This will have effects on several species at risk that depend on this habitat such as Fowler's toad, eastern prickly pear cactus, eastern hognose snake, dusted skipper butterfly, and the Lake Huron grasshopper.

As indicated in the previous section, habitat alterations cause species declines. This is anticipated for the Lake Huron grasshopper which depends on dune habitats to survive. Decreasing Lake Huron grasshopper populations in conjunction with increasing temperatures may co-occur with improved conditions for invasive plant growth on dune habitat. In turn, this changing habitat may be more favourable for other grasshopper species such as the Mottled Sand Grasshopper, which has been shown to displace Lake Huron Grasshoppers in some circumstances (Jones, 2018). Similar scenarios occur in the aquatic environment where declines in Salamander Mussels due to changing temperatures may co-occur with improved conditions for invasive Zebra Mussels. This will further threaten Salamander Mussels by adhering to them and interfering with breathing, feeding, excretion, and movement (Ontario Ministry of the Environment, Conservation and Parks, 2014). The combined impact of these factors may result in range expansions or contractions in many species. The whitetail deer may undergo a range expansion, introducing wolves to caribou and moose habitat, resulting in increased predation (Barber et al., 2018; Rempel et al., 2021; Brown, 2011; Festa-Bianchet et al., 2011). Warming temperatures may cause declines in many species such as the northern myotis. This species of bat usually consumes large quantities of forest pest insects; therefore, decreasing abundance of northern myotis may increase forest pest abundance and take a toll on forest health (Ducummon, 2000).

Drought, wildfire, and extreme precipitation will cause indirect impacts by reducing suitable habitat in Ontario. Drought may reduce insect and spider abundances and cause an indirect impact on terrestrial and freshwater food webs. Many species of birds, bats, reptiles, amphibians, small mammals, and fish rely on insects and spiders as food and will disappear without them. Further, a large portion of plant species rely on pollination by insects. Increased wildfire frequency will put pressures on species at risk in boreal forest such as woodland caribou and wolverine. Additionally, other charismatic species in northern regions, such as grey wolf, moose, Canada jay, and bald eagle may be negatively impacted by loss of habitat.

Finally, if extreme precipitation forces Piping Plover breeding habitat further inland, there may be an increased likelihood of conflict between plover habitat protection and human recreation that takes place close to shorelines. Increased human disturbance has been shown to negatively impact chick survival, and increased plover-human interactions due to shifting habitats may further exacerbate population losses.

7.7.2 Flora

Overview

Flora refers to the plant life in a particular region. Flora covers most parts of the province and are essential for the planet and all living things. Within the categories of flora assessed for this report (vascular plants, bryophytes, and lichen), vascular plants make up about 70% of the list of Ontario species maintained by the Natural Heritage Information Centre. Although most of Ontario's flora species are secure, just over 1% are species at risk – that is – species that are in danger of disappearing (Office of the Auditor General of Ontario, 2021a). As with fauna, threats to flora species diversity include habitat loss/degradation and fragmentation, overexploitation, invasive species, spread of disease, climate change, and pollution (IPBES, 2019). These are broadly similar to threats to flora species in Ontario overall, but differ by region and extent of development pressures. Compared to fauna, flora species are under-represented in land protection and habitat stewardship programs (McCune and Morrison, 2020).

Flora provides numerous social, economic, and cross-sectoral benefits to people and their well-being (Nantel et al., 2014). For instance, wild rice (*Zizania palustris*), a cold-water annual plant species that occurs in northern coastal wetlands and inland water bodies, has a modest commercial value, but is of great cultural and spiritual importance to Indigenous nations in the Great Lakes region (Sierszen et al., 2012). Sugar maple (*Acer saccharam*) is the species most tapped for maple syrup, which is an iconic Canadian non-timber forest product (Murphy et al., 2012), and a source of employment and GDP in Ontario (EcoResources, 2013); its sap is also a traditional cleansing medicine for Indigenous Communities (Huron, 2014). Sphagnum mosses composing peatlands are harvested for horticultural purposes as a soil amendment.

Understanding the climate change vulnerability of flora is a complex endeavor, as the effect of climate change occurs on a species, population and community level, and overall threats are regionally specific (Geyer et al., 2011; Young, 2016). Furthermore, many flora species depend on other organisms for critical functions including growth and/or dispersal (Brinker et al., 2018). Thus, impacts on one species, may have indirect effects on others. Indeed, thermal and hydrological niches and dispersal/movement capabilities stand out as key factors influencing the climate change vulnerability of flora species, with species restricted to cool, cold or moist environments, those in isolated locales (e.g. canyons) or requiring other specialized growing conditions, and those with limited dispersal adaptations most susceptible to changing climate conditions.

For the purposes of the PCCIA, three Level 2 categories were used to assess the risks associated with direct impacts to flora: vascular plants, bryophytes, and lichens. To make the assessment tractable, illustrative species were selected for quantitative risk assessment. However, it is critical to recognize the regional diversity of flora and the unique climate sensitivities of species (including conservation status) in extrapolating or generalizing risk results to the level of taxonomic groups. Brinker et al.'s (2018) climate change vulnerability assessment of species in the Great Lakes Basin found lichens to be relatively more vulnerable than vascular plants and bryophytes. Support for comprehensive and broad-scale studies such as Brinker et al., (2018) is necessary to continue building Ontario's knowledge base on climate change risks to the natural environment.

Direct Impacts

The following sections provide characterizations of each Level 2 category assessed for flora across Ontario and related risk results. Risk scenarios for flora were driven by climate variables related to temperature and precipitation: average temperatures, high and extreme temperature, drought, and extreme precipitation events and winter precipitation.

The impact assessment highlights the following types of environmental responses resulting from changes in severity and occurrence of the assessed climate variables:

- Changes in population dynamics
- Increases in habitat-related stressors

Table 7.7 includes example risk scenarios for each Level 2 category assessed under flora. The climate risk profiles for each Level 2 category are presented by timeframe and region in Table 7.8 (operating under RCP8.5), found at the end of this section.

Table 7.7: Illustrative Risk Scenarios for Flora

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Lichen (Alpine dot lichen)	Warming temperatures reduce suitable habitat for alpine dot lichen resulting in population contractions.	**Medium**
Vascular plant (Eastern white pine)	A longer growing season decreases Eastern white pine productivity and limits regeneration in sites limited by moisture and with favourable conditions for pathogen infection.	**Medium**
Bryophyte (Alpine copper moss)	Moisture Deficits negatively impact the maintenance and establishment of alpine copper moss resulting in local extirpation.	**Low**

Bryophytes

According to the Natural Heritage Information Centre, 826 species of bryophytes are present in Ontario[21], with 0.1% of those species threatened or of special conservation concern (Office of the Auditor General of Ontario, 2021a). Bryophytes are low-lying plants that consist of mosses, liverworts, and hornworts, found across several microhabitats, predominantly in the coniferous boreal forest (Environment and Climate Change Canada, 2015; Barbé et al., 2018).

In general, bryophytes exhibit delays in responding to rapid changes in climate despite their high dispersal capabilities via wind (Zanatta et al., 2020). Bryophytes are susceptible to changes in precipitation and temperatures. They rely on atmospheric precipitation for water intake, hence fluctuating periods of extreme drought and periods of intense rainfall can influence bryophyte survival rates (Vile et al., 2011; Zanatta et al., 2020). Arctic tundra and alpine bryophyte communities are particularly sensitive to warming (Alatalo et al., 2020). Despite their ecological importance in arctic and alpine environments where vascular plant biomass is significantly lower, bryophyte communities are understudied compared to vascular plants (Alatalo et al., 2014).

Climate risk to bryophytes was assessed in the Northwest region –with risk scenarios driven by drought (Moisture Deficit / Drought). Alpine copper moss (*Mielichhoferia mielichhoferiana*) is the illustrative species used to highlight climate risks to bryophytes. This is a critically imperiled species with low migratory capabilities and restricted to a niche habitat consisting of near-vertical rock faces with high iron levels and reduced sulphur content. These traits confer a high degree of sensitivity to climate change (Brinker et al., 2018). Because of its localized occurrence, substrate fidelity, and conservation status risk results from the assessment of this illustrative species may be applicable to other endangered bryophyte species in Ontario.

The current climate risk profile associated with the environmental consequences from climate change impacts to endangered bryophytes in Northwest Ontario is rated as 'medium', with risk levels staying at 'medium' by mid-century and then increasing to 'high' by late century.

Most bryophytes depend on a moist environment (Environment and Climate Change Canada, 2015). The availability and timing of water is critical for their reproductive success and altered moisture patterns (e.g. drought) will alter growth rate (Vile et al., 2011; Brinker et al., 2018). Warmer temperatures also influence the maintenance and establishment of the alpine copper moss. With low migratory capabilities, the alpine copper moss is unlikely to adapt to these climatic changes by shifting its range (Brinker et al., 2018). Therefore, if moisture and temperature thresholds are exceeded, local extirpation is likely to occur.

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[21] CESCC (2016) lists 608 wild species of bryophytes for Ontario.

Lichens

According to the Natural Heritage Information Centre, 1,146 species of lichens are present in Ontario, with 0.2% of those species threatened or of special conservation concern (Office of the Auditor General of Ontario, 2021a). Lichens are widespread throughout Ontario, with new species increasingly documented in the province (Lewis and Brinker, 2017). Lichens are composed of a symbiosis between algae and fungi, found across a range of ecosystems supporting important functions such as rock weathering (Allen et al., 2019). As with bryophytes, lichen communities remain understudied and under protected (Allen et al., 2019). Among the impacts of climate change, changing air quality and air pollution are among the most widely recognized threats that disproportionately impact lichen populations and distribution compared to other taxonomic groups (Allen et al., 2019). Many lichens' growth and survival rates are influenced by hydrological regimes, including extremes such as spring runoff and seasonal precipitation events (Brinker et al., 2018). These, coupled with the interactions of climate change impacts and barriers to ecological response with current levels of habitat fragmentation and increasing urbanization, limit their dispersal potential and adaptability to a changing environment (Ellis, 2019).

Climate risk to lichens was assessed in two the Southwest and Northwest regions –with risk scenarios driven by temperature (Growing Degree Days) and winter precipitation (Rain to Snow Ratio). Alpine dot lichen (*Arthrorhaphis alpina*) is the illustrative species used to highlight climate risks to lichens. The alpine dot lichen is widespread, but in Ontario its range is limited to sheltered canyons and separated from its main range by 1,500 km (Lewis and Brinker 2017); it is also critically imperiled. Due to its limited range in the province, reliance on niche habitat, and conservation status the species is highly sensitive to climate change (Brinker et al., 2018). Risk results from the assessment of this illustrative species may be applicable to other endangered lichen species in Ontario.

The current climate risk profile associated with the environmental consequences from climate change impacts to endangered lichens in Southwest and Northwest Ontario is rated as 'medium', with risk levels increasing to 'high' by mid-century for both regions due to a combination of exposure to climate hazards and socio-economic pressures. By late century risk levels for Northwest Ontario remain at 'high' and increase to 'very high' for Southwest Ontario on account of elevated pressures from human activities.

Climate risks to lichens stem from habitat-related stresses, where loss of suitable habitat linked to population contractions. For the alpine dot lichen, warming temperatures and related moisture shifts are harmful as they can affect critical processes, such as reproduction, photosynthesis, and cause dry out (Brinker et al., 2018). Given the lack of suitable nearby environments, it is unlikely that this species can accommodate climate change by shifting its range, and there is a high likelihood of population impacts by mid-century. Changing winter precipitation patterns can affect lichen if they experience excess snowpack, which would lead to species decline (Bidussi et al., 2016). Snow can shape the zonation of dominant terrestrial mat-forming lichens from ridge to snow bed habitats. An analogous species to the alpine dot lichen, *F. nivalis*, is a snow-avoidant species and demonstrates negative growth rates at snow depths of ≥120cm (Bidussi et al., 2016). Climate projections indicate an increase in rain to snow ratio in Ontario, potentially representing a decrease in exposure to this snow-related climate threat. However, warmer temperatures and changes in Arctic air circulation patterns create conditions favourable for more frequent heavy snowfall events at mid-latitudes, although this is an evolving research topic (Francis et al., 2017).

Vascular Plants

According to the Natural Heritage Information Centre, 4,322 species of vascular plants are present in Ontario[22], with under 2% of those species threatened or of special conservation concern (Office of the Auditor General of Ontario, 2021a). Vascular plants are a broad group of flora with specialized vascular systems; the group comprises conifers, deciduous trees and other flowering plants, ferns, and horsetails. Ontario has the highest diversity of vascular plants in the country (Leslie, 2018), with a wide distribution throughout the province.

Vascular plants have highly variable traits and habitat preferences, with climate change potentially favouring certain morphologies such as shrubs and grasses. Shrubification and tree line advances have already been observed in higher latitudes (Zhang et al., 2013). Vascular plant physiology has also been observed to change in response to a changing climate, influencing photosynthesis and transpiration, with broader effects on primary productivity if hydraulic efficiency is impaired under climatic stress (Qaderi et al., 2019).

Additionally, climate warming may enhance the biomass of vascular plants such as shrubs and grasses in wetlands at the expense of other flora such as moss and lichens, which have divergent responses to lower water tables (Bao et al., 2022). Climate-related movements and range expansions represent another mechanism of possible impact. Limits to range expansions and dispersal of vascular plant species vary significantly and include natural and anthropogenic barriers, dispersal capacity (Brinker et al., 2018), habitat suitability to uncommon geological features (e.g. marble barrens and talus slopes), and microclimate preferences, which may change in response to climatic shifts (Zhang et al., 2013).

[22] There are contradictions on the number of species occurring in Ontario, as other accounts mention 3,160 native and introduced species, increasing to 4,133 if including subspecies, varieties, and hybrids (Leslie 2018).

Climate risk to vascular plants was assessed in five PCCIA regions – Southwest, Central, Eastern, Northwest and Northeast regions – with risk scenarios driven by temperature changes (Growing Degree Days), drought (Moisture Deficit / Drought), extreme precipitation events (Extreme Precipitation Event-shorter term) and winter precipitation (Rain:Snow Ratio). Eastern white pine (*Pinus strobus*) and the horsetail spike rush (*Eleocharis equisetoides*) are the illustrative species used to highlight climate risks to vascular plants (Box 13).

Box 13: Species Used to Illustrate Climate Risks to Vascular Plants in Ontario

Eastern white pine (Credit: D. Keck, public domain image)

Eastern white pine is a coniferous tree occurring in Southwest, Central, Eastern, Northwest and Northeast Regions of Ontario and is Ontario's provincial tree. Despite being susceptible to the fungus White pine blister rust, the tree species is secure, meaning that it is common, widespread, and abundant in the province (NatureServe , 2016). In 2016, the tree species made up around 2.5 percent of annual harvest and four percent of the total growing stock volume in Ontario (Ontario Ministry of Natural Resources and Forestry, 2016). Human uses of the tree species include lumber, furniture, and trim.

Horsetail spike rush (Credit: S. Brinker, public domain image)

Horsetail spike rush is a perennial sedge with restricted distribution in Ontario, occurring in a single site the Southwest region (Environment and Climate Change CanadaEnvironment and Climate Change Canada, 2006). The sedge is a wetland obligate that grows in water that is 4 to 35 cm deep and is highly vulnerable to hydrologic alterations (Leslie, 2018). Although the species is globally ranked as apparently secure, it is ranked at the provincial level in Ontario as critically imperiled (Brinker et al., 2018) and as endangered under Canada's federal *Species at Risk Act*. Aside from climate change, threats to survival and recovery include habitat alterations caused by the invasive European common reed and loss of genetic diversity (Environment and Climate Change CanadaEnvironment and Climate Change Canada, 2006).

The current climate risk profile associated with the environmental consequences from climate change impacts to vascular plants is rated as ‘medium’ across all assessed regions, with risk levels increasing to ‘high’ by mid-century and stabilizing at that level across the province by late century. The risk results are consistent regardless of whether emissions follow a high emissions scenario (RCP8.5) or a moderate emissions scenario (RCP4.5).

Warming temperatures and an extended growing season can increase tree productivity and growth, with species’ resilience also shaped by moisture shifts and climate-driven changes in the incidence and severity of pests and disease. For example, Eastern white pine grows optimally between 500 and 4,261 Growing Degree Days (GDDs) so warmer conditions projected to mid-century can result in increased biomass growth rates (Boulanger et al., 2017). However, coupled with changes in moisture, growing conditions become sub-optimal at temperatures exceeding these ranges, since the tree species presents low to moderate ability to tolerate drought (Aubin et al., 2018) and excessive hot days reduce trees’ capacity for photosynthesis and increase metabolic respiration (Boulanger et al., 2017). Therefore, exposure to increased occurrence of hot days and drought reduces growth rates and contributes to tree mortality. At the same time, the resilience of trees may be tested by climate-driven changes in the incidence and severity of pathogen infections, such as the white pine blister rust (*Cronartium ribicola*). This invasive pathogen alternates between five-needle pines and Ribes species (currants and gooseberries) as hosts; it causes branch die back, reproductive failure through the loss of large cone-producing trees and tree mortality. Wetter conditions increase the habitat quality for the pathogen, but the probability of tree infection sharply decreases with higher temperatures (Thoma et al., 2019).

Warmer temperatures create conditions for range contraction of trees species whose southern edge lies within the Great Lakes Basin, with trees subject to reduced growth rates, reproductive failure, and increased disease and mortality (McDermin et al., 2015). It’s likely that eastern white pine (among many other vascular plant species in Ontario) will shift northward but it is uncertain whether temperatures will increase faster than they can migrate (McDermid et al., 2015; Johnston et al., 2010). Suitable habitat for eastern white pine is likely to contract in the Southwest, Central and Eastern regions in the absence of substantial artificial reforestation efforts to keep pace with climate envelopes (Joyce and Rehfeldt, 2013).

Climate risks to vascular plants also stem from shifting patterns of climate extremes, with species with specialized habitats being most vulnerable to impacts including extirpation. For example, the Horsetail spike rush is highly vulnerable to hydrologic alterations (Leslie, 2018). Although precipitation is expected to increase in Horsetail spike-rush's range in southwestern Ontario, summer droughts are also anticipated to occur more frequently. The low genetic diversity and narrow habitat requirements for the species will likely limit its ability to survive even if the climate becomes more favourable for it in southern Ontario (Lundy, 2008). Climate drying in the Holocene resulted in local extirpation of Horsetail spike-rush from Indiana (Ontario Ministry of Natural Resources and Forestry, 2011). By extension, if drought and Moisture Deficits reduce water levels and the specific biological requirements of the Horsetail spike rush cannot be met, the species may be extirpated from Ontario. Additionally, the increased incidence of extreme precipitation events over the shorter-term represents a hazard for the Horsetail spike rush. Since there is only one occurrence of the species in Ontario and it is small in size (5-10 square metres), the species is extremely vulnerable to losses from stochastic events such as an extreme precipitation event (Ontario Ministry of Natural Resources and Forestry, 2011).

Table 7.8: Risk Scores for Flora Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Flora	Bryophyte	Northwest Region	Medium	Medium	High
Flora	Lichen	Northwest Region	Medium	High	High
Flora	Lichen	Southwest Region	Medium	High	Very High
Flora	Vascular plant	Central Region	Medium	High	High
Flora	Vascular plant	Eastern Region	Medium	High	High
Flora	Vascular plant	Northeast Region	Medium	High	High
Flora	Vascular plant	Northwest Region	Medium	High	High
Flora	Vascular plant	Southwest Region	Medium	High	High

Indirect Impacts

Climate change will result in several indirect impacts to flora across the province. For example, species of vascular plants like the eastern white pine will experience an increase in the prevalence of pests and pathogens, as warmer winters increase survival rates (Rustad et al., 2012; Candau and Fleming, 2011). The risks from pest and pathogen outbreaks are compounded by the increasing wildfire risk caused by increasing temperatures and lower precipitation (Colombo, 2008, Brandt et al., 2014), which will further stress flora species in the province. Rapid changes in vegetation succession due to climate change will also alter ecosystem functions, such as carbon sequestration and storage and other large-scale vegetation attributes (Price, 2013). Similarly, bryophytes are important for carbon storage and nitrogen fixing, and a major food source for various invertebrates and some vertebrate species (Shaw et al., 2018, Zuijlen et al., 2021), hence, climate-induced range shifts in bryophyte communities may alter community composition and the range of ecosystem functions present in the region (Alatalo et al., 2014, Zuijlen et al., 2021). Lichens also support a range of important functions such as rock weathering, nutrient cycling, soil formation, and regulating humidity (Allen et al., 2019), as well numerous species across trophic webs also use lichens for food, camouflage, and shelter. Therefore, climate change impacts on lichen populations and communities result in cascading ecosystem impacts.

7.7.3 Aquatic Ecosystems

Overview

Aquatic ecosystems are habitat for animals, plants, microbes, and other living species that depend on water. Aquatic ecosystems include freshwater habitats, such as lakes, ponds, and rivers, as well as marine habitats, including oceans and intertidal zones. In Ontario, freshwater habitats predominate, including the Great Lakes basin, a region straddling Ontario and the U.S. that holds a fifth of the world's fresh surface water, regulates seasonal weather, and provides freshwater resources for drinking, fishing, agriculture, shipping, and other important activities to surrounding communities (Douglas and Pearson, 2022).

Within the categories of aquatic ecosystems assessed for the PCCIA (clear open water –lakes, rivers, and streams—bog, marsh, and mudflats), clear open water has the most extensive surface area (Miller et al., 2021). Freshwater fish and mussel species occur throughout Canada, but a particularly high diversity of freshwater mussels and fishes can be found in southern Ontario's aquatic systems (Tognelli et al., 2017). Beyond freshwater fish and mussel populations, Ontario's aquatic ecosystems support numerous reptile and amphibian species, waterfowl, mammals, rare vegetation communities, and support specialized habitats for a variety of species (Ontario Ministry of Natural Resources and Forestry, 2014c). Threats to the health of Ontario's aquatic ecosystems, as measured by biodiversity, include urbanization and habitat loss, invasive species, pollution and excessive nutrient flows, unsustainable use, and climate change, with relative improvements in some status indicators and deterioration in others (Ontario Biodiversity Council, 2021) (see Table 7.9).

Table 7.9: Aquatic Ecosystems and Biodiversity in Ontario (Source: Ontario Biodiversity Council, 2021).

Indicator	Status	Trend
Pressures on biodiversity		
Invasive species – Alien species in Great Lakes	Four new alien species discovered in the Great Lakes since 2010 – the lowest number in over 5 decades.	Improvement
Pollution – Water quality in inland lakes	94% of sampled lakes had phosphorus, pH, and calcium within acceptable limits. 3% of the sampled lakes had critically low calcium levels.	No change
Climate change – Great Lakes ice cover	Ice cover on the Great Lakes has been in decline since 1973 when recordings began.	Deterioration
Ecosystems and species		
Ecosystems – Wetland cover	0.7% of Southern Ontario's wetlands were lost between 2011-2015, which is an increased rate of loss since 2011.	Deterioration
Ecosystems – State of Great Lakes	Despite successful restoration efforts and improvement in some areas, the cumulative impacts of many pressures continue to threaten the Great Lakes.	Mixed

Aquatic ecosystems are vulnerable to the impacts of climate change because once degraded they can lose functionality and factors such an increased surface water temperature can have detrimental effects on aquatic biota such as fish (Poesch et al., 2016; Sutton and Jones, 2021; Smith et al., 2021). Direct climate change impacts to aquatic ecosystems include warmer temperatures, changes in precipitation, and shifting wind patterns affecting water budgets and thermal regimes; these have cascading effects, such as changes in hydrology, reduced ice cover on lakes, nutrient cycling, groundwater flow, sedimentation patterns, and mixing in lakes (Poesch et al., 2016; Woolway et al., 2020). These physical changes affect the quality and quantity of aquatic habitats and the health of ecological functions. Indeed, the combination of climate and non-climate stressors can diminish the health of aquatic ecosystems. For example, the impact of climate change on extreme precipitation events like intense downpours is related to runoff events, which, combined with nutrient and other pollution runoff can result in algae blooms, the loss of rare plant species, and reduction in wildlife diversity (Moore et al., 1989).

For the purposes of the PCCIA, four Level 2 categories were used to assess the risks related to the direct impacts to aquatic ecosystems, referred to as focal ecosystems: clear open water (lakes, rivers, and streams), marshes, bogs, and mudflats. The selection of focal ecosystems considered representation of Ontario's diverse ecoregions (hence, inclusion of mudflats as unique to the Far North), evidence base on climate change impacts, importance to humans (socio-culturally or economically), and importance to species (e.g. key nesting or breeding habitat).

Direct Impacts

The following sections provide brief characterizations of each Level 2 category assessed for aquatic ecosystems across Ontario and related risk results. Risk scenarios for aquatic ecosystems were driven by climate variables related to temperature and precipitation, including average temperature, high and extreme temperature, drought, extreme precipitation events, and winter precipitation. Changes in severity and occurrence of these climate variables could lead to environmental consequences of the following types:

- Change in freshwater hydrological regimes
- Increases in habitat-related stresses
- Changes in food web interactions
- Changes in relative abundance of a species within a community
- Change in energy flows and nutrient or matter cycle-related ecosystem processes

Table 7.10 includes example risk scenarios for each Level 2 category assessed under aquatic ecosystems. The climate risk profiles for each Level 2 category are presented by timeframe and region in Table 7.11 (operating under RCP8.5), found at the end of this section.

Table 7.10: Illustrative Risk Scenarios and Risks to Aquatic Ecosystems

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Bog	Extreme temperatures can cause loss of bog productivity from declining Sphagnum cover will lead to reduced peat accumulation in bogs, turning bogs from being carbon sinks to sources because annual productivity will no longer exceed annual decomposition.	**Low**
Clear Open Water	Heavy rainfall events increase water turbidity leading to changes in energy flows through the food web and shifts in community composition.	**Medium**
Marsh	Moisture Deficit events cause water-level fluctuations, changing the vegetation and nesting habitat of freshwater marshes, with possible decrease in abundance of marsh nesting obligate bird species and increase in tree or shrub nesting species.	**Low**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Mudflats	The Far North's mudflats provide resting habitat and food resources for migrating arctic breeding shorebird species. Degradation or disappearance of these mudflats due to the combined effect of climate change (e.g. high temperatures) and isostatic rebound resulting in long-term reductions of migrating shorebird habitat.	**Low**

Bog

A bog is a type of peatland. Bogs are open, shrub, or treed communities in which the water table is seasonally or permanently at the substrate surface (Ontario Ministry of Natural Resources and Forestry, 2014c). They are distinguished from marshes in part by the accumulation of *Sphagnum* peat substrate and from fens by receiving all or most of their water from precipitation as opposed to runoff, groundwater, or streams (FGDC, 2013). Bog ecosystems are nutrient-poor and acidic, with trees and shrubs growing to less than two metres high and tree cover making up less than or around 25% of the area. Bogs occupy 157,933 ha (Miller et al., 2021).

In Ontario's Far North bogs contain permafrost (soil that remains below 0 °C for two or more consecutive years). Climate change concerns in peatlands, including bogs, relate to those ecosystems' ability to conserve carbon sequestration and storage potential as temperatures rise, precipitation, and moisture balances shift in a changing climate (McLaughlin et al., 2018). Intensifying fire regimes and a longer fire season also pose a threat to peatland carbon stocks, increasing vulnerability to deep burns, especially in disturbed bogs that were drained for agriculture or mined (Granath et al., 2016).

Climate risks to bogs were assessed across all six PCCIA regions, focusing on risk scenarios driven by temperature changes, specifically Cooling Degree Days, which is a proxy for annual average changes, and drought (Moisture Deficit).

The current climate risk profile associated with the environmental consequences from climate change impacts to bogs is rated as 'medium' in southern regions of Ontario (Central. Eastern, Southwest) and 'high' in northern regions of Ontario (e.g. Northeast, Northwest, Far North), considering the consequences if risks were to occur. By mid-century risk levels increase to 'high' for all regions, except the Far North where the risk level is 'very high' (under RCP8.5). Risk profiles in the Far North and southern regions of Ontario stay 'high' and 'very high' by late century, with risk levels increasing to 'very high' in Northeast and Northwest regions, considering pressures from human activities and development. These results for end of century are consistent across both emissions concentration scenarios (RCP4.5 and RCP8.5).

Warming air temperatures have the potential to shift the composition of flora in bogs. In general, increased temperatures would promote vascular plant growth (initially increasing Sphagnum growth) and would also increase evaporative demand (ultimately leading to Sphagnum water stress) and increase rates of decomposition (Waddington et al., 2015). Vascular plants compete directly with Sphagnum and increase rates of evapotranspiration, which acts in a positive feedback loop to dry out the peat (Waddington et al., 2015). Evidence of mechanisms for Sphagnum decline include a site-level glasshouse experiment examining drivers of shifts in peatland ecosystem plant communities. This study observed that the sedge *Carex disperma* was found to displace *Sphagnum* in a single growing season at temperatures greater than 8˚C (Dieleman et al., 2015). The experimental mesocosms used to determine this limit were taken from a peatland in the northwest region of Ontario, a nutrient-poor fen ecosystem (Dieleman et al., 2015). This study is relevant to bogs since nutrient-poor fens share many similar characteristics to bogs and may react similarly to climactic changes however it should be noted that fens have higher resilience than bogs due to water table drawdown.

Over the long term, shifts in air temperature and peatland moisture status would be expected to be accompanied by changes in carbon cycling processes linked to a loss of productivity of bog's vegetation cover (Humphreys et al., 2014). For every degree Celsius increase in air temperature, there will be a loss in *Sphagnum's* net primary productivity of 13-29 g C/m^2 (Norby et al., 2019). Loss of productivity from declining *Sphagnum* cover will lead to reduced peat accumulation in bogs (Humphreys et al., 2014). Reduced net ecosystem production, in turn, has been shown through simulation studies to reduce the carbon sequestration capacity of northern bogs (Wu and Roulet, 2014).

Fens, in contrast, could turn from carbon sinks to sources, as decomposition (from increased temperatures and lower water levels), or wildfire (for the same reasons) will cause emissions to outpace sequestration. More recently, a probabilistic modelling study of peat carbon sinks indicated that, in the study area (located within the Hudson Bay Lowlands, captured in the PCCIA Far North region), the peat carbon sink strength is expected to be moderately vulnerable to increasing mean annual air temperature (McLaughlin et al., 2018). Other studies indicate that peatlands may still function as carbon sinks to the end of the century even if the peatlands transform into a thawed bog; however, any carbon storage in peatlands in the North will be offset by methane emissions related to permafrost thaw (Webster et al., 2018).

Clear Open Water

Clear open water ecosystems in Ontario are water bodies that have minimal evidence of turbidity or suspended sediment and lack macrophyte vegetation, tree, or shrub cover (Ontario

Ministry of Natural Resources and Forestry, 2014c). These ecosystems are distributed throughout all regions of Ontario as lakes, rivers, and streams, occupying 14,453,250 hectares (ha) (8,241,400 if which constitutes the Great Lakes' Ontario extent), as delineated in the Ontario Land Cover Compilation (Ontario Ministry of Natural Resources and Forestry, 2014a).

The impacts of climate change on the Great Lakes are widely studied, and include decreased seasonal ice cover, increased surface water temperatures, lengthened periods between turnover of dissolved oxygen and nutrients (Douglas and Pearson, 2022). Other impacts on water bodies include enhanced sedimentation caused by more frequent heavy rainfall events (Goldsmith et al., 2021). These physical changes affect the functioning of aquatic ecosystems, such as nutrient cycles, phenology, and lake productivity (Douglas and Pearson, 2022). Streamflow influences the distribution and abundance of aquatic species (Poff et al., 1997) and more increased frequency and longer lasting extreme high and low streamflow events are likely to have significant consequences for stream populations (Nislow et al., 2004; Wenger et al., 2011, Letcher et al., 2015).

Climate risks to clear open water were assessed across all six PCCIA regions, focusing on risk scenarios driven by temperature changes, specifically Cooling Degree Days, which is a proxy for annual average changes, drought (Moisture Deficit / Drought), and extreme precipitation (shorter term). The current climate risk profile associated with the environmental consequences from climate change impacts to open clear water is rated as 'medium' across all regions of Ontario, increasing to 'high' by mid-century in southern regions of the province (Central, Southeast and Eastern), as socio-economic projections of population growth, urban and industrial development exacerbating risk here. By late century (2080s) risk levels are 'high' in all regions of the province, largely driven by increases in extreme precipitation events.

Warmer temperatures and drought conditions influence dissolved organic content in lakes, with several ecological consequences. Dissolved organic content (DOC) controls several chemical, physical, and biological processes in water bodies, including thermal structure, light transmission for photosynthesis, attenuation of high levels of ultraviolent light, vertical distribution of plants and animals, the form and availability of toxic metals (Gunn et al., 2001). Warming temperatures lead to higher DOC levels in lakes and streams, resulting in "brownification" of waters and thermal stratification (Gaibisels, 2019, Gunn et al., 2001). These conditions favour the persistence of phytoplankton adapted to low light conditions, including noxious cyanobacteria. A study of Lake Michigan and Ontario indicated that thermal warming of lake surface water can lead to more frequent incomplete fall overturnings and partial winter stratifications, which can have significant consequences for the functioning of these ecosystems (Fichot et al., 2019). Drought events can, conversely, decrease the export of dissolved organic carbon from catchments into lakes, increasing water clarity and creating broader transition zone between surface and bottom water habitats, with biological consequences including shifts in predator-prey dynamics and expanded ranges of warmwater fishes (Gunn et al., 2001).

Heavy rainfall events increase erosion, wash inorganic sediment, and increase limiting nutrients into water bodies, leading to changes in energy flows through the food web and shifts in community composition. Sedimentation caused by intense rain events will be particularly high in winter and spring when rain will fall on bare ground, which is more easily eroded than ground with vegetation cover (Assembly of First Nations, 2008).

Turbid water alters fish predator-prey interactions for predators that rely on vision to detect and capture prey (e.g. salmonids). Turbidity will provide prey with a refuge from predation, which may alter recruitment rates for both predators and prey. In contrast, many cool (e.g. percids) and warm water species are adapted to turbid conditions, which will allow them to invade new freshwater areas that become accessible to them due to warming temperatures, despite projected reductions in water clarity. Increases in suspended solids can impact freshwater mussels by decreasing food availability, impeding filter feeding and respiration, and inhibiting aspects of the mussel-host relationship. Studies show that clearance rates, a measure of feeding for mussels, are negatively impacted by total suspended solids (TSS) concentrations > 8 mg/L, and respiratory stress occurred at ~600 mg/L (Goldsmith et al, 2021). Increase in turbidity in clear open water systems can have negative impacts on species at risk mussels such as the salamander mussel (*Simpsonaias ambigua*) discussed in Section 7.7.1. Additionally, nutrient runoff will stimulate production of phytoplankton such as noxious cyanobacteria, resulting in creation of harmful algal blooms.

Marsh

Marshes make up 228,874 ha of the province and refer to open, shrub, and treed communities in which the water table is seasonally or permanently at the substrate surface (Ontario Ministry of Natural Resources and Forestry, 2014c). Marshes are dominated by aquatic plants, with trees and shrubs representing less than or around 25% of the vegetation. Marshes can be marine (intertidal and supratidal) and freshwater. Marshes are one of four types of wetlands, the other three being swamps, bogs, and fens. Freshwater marshes are highly productive ecosystems, sustaining diverse plant communities as well as wildlife (FGDC, 2013). Indeed, marshes provide staging areas for countless waterfowl species, are home to species at risk birds, fish, mammals, reptiles, and amphibians (Miller et al., 2021; Ontario Ministry of Natural Resources and Forestry, 2014c). Aside from providing habitat, marshes help restore groundwater supplies, moderate streamflow, mitigate floods, filter excess nutrients, sediment, and pollutants from surface runoff, and contribute to climate regulation through carbon removal from the atmosphere and storage in plants and soils (FGDC, 2013; Richardson, 1994). The impacts of climate change on wetlands primarily relate to hydrological shifts, although temperature-related impacts are also significant. Climate change impacts combine with other human pressures to enhance ecosystem vulnerability (see Table 7.11). For example, loss of marshes in southern Ontario continues to occur due to drainage for agriculture and development (Byun et al., 2018).

Table 7.11: Climate Change Impacts for Wetlands

Climate Condition/Hazard	Impacts for Wetlands
Extreme precipitation events	- Increased overland runoff and nutrient loading resulting in pollution-related impacts - Increased sedimentation that covers organic substrate and seed banks - Increased flooding and erosion in watershed and coastal zone
Change in precipitation timing and amount	- Increased seasonal precipitation - Increased runoff and salt - Degraded water quality - Reduced wildlife abundance
Changing / variable water levels (including sea-level rise)	- Changes in wetland area due to lakeward migration of terrestrial vegetation during prolonged low water or due to inland migration of water body during prolonged high water
Temperature increases and changes in climatic envelopes	- Anoxia - Loss of species diversity - Increase in invasive species - Change in coastal energy dynamics
Reduction of ice cover	- Erosion, movement of sediment

Modified from: Mortsch, 2020

Climate risks to marshes were assessed across Ontario's six PCCIA regions, focusing on risk scenarios driven by drought (Moisture Deficit / Drought), and winter precipitation (Rain:Snow Ratio), and temperature changes, specifically Cooling Degree Days, which is a proxy for annual average changes.

The current climate risk profile associated with the environmental consequences from climate change impacts to marshes is rated as 'medium' across Ontario, increasing to 'high' by mid-century in all regions of Ontario except for the Northwest. By late century risk levels are 'high' in all regions of the province, except for the Central region, where risk levels are 'very high'. These patterns are consistent across emissions concentration scenarios.

Dry conditions present risks to freshwater marshes because of the potential to cause fluctuations in water levels, changing vegetation profiles and nesting habitat of freshwater marshes. Fluctuating water levels do not alter the overall extent of wetlands but do have the potential to alter the structure of marsh plant communities (Mortsch et al., 2006). For example, one study found water level fluctuations to account for 88% of the variation in cover of Typha latifolia, with less of the species occurring at low water levels (Wei and Chow-Fraser, 2005). In contrast, the study found that two invasive species (Glyceria and Phragmites) were more efficient colonizers of marsh habitats that are experiencing Moisture Deficits (Wei and Chow-Fraser, 2005). A general response to declining water levels is for vegetation to shift to species that are more tolerant of dry conditions (particularly sedges and grasses), with patches of these species becoming more contiguous and elongated, wetlands became less fragmented but less complex (Mortsch et al., 2006).

Changes in seasonal precipitation have the potential to affect freshwater marshes by shifting the amount and timing of flooding and spring freshets. Changes in flooding will have impacts on marsh water levels and hydrology, including a reduction or elimination of meltwater fed marshes, which in turn will alter the flora and fauna communities found within the marsh.

High and extreme temperatures have the potential to contribute to the loss of coastal marsh in James Bay and Hudson Bay in the Far North region (Erwin, 2009; Lemmen et al., 2016). Elevated air temperatures accelerate permafrost degradation, which may lower the water table, cause slumping, and degrade water quality. These events could lead to degradation and loss of coastal wetlands, including marshes, and erosion of shorelines by the end of the century. Degradation and loss of marshlands in the Far North could lead to long-term reductions of wildlife habitat, particularly for shorebirds that rely on these wetlands for food during migrations.

Mudflats

Mudflats are unvegetated coastal areas of the Hudson Bay-James Bay Lowlands, which are partly submerged at high tide (Ontario Ministry of Natural Resources and Forestry, 2014c). Found in the Far North region of Ontario, mudflats occupy 10,739 ha and are essential resting and feeding habitat for migratory shorebirds (Miller et al., 2021; Smit and Wandel, 2006). As with other aquatic ecosystems, mudflats also contribute to global carbon regulation through carbon sequestration and storage in their sediment and vegetation (Lovelock and Reef, 2020). A changing climate, including changes in temperature, precipitation, cryology, storms, and sea levels) affects the habitat area occupied by mudflats, sediment supply to them, erosion and accretion rates, as well as nutrient flows (Lovelock and Reef, 2020).

Climate risks to mudflats were assessed for the Far North region of Ontario, focusing on a risk scenario driven by temperature changes, specifically Cooling Degree Days, which is a proxy for annual average changes.

The current climate risk profile associated with the environmental consequences from climate change impacts to mudflats is rated as 'high', with the risk staying at that level by mid-century. By late century, risk levels increase to 'very high', as the intensity of the climate hazard increases. These patterns are consistent across emissions concentration scenarios.

Warmer temperatures combined with land uplift creates coastal squeeze of the intertidal mudflats. Elevated temperatures in Hudson Bay and James Bay are anticipated to result in a considerably shorter ice cover season, much warmer and longer summers, and warmer and shorter winters (Lemmen et al., 2016). Intertidal mudflats will be degraded or lost entirely, as land undergoes post-glacial coastal uplift, the tundra ecozone advances poleward and is replaced by forests (Smit and Wandel, 2006; Environment and Climate Change Canada, 2017).

Degradation and loss of intertidal mudflats will reduce habitat available for migrating shorebirds and other species that live or spend part of their life cycle in the Far North of Ontario, commonly congregating on mudflats in the winter (Lemmen et al., 2016; Smith et al., 2006). In Ontario, the James Bay shoreline is the most important staging area for migrant shorebirds, offering almost entirely undisturbed expanses of rich tidal mudflats and intertidal wetlands (Abraham and McKinnon, 2011). Degradation or disappearance of these mudflats due to the combined effect of climate change and isostatic rebound will result in long-term reductions of migrating shorebird habitat. This means that the availability of food resources will no longer coincide with migration timing and breeding events. For example, Hudsonian godwits require breeding ranges near tidal mudflats where the non-incubating member of the pair is able to feed (Abraham and McKinnon, 2011).

Table 7.12: Risk Scores for Aquatic Ecosystem Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Aquatic Ecosystems	Bog	Central Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Bog	Eastern Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Bog	Far North Region	**High**	**Very High**	**Very High**
Aquatic Ecosystems	Bog	Northeast Region	**High**	**High**	**Very High**
Aquatic Ecosystems	Bog	Northwest Region	**High**	**High**	**Very High**
Aquatic Ecosystems	Bog	Southwest Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Clear Open Water	Central Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Clear Open Water	Eastern Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Clear Open Water	Far North Region	**Medium**	**Medium**	**High**
Aquatic Ecosystems	Clear Open Water	Northeast Region	**Medium**	**Medium**	**High**
Aquatic Ecosystems	Clear Open Water	Northwest Region	**Medium**	**Medium**	**High**
Aquatic Ecosystems	Clear Open Water	Southwest Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Marsh	Central Region	**Medium**	**High**	**Very High**
Aquatic Ecosystems	Marsh	Eastern Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Marsh	Far North Region	**Medium**	**High**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Aquatic Ecosystems	Marsh	Northeast Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Marsh	Northwest Region	**Medium**	**Medium**	**High**
Aquatic Ecosystems	Marsh	Southwest Region	**Medium**	**High**	**High**
Aquatic Ecosystems	Mudflats	Far North Region	**High**	**High**	**Very High**

Indirect Impacts

Degradation and loss of aquatic ecosystems will have significant impacts on the flow and reliable supply of ecosystem services, including reduced contributions to global climate regulation, the loss of nutrient filtering from agricultural runoff, loss of flood protection during major precipitation events putting more pressure on built infrastructure, and loss of recreational fishing and nature-based recreation resulting in economic losses for communities reliant on these industries (Garcia-Hernandez and Brouwer, 2020).

Climate change impacts on aquatic ecosystems drive changes to species and create new opportunities for invasive species, in turn reducing habitat and resources for species at risk. For example, the most recent State of the Great Lakes report indicates that new populations of the invasive species *Typha spp.* have established populations in all the Great Lakes basins increasing overall impact on coastal wetlands (Environment and Climate Change Canada and US EPA, 2022). The presence of *Typha spp.* and *Phragmites australis* in marsh ecosystems affects aquatic macroinvertebrate structure as well as physical habitat structure and food web dynamics (Environment and Climate Change Canada and US EPA, 2022). The persistence of *Phragmites australis* hinders conservation efforts, as its presence adversely affects the health of breeding marsh bird species of conservation concern and reduces habitat for endangered amphibians, such as the Blanding's turtle (Tozer and Mackenzie, 2019; Markle and Chow-Fraser, 2018).

7.7.4 Terrestrial Ecosystems

Overview

Terrestrial ecosystems are land-based communities of organisms and the interactions between them and abiotic components of the community in a given area. In addition to supporting biodiversity and providing habitat for wildlife, the functioning of terrestrial ecosystems like forests supply ecosystem services, such as water flow regulation (Rezanezhad et al., 2016), carbon sequestration and storage (Magnus et al., 2021; Kayranli et al., 2010; Sierszen et al., 2012), nature-based recreation such as hiking.

Within the categories of terrestrial ecosystems assessed for the PCCIA (heath, coniferous forest, deciduous forest, sand barren and dune, open tallgrass prairie, and tallgrass savannah), forested areas are most extensive (Miller et al., 2021). The extent and composition of terrestrial ecosystems is a function of climate, landscape attributes (e.g. geomorphology, topography, soil), and landscape history. For example, forests have been most altered in areas where soil and topography are suitable for agriculture and settlement, with their composition, age, and structure of forest stands also affected by disturbances (e.g. harvest, fires, insects, and disease) (Ontario Biodiversity Council, 2021). Threats to the health of Ontario's terrestrial ecosystems, as measured by biodiversity, include habitat fragmentation, land-use pressures, pollution, invasive species, unsustainable use, and climate change, with relative improvements in some status indicators and deterioration in others (Ontario Biodiversity Council, 2021) (see Table 7.13).

Table 7.13: Terrestrial Ecosystems and Biodiversity in Ontario

Indicator	Status	Trend
Pressures on biodiversity		
Habitat loss – Land cover	Natural terrestrial cover continues to decline in southern Ontario, with a slight increase in northern Ontario (the Ontario Shield ecozone).	Increasing
Habitat loss – Terrestrial fragmentation	Terrestrial fragmentation is highest in southwestern Ontario, and, while still baseline, the trend appears to be deteriorating.	Baseline
Climate change – Afforestation/deforestation	Constant afforestation rates from 2008-2018. Increased deforestation in southern Ontario, resulting in a net loss of forest of 38,003 ha.	Mixed
Ecosystems and species		
Ecosystems – Forest cover	Forest cover continues to decline in southern Ontario, in spite of afforestation efforts.	Mixed
Ecosystems – Rare ecosystems	62% of prairies and 79% of coastal dune ecosystems are legally protection, up by 1% and 4% since 2015. Most of the area of these rare ecosystems continues to be ranked as good or high.	Baseline

Source: Ontario Biodiversity Council, 2021

For the purposes of the PCCIA, six Level 2 categories were used to assess the direct impacts to terrestrial ecosystems, referred to as focal ecosystems: heath, coniferous forest, deciduous forest, sand barren and dune, open tallgrass prairie, and tallgrass savannah. The selection of focal ecosystems considered representation of Ontario's diverse ecoregions (hence, inclusion of heath as unique to the Far North), evidence base on climate change impacts, importance to humans (socio-culturally or economically), and importance to species (e.g. key nesting or breeding habitat). Three of the six Level 2 categories of terrestrial ecosystems are rare vegetation communities (Tallgrass Savannahs, Open Tallgrass Prairie, Sand Barren and Dune) or habitats and breeding areas for migratory birds (Deciduous and Coniferous Forests) as defined in the province's Significant Wildlife Habitat Technical Guide (Ontario Ministry of Natural Resources and Forestry, 2000) and related Significant Wildlife Habitat Criteria Schedules (Ontario Ministry of Natural Resources and Forestry, 2015).

Direct Impacts

This section describes the quantitative scores for direct risks assessed for the Level 2 Terrestrial Ecosystem categories. Over 100 separate interactions were assessed for Terrestrial Ecosystems, considering relevant climate variables to each Level 2 category and were evaluated under current and future timeframes. The assessment has drawn on research, provincial data, and literature to inform scenario development and consequence scoring related to direct climate risks on aquatic ecosystem types.

Table 7.14 includes example risk scenarios for each Level 2 category assessed under terrestrial ecosystems. The climate risk profiles for each Level 2 category are presented by timeframe and region in Table 7.16 (operating under RCP8.5), at the end of this section.

Table 7.14: Illustrative Risk Scenarios and Risks to Terrestrial Ecosystems

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Coniferous Forest	Warming contributes to the northward shift of coniferous forest ranges. Contraction of coniferous forest ecosystem region due to increased disturbance rate and encroachment of deciduous southern tree species.	**Medium**
Deciduous Forest	Moisture Deficits promote a transition to patchy forest cover and grassland habitat with drought-stressed trees more prone to disease	**Low**
Heath	Fluctuations in summer precipitation frequency and amount changes soil moisture and negatively impacts respiratory activity of heath systems, degrading the health of these systems	**Low**

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Sand Barren and Dune	Warming and related loss of protective ice cover reduces extent of sand barren and dune ecosystems in Ontario and reduces species richness.	**Medium**
Tallgrass Savannah	Degraded tallgrass savannah systems become vulnerable to environmental stress and biotic threats in the face of extended hot-weather seasons.	**Low**

Coniferous Forests

Coniferous-dominated forests are continuous forests canopy composed mainly of coniferous species, primarily jack pine, black spruce, and white spruce. Vegetation cover tends to be closed and tall (60% closure and greater than 10 m), but can also be open and tall, and low communities. Coniferous-dominate forests make up 21.2 million ha of Ontario, with the majority of these ecosystems occurring in the northern regions of the province (Watkins, 2021; Miller et al., 2021). Studies indicate that the boreal forest is relatively sensitive to climate change, having already shown responses despite relatively small changes (Colombo, 2008). This is concerning since the projected comparatively large changes in climate may result in more substantial responses than previously projected (Colombo, 2008). Due to the long lifespan of tree species, rapid climate change is likely to have direct and indirect negative impacts on vegetation health, composition, structure, and productivity within half of many species' lifetimes (Puric-Mladenovic et al., 2011).

The recent assessment of climate change impacts and adaptation knowledge for Ontario synthesizes the latest research on forests' vulnerability to climate change and the benefits of sustaining resilient forested landscapes (Douglas and Pearson, 2022). Direct impacts for forests overall include i) increased survival rates of forest pests and diseases linked to warmer winters; ii) reduced tree resistance to cold linked to warming winters and abrupt transitions from warm to freezing in late fall, resulting in forest decline; iii) increased disturbance to forests due to the increased frequency, intensity, extent, timing, and duration of forest fires; iv) reduced productivity and growth of boreal species because of warming and drought-induced mortality and increased migration failure; v) a long term northward migration of tree species as climate suitability envelopes shift. Significant uncertainty remains regarding boreal and temperate trees species response to climate change, including limits of tree community recovery from disturbance (Park et al., 2014).

Climate risks to coniferous-dominated forests were assessed across four PCCIA regions: Eastern, Northeastern, Northwestern, and Far North. Our decision criterion was to include PCCIA regions with over two percent of land cover dominated by coniferous forests (Table 7.15). We focused on risk scenarios driven by temperature changes, specifically Growing Season Length, and wildfires.

Table 7.15: Regional Distribution of Areas with Coniferous-Dominated and Deciduous-Dominated Forests

Land cover (%)	Far North	Northwest	Northeast	Southwest	Central	Eastern
Coniferous-dominated forests	39	36	24	1	1	4
Deciduous-dominated forests	1	9	15	9	14	25
Mixed forest	3	18	39	5	9	27
Other land classes	57	36	23	84	76	44

The current climate risk profile associated with the environmental consequences from climate change impacts to coniferous forests is rated as 'medium' across the four regions assessed, increasing to 'high' by mid-century. Risk stays at that level by the end of century for all assessed regions except for Eastern Ontario, where risk increases to 'very high'.

Warming contributes to the northward shift of coniferous forest ranges. Climate suitability, a combination of temperature and precipitation, for different tree species is shifting, affecting tree species' productivity (and total biomass) and causing changes in forest composition. Trees species whose southern edge lies within the Great Lakes Basin, such as white pine, jack pine, and red pine will likely experience reduced growth rates, reproductive failure, and increased disease and mortality. The amount of suitable habitat is expected to increase for some deciduous species like sugar maple, red oak and deciduous Carolinian species. What had been considered boreal regions will undergo shifts to include species from ecosystems characterized by more southern ecoregions such as: boreal forest to wetland, boreal forest to Great Lakes- St. Lawrence forest, or boreal forest to aspen parkland. A study of changes to the parkland-boreal forest ecotone through sediment core analysis and pollen inferences indicates that the boreal forest will likely become more open and even with a projected increase in precipitation will see a decrease in effective moisture due to an overall increase in evaporation and evapotranspiration with future increased temperatures (Moos and Cumming, 2011).

The potential exists for the contraction of coniferous forest ecosystems due to increased disturbance rates and encroachment of deciduous southern tree species, with several cascading effects. With the increase of wildfire occurrence and area burned, pioneer species abundance will increase (Gauthier et al., 2014). An increase in area burned will hasten the establishment of young stands with low biomass. Young forests often have higher productivity in terms of annual growth but accumulate less biomass and carbon. Their total biomass and carbon storage will recover to mature forest levels as they age. Although several studies suggest that CO_2 fertilization can have a positive effect on net primary production in conifer-dominated forests, a study comparing model simulations to growth in Manitoba's boreal forest indicates that these results cannot be directly extrapolated to large, forested areas without considering local growth constraints (Girardin et al., 2011).

Increased wildfire occurrence in combination with rising temperatures could also result in degraded permafrost and therefore the replacement of black spruce by other species in northern regions (Gauthier et al., 2014). Temperature is directly related to the persistence and expansion of defoliation caused by spruce budworm (*Choristoneura fumiferana*) in Ontario (Candau and Fleming, 2011). This invasive species impacts coniferous forest species such as balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*). The combination of climate change-induced shifts in fire, insect disturbances, and tree mortality is projected to reduce above-ground biomass in the boreal, with the most pronounced impacts occurring in Northwest Ontario along the southern part of the boreal (Brecka, 2018).

Deciduous Forests

Deciduous-dominated forests are continuous forests canopy composed mainly of deciduous (hardwood) species, primarily poplar and birch. Vegetation cover tends to be closed and tall (60 percent closure and greater than 10 m), but can also be open and tall, and low communities (Watkins, 2021; Miller et al., 2021; Ontario Ministry of Natural Resources and Forestry, 2014a; Khan and Conway, 2020).

Climate risks to deciduous-dominated forests were assessed across Ontario, except the Far North. Risk profiles are driven by temperature changes, specifically Growing Degree Days, and drought (Moisture Deficit).

The current climate risk profile associated with the environmental consequences from climate change impacts to deciduous forests is rated as 'medium' across the five regions assessed, increasing to 'high' by mid-century. Shifts in dominant species are occurring in managed, deciduous forests in response to both active harvest management and no-harvest management systems, indicating that climate-influenced changes are occurring both with and without human intervention (Olson et al., 2017). Risk remains at this level by the end of century. The risk profiles for this category have a significant degree of uncertainty with regard to how pressures from socio-economic activities could interfere with conditions favouring migration.

Warming temperatures have the potential to drive changes to the composition of deciduous forests, favouring warm-adapted species. Climate suitability – a combination of changes in temperature and precipitation— for different tree species is shifting, affecting tree species productivity (and total biomass) and causing changes in forest composition. Trees species whose southern edge lies within the Great Lakes Basin, such as trembling aspen and yellow birch will likely experience reduced growth rates, reproductive failure, and increased disease and mortality. As climate change progresses, suitable habitat for trembling aspen may be limited to the northern upper Great Lakes. The amount of suitable habitat is expected to increase for some species like sugar maple, red oak, and deciduous Carolinian species. Taylor et al., (2017) illustrated the effects of climate change on the composition of the Canadian Acadian Forest region using process-based modelling, projecting by end of century a persistent increase in relative abundance of temperate species (e.g. American beech, red maple, red oak, and white ash) and a decrease in cold-adapted species (eastern larch, trembling aspen, and white birch) over time. This modelling work highlighted the importance of interspecific competition as a key driver of forest community shifts, which is an indirect effect of warmer and drier conditions.

Northward colonization of temperate species will not be able to keep pace with projected changes in climate envelopes, leaving less productive forests as a result. Both climatic and non-climatic factors (stand attributes, biotic interactions, soil conditions, geographical barriers) influence colonization but these nuances are not typically accounted for in species distribution modelling. A recent study focused on 10 forest species common in eastern Canada highlights the likely inability of tree species to track climate suitability over time (Boisvert-Marsh- et al., 2022). Species distribution modelling informed by species-specific data on dispersal abilities and regeneration time suggests a lag between simulated distribution limits and climatically-suitable limits, particularly for temperate species (Boisvert-Marsh et al., 2022). This lag increases over time. Exposure to soil moisture stress is one mechanism causing negative responses by temperate species (Taylor et al., 2017). Trees exposed to intermittent summer drought because they are in dry habitats may be more prone to disease if climate change further reduces soil moisture. In some cases, Moisture Deficits could promote a transition to patchy forest cover and grassland habitat (Khan and Conway, 2020).

Heath

Heath ecosystems are shrubland habitats found mainly on free-draining infertile, acidic soils deposited on raised beaches and ancient shorelines. Heaths in Ontario have greater than 25 percent of vegetation cover, which is limited to low-growing woody vegetation, lichen, Arctic herb, and various acidic soil loving shrub species. These ecosystems are localized, occurring in Ontario's Far North region and constituting 67,122 ha of Ontario (Miller et al., 2021), as delineated in the Ontario Land Cover Compilation (Ontario Ministry of Natural Resources and Forestry, 2014a). The impacts of climate change on heath ecosystems are understudied relative to other terrestrial ecosystems but their sensitivity to climate change stems from the specialist vegetation that grows in these complex habitats. Literature from outside Ontario highlights shifts toward shrub dominance and changes in nutrient fluxes as among the direct impacts of warmer temperatures in low arctic tundra and heathlands (Fagúndez, 2013; Dumais et al., 2014; Alvarenga and Rousk, 2021).

Climate risks to heath ecosystems were assessed for the Far North region, focusing on risk scenarios driven by change in precipitation (Mean Summer Precipitation) and wildfire.

The current climate risk profile associated with the environmental consequences from climate change impacts to heath ecosystems is rated as 'medium', staying at that level by mid-century. By late century the risk level is 'high', mainly driven by assumptions around land use pressures in the northern Boreal (Lonsdale et al., 2017), which exacerbate the consequences of climate change impacts.

Changes in summer water balance can affect net ecosystem carbon exchange in heath ecosystems. Experimental treatments on temperate heather indicate that warming enhances increases in plant productivity, photosynthesis, and respiration due to rising CO_2 levels, but drought decreases these effects (Albert et al., 2011). Other studies, also suggest that differences in precipitation and moisture affect net ecosystem CO_2 exchange in heath environments, with site-specific moisture regimes restricting respiratory activity at the heath and sedge systems when they are too dry or too wet (Nobrega and Grogan, 2008). Fluctuations in summer precipitation frequency and amount changes soil moisture and negatively impacts respiratory activity of heath systems, changing rates of plant carbon uptake (Nobrega and Grogan, 2008; Albert et al., 2011).

The intensification of wildfire regimes has the potential to decrease plant richness in heaths, affecting ecosystem function. The severity and frequency of forest fires have powerful effects on regeneration dynamics of heath ecosystem species especially in those sites subject to warming and drying (St. James and Mallik, 2021; Fagúndez, 2013). Heath regeneration relies on resprouting and seed germination. Experimental research from heath ecosystems outside of Ontario links drought and warming to reduced seedling diversity (Fagúndez, 2013). Therefore, the combined effect of more frequent wildfires, warmer temperatures and dryer conditions can delay regeneration and result in vegetation communities that support less species diversity, with negative implications for ecosystem function. (St. James and Mallik, 2021).

Sand Barren and Dune

Sand barren and dune ecosystems are natural ecosystems not originating from anthropogenic or cultural disturbances with severe environmental limitations and tree cover of less than 60% (Lee et al., 1998). Sand barrens are not restricted to shorelines and are characterized by sand substrate, low and patchy vegetation cover, stunted trees and shrubs if present, with conditions maintained through environmental limiting factors such as drought or lack of nutrients (Lee et al., 1998). Sand dues are restricted to active shorelines or near lakes, rivers, streams, or ponds and are characterized by active hills of accumulated sand above the normal reach of waves and subject to erosion from wind (Lee et al., 1998). Dune ecosystems sustain rare vegetation communities and associated wildlife, with dune habitat supporting human recreation (e.g. Sandbanks Provincial Park). Sand dune and barren habitats combined cover 698 ha of Ontario, as delineated in the Ontario Land Cover Compilation (OMNRF 2014). Open sandy areas in eastern Ontario have declined to approximately 1% of their former range over the past 60 to 70 years due to a variety of anthropogenic forces, heightening these systems' vulnerability to the impacts of climate change (Catling et al., 2008). The 2022 State of the Great Lake report indicates that the overall 10-year assessment for Great Lake shorelines (excluding Lake Superior, which has insufficient data for Canada as of 2022) is deteriorating, as hardened shorelines have increased for all lakes. This increase in hardened shorelines is a concern as physical modifications to the shoreline have altered or eliminated connectivity to sand barren and dune habitats (Environment and Climate Change Canada and US EPA, 2022).

Climate risks to sand barren and dune ecosystems were assessed for the southern regions of Ontario (Central, Southern, Eastern), focusing on risk scenarios driven by changes in temperature (Growing Season Length, as a proxy for average annual temperature change).

The current climate risk profile associated with the environmental consequences from climate change impacts to sand barren and dune ecosystems is rated as 'medium'. Risk levels across southern Ontario increase to 'high' by mid-century and are anticipated to remain at this level to the end of the century.

Warming alters abiotic conditions that are important to the maintenance of sand barren and dune ecosystems. These ecosystems are vulnerable to degradation and erosion from high wave energy. Recent observations of ice duration on the Great Lakes and climate change projections indicate a trend of shorter ice durations and more frequent ice-free winters in Lake Erie (BaMasoud and Byrne, 2012). If warmer trends continue, areas of the Great Lakes shoreline will be exposed to winter storm wave action throughout the season (BaMasoud and Byrne, 2012). The loss of protective ice cover combined with increases in extreme weather events that may affect wave energy present risks to the integrity of sand barren and dune ecosystems (Environment and Climate Change Canada and US EPA, 2022). Warming also induces physiological stress to vegetation communities that sand barren and dunes support. For example, a 5˚C increase in temperature relative to current climate in northern Michigan reduced A. breviligulata (a foundational sand dune species) survival by 45% (Emery and Rudgers, 2013). Ultimately, warming and related loss of protective ice cover over the winter reduces the extent of sand barren and dune ecosystems in Ontario and reduces species richness.

Open Tallgrass Prairie

Open tallgrass prairie is a habitat dominated by grasses or grass-like plants (prairie graminoids); tree and shrub cover are less than 25% of the surface coverage, respectively. This focal ecosystem is proportionally the smallest of all terrestrial ecosystems assessed as Level 2 categories for Ontario, consisting of 336 ha and is one of the rarest and most endangered ecosystems globally (Miller, 2021; Nemec, 2014).

Climate risks to open tallgrass prairie were assessed for the southern regions of Ontario, (Central, Southwest and Eastern) focusing on risk scenarios driven by drought conditions and high temperatures.

The current climate risk profile associated with the environmental consequences from climate change impacts to open tallgrass prairie is rated as 'medium', staying at that level until mid-century. Risk levels across southern Ontario increase to 'high' by the end of the century.

Repeated seasonal droughts combined with warming have the potential to reduce biodiversity of open tallgrass prairie ecosystems. Climate change is unlikely to unilaterally alter the functional composition of tallgrass prairie flora (Bachelet et al., 2011; Craine et al., 2011), as many functional traits including physiological drought tolerance have not been shown to be related to climate envelope parameters (Craine et al., 2011). In a changing climate, drier conditions could cause species losses, indirectly altering the productivity of the system. However, the system's overall biodiversity should enable continued functioning in the face of climate change (Craine et al., 2011). Collins et al., (2012) found that a 19-year experiment of water addition during the growing season did not have a significant impact on community structure as opposed to other key drivers of change in this grassland. Overall, repeated seasonal droughts combined with warming could cause losses of some species within the open tallgrass prairie ecosystem although functionality would likely be retained.

The co-occurrence of wildfire and extreme heat and water stress during growing seasons has the potential to lead to lasting shifts in community structure of tallgrass prairie ecosystems. Fire and nitrogen availability are key drivers of changes in community structure, diversity, and composition of this grassland ecosystem. The expectation exists that drought, heat, and fire favour maintenance of this tallgrass ecosystem. However, plot-based research comparing plots exposed to heat and water stress (high temperatures and low growing season precipitation) but not wildfire and plots exposed to both heat and water stress and wildfire counter this expectation (Ratajczak et al., 2019). Community structure, diversity, and composition showed minor to insignificant changes, such as a 20% reduction in grass cover and a slight increase in species diversity, in the former plots. Plots exposed to heat and water stress and wildfire underwent larger changes, including an 80% reduction in grass cover, 50 percent increase in forb cover, and increased plant diversity. Two years after exposure to heat and water stress, structural shifts in burned plots showed little sign of recovery, indicating a potentially lasting shift in plant community structure.

Tallgrass Savannah

Tallgrass savannah ecosystems are dominated by prairie grasses, with open tree cover between 25 and 35%. They are some of the most endangered ecosystems in Canada and only consist of 693 ha of the Ontario landscape (Rodger & Woodliffe, 2001; Miller, 2021).

Climate risks to tallgrass savannah were assessed for the southern regions of Ontario (Central, Southwest, Eastern), focusing on risk scenarios driven by temperature change (Growing Degree Days) and drought (Moisture Deficit / Drought). Tallgrass savannahs and the vulnerable plant and animal species they support are currently assessed as having ‘medium’ climate risk scores, with scores increasing to ‘high’ by mid-century and staying at that level through to the end of the century.

Repeated seasonal droughts have the potential to reduce biodiversity of tallgrass savannah ecosystems. Tallgrass savannahs are less vulnerable to the impacts of climate change than other terrestrial ecosystems. For example, many native prairie and savannah species are well adapted to drought during the summer season (Bachelet et al., 2011). These adaptations may provide an advantage to native species over invasives that may be introduced to tallgrass savannah systems that are not drought tolerant (Bachelet et al., 2011). If tallgrass savannah ecosystems are able to maintain high species richness levels, recovery from extreme drought events is likely (Dey and Kabrick, 2015). However, repeated seasonal droughts impacting tallgrass savannah systems with low species richness (degraded systems) may result in an inability to recover from extreme events.

Degraded tallgrass savannah systems are likely to be resilient to environmental stress and biotic threats in the face of extended hot-weather seasons. Although many native prairie and savannah species are well adapted to high temperatures during the summer season and with these seasons extended, prairie and savannah species may in fact thrive (Bachelet et al., 2011). If tallgrass savannah ecosystems are able to maintain high species richness levels, they should be less vulnerable to environmental stress and biotic threats.

Table 7.16: Risk Scores for Terrestrial Ecosystem Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Terrestrial Ecosystems	Coniferous Forest	Eastern Region	**Medium**	**High**	**Very High**
Terrestrial Ecosystems	Coniferous Forest	Far North Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Coniferous Forest	Northeast Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Coniferous Forest	Northwest Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Deciduous Forest	Central Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Deciduous Forest	Eastern Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Deciduous Forest	Northeast Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Deciduous Forest	Northwest Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Deciduous Forest	Southwest Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Heath	Far North Region	**Medium**	**Medium**	**High**
Terrestrial Ecosystems	Open Tallgrass Prairie	Central Region	**Medium**	**Medium**	**High**
Terrestrial Ecosystems	Open Tallgrass Prairie	Eastern Region	**Medium**	**Medium**	**High**
Terrestrial Ecosystems	Open Tallgrass Prairie	Southwest Region	**Medium**	**Medium**	**High**
Terrestrial Ecosystems	Sand Barren and Dune	Central Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Sand Barren and Dune	Eastern Region	**Medium**	**High**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Terrestrial Ecosystems	Sand Barren and Dune	Southwest Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Tallgrass Savannah	Central Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Tallgrass Savannah	Eastern Region	**Medium**	**High**	**High**
Terrestrial Ecosystems	Tallgrass Savannah	Southwest Region	**Medium**	**High**	**High**

Indirect Impacts

There are several indirect impacts that may occur due to the impacts of climate change on terrestrial ecosystems. Changes to carbon cycling in Heath ecosystems could indirectly impact adjacent but highly different hydrological systems (for example, aquatic systems) resulting in overall changes to CO_2 cycling in the tundra and other northern ecosystems (Vile et al., 2011). In deciduous forest systems, increased temperatures and lower precipitation increases the likelihood of forest fires. This increase in temperature and change to precipitation makes forests vulnerable to pests and disease and also increase fuel loads, indirectly increasing the area burned by forest fires (Colombo, 2008; Brandt et al., 2014). This is especially of concern due to the high proportion of deciduous forests in close proximity to urban and highly populated areas, the current mapped wildland-urban interface (WUI) in Ontario that is categorized as having “High Interface”, “High fuels”, and “High structures” across three-way categorical maps can be found in the Great-St. Lawrence Forest region (captured in PCCIA Eastern region, the southern part of the Northeast region, the northwest part of Central region, and the northern tip of the Southwestern region), while there have not been many large fires that have occurred within this WUI area in the past few years, likely as a result of suppression activities, future housing development is likely to increase this area and more fire suppression measures may need to take place (Johnston and Flannigan, 2017; Johnston, 2010).

Changes to the boreal ecosystem composition indirectly cause increasing detrimental effects on species that depend on mature and old-growth ecosystems, for example woodland caribou a SAR, when combining increased natural disturbance rate with harvesting (Gauthier et al., 2014). Changes to vegetation in the boreal forest will indirectly cause negative impacts on boreal carbon balance and other large-scale vegetation attributes (Price et al., 2013).

Sand Barren and Dune habitats may continue to recede, resulting in wide areas of provincial and national parks' ecologically and economically viable spaces being lost to the lake as a result of enhanced erosion (BaMasoud and Byrne, 2012). The implications for the impact of low ice cover on coasts with similar conditions to sand barren and dune habitats indicate increased opportunities for shoreline erosion. Loss of dune vegetation species through increased temperature and changes to precipitation could result in reduction of carbon storage and organic matter build-up in early successional systems due to reduced plant survival and root growth (Emery and Rudgers, 2013). The erosion of sand barren and dune habitat and the beaches that go along with them will impact the tourism industries in Eastern, central, and southwest regions of Ontario where many tourist destinations are located along the shores of the Great Lakes where dune habitats are present (BaMasoud and Byrne, 2012). This erosion will also impact property owners that own property along the coasts of the Great Lakes. Numerous species at risk will be impacted by the loss of sand barren and dune habitats such as Fowler's toad, eastern prickly pear cactus, eastern hognose snake, and dusted skipper butterfly (Carolinian Canada, 2009).

7.7.5 Regulating Services

Overview

Regulating services refer to processes that are required for the maintenance of earth's systems and moderate natural phenomena affecting human health, safety, or comfort (Haines-Young and Potschin, 2017). Categories of regulating services include water quality regulation, water flow regulation, waste treatment, erosion and flood control, decomposition, pest control, air filtration, local climate regulation (shade and evaporative cooling), natural carbon storage and sequestration, and pollination (CICES V5.1). These services are available across Ontario, although the capacity of natural features (living and non-living) to generate services differs regionally. For example, the supply of natural carbon storage services is concentrated in Hudson Bay Lowlands and boreal ecosystems (Mitchell et al., 2021).

Although essential to human well-being, regulating services are not commonly traded in markets and their value is not always appreciated. Concepts such as natural capital and economic techniques help bring to light the monetary value of ecosystem service flows, providing evidence on nature's benefits and the costs if an ecosystem service is impaired or lost. For example, the annual value of four regulating services supplied by terrestrial and aquatic ecosystems as well as farm fields in Lake Simcoe's watershed is estimated to be $255 million (in 2016$) (LSRCA, 2017).

Land use change, habitat fragmentation, pollution, resource extraction activities, and other development pressures affect the flows of regulating services, with climate change as an additional stressor. As reviewed under this Area of Focus, changes in climate have direct and cascading effects on ecosystems, which, in turn, can compromise the reliability of ecosystem services. For example, warmer temperatures and drought play a particular role in carbon storage as the ecosystems acting as carbon sinks may lose their capacity to store carbon under these conditions (Grosse et al., 2011).

For the purposes of the PCCIA, three Level 2 categories were used to assess the direct impacts to regulating services: natural carbon storage, pollination, and water flow regulation. The selection of Level 2 categories considered applicability across Ontario, information on climate change impacts, and management of the Government of Ontario.

Direct Impacts

The following sections provide brief characterizations of each Level 2 category assessed for regulating services across Ontario and related risk results. Risk scenarios for regulating services were driven by climate hazards related to temperature, precipitation, and drought. Changes in severity and occurrence of these climate hazards could lead to environmental consequences of the following types:

- Change in availability of services
- Change in quality of services
- Change in abiotic conditions (freshwater hydrological regime)

Table 7.17 includes illustrative risk scenarios for each Level 2 category assessed under regulating services. The climate risk profiles for each Level 2 category are presented by timeframe and region in Figure 7.18 (operating under RCP8.5), found at the end of this section.

Table 7.17: Illustrative Risk Scenarios for Regulating Services

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Carbon Storage	Slow increases in temperature result in gradual shifts in ecosystem composition and carbon cycling, causing less carbon to be sequestered across the region.	**High**
Pollination	Loss of suitable habitat for *Bombus* pollinators at their southern range boundaries, a lack of range expansion at their northern range boundaries, and a mismatch in the timing of bee emergence and floral resource availability in the spring results in a decrease in pollination services.	**Medium**
Water Flow Regulation	Drought affects Ontario's natural areas in a way that makes them less effective at regulating water flow. This occurs through direct losses of available water (reduced water flow) and reduced capacity of systems to take in, store, and slowly provide water over time (increased peak flows, reduced water availability over time).	**Medium**

Carbon Storage

Natural carbon storage is an important aspect of global climate regulation, contributing to reduced atmospheric carbon levels or limiting further accumulation. Ontario's natural ecosystems play an important role in this service, with forests, wetlands, croplands, and rangelands storing carbon in soils and vegetation. Carbon storage provision and capacity is variable across the province and most significant in less developed areas with more natural vegetation, with northern Ontario's boreal forests and peatlands as a hotspot with high levels of stored carbon.

Assessing the existing carbon storage regulating services provided by Ontario's ecosystems is important for current greenhouse gas inventories as well as for identifying key locations that may have the capacity to further contribute to carbon storage, or to be particularly sensitive to disruption by climate hazards. This information can influence management decisions and drive changes to global climate projections.

Climate risks to natural carbon storage were assessed across all six PCCIA regions, focusing on risk scenarios driven by temperature changes, specifically Growing Degree Days, which is a proxy for annual average changes, and drought (Moisture Deficit).

The current climate risk profile associated with the environmental consequences from climate change impacts to natural carbon storage is regionally variable, rated as 'low' in southern regions of Ontario, ‘medium’ in Northwest Ontario, and ‘high’ in the Northeast and Far North. By mid-century risk levels are ‘high’ in the Northeast, Northwest, Central, and Eastern region, increasing from ‘low’ to ‘medium’ in the Southwest region, and from ‘high’ to ‘very high’ in the Far North. By end of the century risk levels are ‘very high’ in northern regions of Ontario (Northeast, Northwest, Far North) and ‘high’ in southern regions (Central, Southwest, Eastern). These patterns are consistent across emissions concentration scenarios. Risk levels consider both increasing pressures by human activities and development and changes in global demand for this regulating service.

Warmer air temperatures and drought conditions are the main climate drivers presenting risks to the supply of carbon storage ecosystem services. Forests (Magnus et al., 2021), wetlands (Kayranli et al., 2010; Sierszen et al., 2012), and peatlands (James, 2020; Helbig et al., 2019; McLaughin and Packalen, 2021) are some of the central carbon sinks in the province; however, their capacity to remove carbon from the atmosphere and store it is vulnerable to increasing temperatures. Temperature increases can result in gradual shifts in ecosystem composition and carbon cycling, leading to a net decrease in carbon sequestration (Saarikoski et al., 2015). In particular, the boreal forests and wetlands found in Ontario's Far North, Northeast, and Northwest regions could release substantial amounts of carbon and reduce their capacity to store additional carbon in the future as temperature rises (Grosse et al., 2011). Several researchers also project that peatlands will sequester less carbon over time due to rising temperature (James, 2020; Helbig et al., 2019; McLaughin and Packalen, 2021). If increasing temperatures cross environmental thresholds, they could trigger more acute stressors such as permafrost breakdown/landslides and the release of additional carbon sources (Grosse et al., 2011).

The impacts will vary by region, with the most significant consequences occurring from changes in the northern regions. Furthermore, drought conditions can affect wetlands in a way that makes them less effective at storing carbon, resulting in a slow shift away from being a carbon sink. Drought conditions also have the potential to alter the functioning of Ontario's forests, resulting in carbon release over time as well as rapidly from increased fire activity. The incidence of drought or Moisture Deficits, however, is not expected to increase by the end of the century.

Pollination

Pollination is an ecosystem process by which biota are involved in the transfer of pollen between male and female part of flowers, providing the service of fertilizing wild plant species and crops. Pollination provided by wild pollinators and their supporting habitat is essential for maintaining the abundance and diversity of plant species and for crop cultivation. Globally, about 75% of flowering plants rely on pollinators for fertilization and about 30% of food crops depend on pollinators (see Food and Agriculture Section 5.0 for indirect impacts linked to pollination) (CSPNA, 2007; Klein et al., 2007).

Pollinators are mainly insects (typically bees) but also birds, bats, and several other animals that assist plants in producing fruit and seed (AAFC, 2014). Climate change is one of many factors contributing to the decline of wild and managed bees, affecting the supply of pollination services. Other factors include reduced diversity of flowering plants, habitat loss, degradation and fragmentation, the introduction of invasive plant species, toxicity and use of pesticides, diseases and parasites, and air pollution (AAFC, 2014).

Climate risks to pollination services were assessed across all six PCCIA regions, focusing on risk scenarios driven by temperature changes, specifically Growing Degree Days, which is a proxy for annual average changes.

The current climate risk profiles associated with the environmental consequences from climate change impacts to pollination services are rated as 'medium' across Ontario, increasing to 'high' by mid-century in all regions of Ontario except for the Southwest and Central regions, where risk levels are anticipated to be 'very high'. By late century risk levels are 'very high' in southern regions of the province (Central, Southwest, Eastern) and 'high' in northern regions (Northeast, Northwest, Far North). These patterns are consistent across emissions concentration scenarios and take into account both enhanced pressures from human activities and development and the potential increase in demand for pollination services linked to food production.

Temperature rise (Growing Degree Days) is the primary climate variable affecting pollination. The most significant impact occurs when increasing mean ambient air temperatures exceed pollinator species' thermal limits (Soroye et al., 2020). Range shifts are almost certain to occur as a result, but there are concerns that pollinators will not shift their range quickly enough to keep up with climate change (Sirois-Delisle and Kerr, 2018; Kerr et al., 2015). One resulting consequence is a predicted range contraction across Bombus species in North America (Sirois-Delisle and Kerr, 2018). The increasing temperature may also result in a loss of synchrony between pollinator species emergence and the availability of quality floral resources in the spring, causing additional stress (Pyke et al., 2016). As a result, widespread species richness declines are expected for Bombus species.

These impacts are a concern in all provincial regions but are especially concerning in southern Ontario, where most agriculture occurs. Suitable habitat within species' thermal limits is expected to be lost in these regions (Sirois-Delisle and Kerr, 2018). Local extirpation events will be most probable in areas where local temperatures exceed species' historical thermal tolerances (Soroye et al., 2020). In addition to catastrophic ecological consequences, subsequent negative impacts on food yields and human welfare could occur.

Water Flow Regulation

Water flow regulation involves the regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems that assist people in managing and using hydrological systems. Water flow regulation mitigates risks associated with health and safety and maintains environmental flow needs for aquatic species. Water flow regulation provides multiple benefits, including flood prevention, drought mitigation, and flow stability. The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in landcover and by climate conditions directly, influencing service provision.

Climate risks to water flow regulation were assessed across Ontario's six PCCIA regions, focusing on risk scenarios driven by extreme precipitation (Extreme Precipitation Events – Shorter Term), winter precipitation (Mean Winter Precipitation), drought (Moisture Deficit / Drought).

The current climate risk profile associated with the environmental consequences from climate change impacts to water flow regulation is rated as 'medium' across Ontario, increasing to 'high' by mid-century in southern regions of the province (Central, Southwest, Eastern). By late century risk levels are 'high' across Ontario. These patterns are consistent across emissions concentration scenarios and consider both enhanced pressures from human activities and development and the potential increase in demand for water flow regulation for a range of outcomes (e.g. flood risk mitigation).

Water flow regulation is relevant across all six provincial regions, given the vast hydrological network throughout Ontario. Drought and extreme precipitation are the primary climate hazard groups that will impact this regulating service. Drought can affect the function of ecosystems that provide the water flow regulation service by leading to changes in community composition, physical changes to hydraulic connectivity and routing, and reduced groundwater levels (Krantzberg and Boer, 2006). These changes will decrease water availability if water levels are too low. It can also result in reduced capacity to retain water and buffer against high flows if vegetation communities change or physical hydraulic properties are altered (Rezanezhad et al., 2016).

Extreme precipitation events have the potential to adversely affect the structure and function of wetlands and riparian areas that regulate water flow, increasing flashiness of water flows. Protecting forests and wetlands will be vital to maintaining water flow regulation services. Wetlands retain high volumes of water and slowly discharge into rivers over time, while forests reduce the speed and quantity of runoff (Kennedy and Wilson, 2009).

Changes to winter precipitation can affect water flow regulation in terms of seasonality and timing of overall runoff magnitudes individual runoff events (Crossman et al., 2013). Winter precipitation is projected to increase, resulting in more winter flooding. Changes to flows can also affect timing and duration of lake ice cover, further affecting water flow regulation (Erler et al., 2019). Overall, increases in winter precipitation can lead to increased occurrence and changed timing of harmful flood events, which will require adjustments to flood protection strategies.

Changes in flows (timing, duration, and magnitude) and in the quality of water flow regulation services caused by climate change and non-climate stressors influence the distribution and abundance of aquatic species. More frequent, longer duration, and/or more extreme high and low streamflow events are likely to have significant consequences for stream populations (Nislow et al., 2004; Wenger et al., 2011; Letcher et al., 2015) For example, extreme high stream flows in the winter and low stream flows in the fall can diminish the reduce reproductive success of Brook Trout (Blum et al., 2018).

Table 7.18: Risk Scores for Regulating Services Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Regulating services	Carbon Storage	Central Region	Low	High	High
Regulating services	Carbon Storage	Eastern Region	Low	High	High
Regulating services	Carbon Storage	Far North Region	High	Very High	Very High
Regulating services	Carbon Storage	Northeast Region	High	High	Very High
Regulating services	Carbon Storage	Northwest Region	Medium	High	Very High
Regulating services	Carbon Storage	Southwest Region	Low	Medium	High
Regulating Services	Pollination	Central Region	Medium	Very High	Very High
Regulating Services	Pollination	Eastern Region	Medium	High	Very High

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Regulating Services	Pollination	Far North Region	**Medium**	**High**	**High**
Regulating Services	Pollination	Northeast Region	**Medium**	**High**	**High**
Regulating Services	Pollination	Northwest Region	**Medium**	**High**	**High**
Regulating Services	Pollination	Southwest Region	**Medium**	**Very High**	**Very High**
Regulating services	Water Flow Regulation	Central Region	**Medium**	**High**	**High**
Regulating services	Water Flow Regulation	Eastern Region	**Medium**	**High**	**High**
Regulating services	Water Flow Regulation	Far North Region	**Medium**	**Medium**	**High**
Regulating services	Water Flow Regulation	Northeast Region	**Medium**	**Medium**	**High**
Regulating services	Water Flow Regulation	Northwest Region	**Medium**	**Medium**	**High**
Regulating services	Water Flow Regulation	Southwest Region	**Medium**	**High**	**High**

Indirect Impacts

The indirect impacts of climate change on regulating services have local, provincial, and global ramifications. The decreased capacity of Ontario's terrestrial ecosystems to remove carbon from the atmosphere and store it can hamper efforts like natural climate mitigation solutions. In addition, depending on the magnitude of the stores, the shift of terrestrial ecosystems as sinks to sources of carbon can undermine government commitments to cut emissions of greenhouse gases, enhancing contributions to changes in the Earth's climate system.

Pollination relies on healthy insect populations; therefore, any decline in insect abundance, and especially the abundance of wild pollinators, will affect pollination rates throughout the province. In addition to catastrophic ecological consequences, impairments to wild pollination services can negatively affect plant cultivation (e.g. field crops and horticulture), increasing the need for alternative sources of pollination and therefore costs to growers and affecting food yields.

Since water flow regulation services support flood prevention, drought mitigation, and flow stability, which are essential to the well-being of people and the integrity and usefulness of physical infrastructure, impairment of these services will require adjustments to current strategies to manage the risks from water extremes, both excess moisture and drought.

7.7.6 Provisioning Services

Overview

Provisioning services were assessed as a Level 1 category under the Natural Environment Area of Focus. Provisioning services are materials or energy harvested from the natural environment that can benefit humans in terms of use, consumption, or inherent value (Rolando et al., 2017). These services include freshwater, energy, wild foods, traditional medicines, oils, and wood supplies. For this risk assessment, freshwater and wood supplies were analyzed.

Provisioning services are susceptible to climate change, but the associated impacts have high uncertainty. Potential opportunities exist in some cases, such as increased forest biomass in the northern regions for timber production with some uncertainty given stresses on the growth of coniferous tree species from insects and disease (McKenney et al., 2016) and possible increased groundwater recharge rates (Jyrkama and Sykes, 2007; Veettil and Mishra, 2018); however, there is a lack of consensus on groundwater predictions. The risks associated with climate change are generally significant and include increased temperature, drought, wildfire, and precipitation.

The PCCIA aims to understand the climate change impact on provisioning services throughout the provincial regions. Temperature and drought present the most significant impacts in the province and lead to secondary impacts such as wildfire and changing precipitation patterns. And these risks have regional variations. For instance, warming temperature has a widespread impact across all regions, while drought primarily impacts the Northwest and Northeast regions. The impacts discussed below cover a wide range of hazards in the province, but other indirect effects may impact provisioning services that were not addressed in the risk assessment.

Direct Impacts

The following sections provide brief characterizations of each Level 2 category assessed for provisioning services across Ontario and related risk results. Risk scenarios for regulating services were driven by climate hazards related to temperature, precipitation, drought, and wildfires. Changes in severity and occurrence of these climate hazards could lead to environmental consequences of the following types:

- Change in availability of services

- Change in access to services
- Change in quality of services

Example risk scenarios for each Level 2 category can be found in Table 7.19. The climate risk profiles for each Level 2 category are presented by timeframe and region in Table 7.20 (operating under RCP8.5), at the end of this section.

Table 7.19: Illustrative Risk Scenarios for Provisioning Services

Level 2	Illustrative Risk Scenario	Strength of Evidence
Freshwater Provision	Drought can reduce water availability and stresses the systems that provide freshwater. Freshwater is still available, but conflicts and restrictions are heightened, and timing of freshwater provision is altered.	**Medium**
Wood Supplies	Intensification of forest fire regimes creates significant challenges in supplying mills with mature, harvestable wood, especially softwood.	**Low**

Freshwater Provision

Ontario's natural and semi-natural systems include surface and ground water bodies and runoff that provide water for human consumption and for direct uses other than drinking (e.g. safe navigation, cooling, and materials), supporting human development and well-being. Areas with large areas of open water and high runoff potential (e.g. high capacity) that serve downstream areas with high demands are the most important for freshwater provision. Hotspots of freshwater provision in Ontario generally mirror population patterns and are most prevalent in the south of the province (Mitchell et al., 2021). Canada consumes vast amounts of water on an annual basis. In 2013, 37,892 million cubic meters of water were used across all sectors of the economy (Statistics Canada, 2013). In Ontario, use of water from lakes, rivers, streams, ponds and groundwater is regulated through the Ontario Water Resources Act, with industrial uses, power production, and potable water supply making up close to 98 percent of water takings in 2019 (Ontario Ministry of the Environment, Conservation and Parks, 2021). Climate impacts can affect the ability of natural systems to function properly and to provide freshwater for human use.

Climate risks to freshwater provision were assessed across Ontario’s six PCCIA regions, focusing on risk scenarios driven by temperature changes (specifically Growing Degree Days, which is a proxy for annual average changes, and Extreme Hot Days), extreme precipitation (Extreme Precipitation Events) and drought (Moisture Deficit / Drought).

The current climate risk profile associated with the environmental consequences from climate change impacts to freshwater provision is rated as 'medium' in all regions of Ontario. Although Ontario has abundant, clean water resources, freshwater provisioning services are already at risk locally. Seasonal water shortages do take place in some local watersheds and areas where groundwater supplies are naturally limited (Ontario Ministry of the Environment, Conservation and Parks, 2021). In warm weather, reports of blue-green algal blooms occur across the province (Ontario Ministry of the Environment, Conservation and Parks, 2022).

Climate risk scores for the Central, Eastern, and Southwest regions increases from 'medium' to 'high' by mid-century and to 'very high' by end of century. Climate risk scores for the Northeast, Northwest, and Far North regions increases from 'medium' to 'high' by mid-century and remain at that level by end of century. Aside from exposure to climate conditions, regional differences in risk scores reflect the combined effect of 1) non-climate pressures on the natural environment, which influences their vulnerability to climate change and affects the flows of provisioning services, and 2) assumptions on the increased future demand for freshwater provisioning, which generally increases with population density and the number and type of activities requiring water.

Drought is the primary climate driver that affects freshwater provision in Ontario. Widespread and intense drought conditions lead to an overall loss of available freshwater for human use and affect the ecosystems that process freshwater throughout the year (Saarikoski et al., 2015; Harrison et al., 2014). As a result, drought could lead to heightened restrictions and increased conflict within the province. Drought may also lead to inter-annual patterns of water availability, affecting the timing of provision (Kaur et al., 2019; Veettil and Mishra, 2018).

Temperature is a secondary climate hazard that will impact freshwater provision. As outlined in Sections 7.7.1 and 7.7.2, increasing temperatures change species compositions and alters long-term ecosystem function, impacting the ecosystem's ability to retain and provide freshwater (Saarikoski et al., 2015; Harrison et al., 2014). Sustained periods of increased temperature and Extreme Hot Days can increase the frequency and severity of nuisance and harmful algal blooms, with the effects being stronger in water bodies with existing elevated nutrient levels. Extreme Hot Days can also change lake water balances, as increased evaporation can cause reduced lake levels as well as reduced runoff, particularly in the spring. Warmer temperatures can also cause reduced summer flows, leading to increased nutrient loading and lack of diluting capacity with reduced water volumes (Paterson et al., 2017; Yao et al., 2009; Crossman et al., 2013).

The occurrence of extreme precipitation events has the potential to affect freshwater provision through direct impacts to water quality. Climate change is predicted to increase extreme flood events, which have been shown to result in increased turbidity in drinking water systems (De

Loe and Plummer, 2010). Increased turbidity is associated with increased outbreaks of waterborne diseases. These effects have been shown to strongly affect small drinking water treatment systems for isolated communities in Ontario.

Wood Supplies

Wood supplies are biomass provided by forest ecosystems that can be harvested and used as raw material for non-nutritional purposes. Ontario's 71 million hectares of forests support the sustainable harvest of timber (and other forest products), which provides social, economic and environmental benefits to the province. The forest industry contributed $4 billion to real GDP in the province in 2019, with $15 billion in revenue from manufactured goods (Natural Resources Canada, 2022c).

In northern Ontario, many communities rely on stable levels of harvesting and a healthy forest industry. Close to 90 percent of Ontario forests are publicly owned; the amount of area available for harvest in Ontario is regulated and planned for, while the actual volume harvested varies annually and over time. Less than 0.5% of the managed Crown Forest of 27.7 million hectares is harvested annually, with harvest levels decreasing since about 2004 and levelling off in 2010. (Ontario Ministry of Natural Resources and Forestry, 2021a; Government of Ontario, 2020g). As seen in Section 7.7.2 (Flora) and 7.7.4 (Terrestrial Ecosystems), select climate variables can affect the distribution, composition, and functioning of forests, affecting the flows of provisioning services.

Climate risks to wood supplies were assessed for all regions in Ontario, except the Far North. Risk scenarios are driven by temperature changes (specifically Growing Degree Days, which is a proxy for annual average changes), drought (Moisture Deficit / Drought), and wildfire.

The current climate risk profile associated with the environmental consequences from climate change impacts to wood supplies is rated as ‘medium’ across the assessed regions of Ontario, increasing to ‘high’ in southern regions of the province (Central, Southwest, Eastern). In Northeast and Northwest Ontario, risk levels are anticipated to remain at ‘medium’ levels. By late century risk levels are ‘high’ across all regions. These patterns consider both enhanced pressures from human activities and development and the potential increase in demand for wood supplies in response to increased economic activity.

Drought-related tree mortality and a decline in abundance of conifer species can place the supply of softwood fibre to mills at risk of disruptions. Drought will impact wood supplies by exacerbating climate change-induced shifts in fire and insect disturbances and tree mortality (Brecka, 2018). The most pronounced impacts will occur in Northwest Ontario along the southern part of the boreal, with up to a 60% decline in above-ground biomass by the end of the century, with projected drops in conifer species (Brecka, 2018). Drought-related tree mortality removes biomass from the landscape, affecting boreal wood supply and harvestable volumes.

In addition, increasing temperature and changes in precipitation patterns are altering the climate suitability for tree species, altering their productivity, and causing changes in forest composition (Brecka et al., 2020). As a result, many tree species whose southern edge lies within the Great Lakes Basin will likely experience reduced growth rates, reproductive failure, and increased disease and mortality (McDermid et al., 2015). A shift in the relative composition of forest species will shape the type and quality of wood products that companies can manufacture.

A third climate risk relates to the intensification of fire regimes in the boreal forest, creating challenges in supplying mills with mature, harvestable wood. In the southern boreal, intensified fire regimes coupled with heat stress and drought conditions are projected to decrease aboveground biomass significantly. Under current harvesting regimes, timber supply harvest could decline by up to 38 percent by end of the century, due to fire (Dhital et al., 2015).

The combined impact of fire and climate change-induced shifts in growth could cause a median period harvest loss of up to 44 to 79% (Dithal et al., 2015) and impact the type and quality of products that companies can manufacture (Gauthier et al., 2014). Ultimately, this may lead to significant consequences for timber production (Brecka et al., 2020; Dithal et al., 2015), with considerable uncertainty attached to these expected impacts. One national study suggests that mills in Ontario may see modest increases in wood supply costs, no projected softwood supply shortages, and relatively minor hardwood supply shortages in the 2050s and 2080s (McKenney, 2016).

Table 7.20: Risk Scores for Provisioning Services Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Provisioning Services	Freshwater Provision	Central Region	**Medium**	**High**	**Very High**
Provisioning Services	Freshwater Provision	Eastern Region	**Medium**	**High**	**Very High**
Provisioning Services	Freshwater Provision	Far North Region	**Medium**	**High**	**High**
Provisioning Services	Freshwater Provision	Northeast Region	**Medium**	**High**	**High**
Provisioning Services	Freshwater Provision	Northwest Region	**Medium**	**High**	**High**
Provisioning Services	Freshwater Provision	Southwest Region	**Medium**	**High**	**Very High**
Provisioning Services	Wood Supplies	Central Region	**Medium**	**High**	**High**
Provisioning Services	Wood Supplies	Eastern Region	**Medium**	**High**	**High**
Provisioning Services	Wood Supplies	Northeast Region	**Medium**	**Medium**	**High**
Provisioning Services	Wood Supplies	Northwest Region	**Medium**	**Medium**	**High**
Provisioning Services	Wood Supplies	Southwest Region	**Medium**	**High**	**High**

Indirect Impacts

Climate change leads to increased temperature, drought, wildfire, and changing precipitation patterns in the province. This risk assessment addressed these hazards, but not the additional indirect impacts they cause. For instance, climate change can affect the abundance and distribution of forests pests and diseases (Price et al., 2013; Gauthier et al., 2014; Wang et al., 2014; Terrier et al., 2013). The increasing prevalence of invasives may exacerbate other climate hazards, such as wildfire, and lead to forest loss, damage, reductions in wood supply provision, threats to public safety and regional economies (Price et al., 2013; Gauthier et al., 2014; Wang et al., 2014; Terrier et al., 2013). In addition, extreme precipitation events often result in changes to road conditions (washout of roadways), and warmer temperatures can cause ground thaw on logging roads, disrupting operational practices for access to timber supplies (Brecka, 2018; Brecka et al., 2018, McKenney et al., 2016). Lower than planned harvest levels can have negative effects on employment and local economies. In addition, environmental objectives may also be at risk, since failing to achieve planned levels of harvest affects the ability to achieve desired forest condition (area, type and age) and related habitat diversity (Ontario Ministry of Natural Resources and Forestry, 2021a). Conversely, warming temperatures can also result in faster tree growth, which may drive economic opportunities for communities currently at the northern limit of forest harvesting (Price et al., 2013; Gauthier et al., 2014; Brecka et al., 2018; McKenney et al., 2016).

Section 10.3 on Water Security describes the indirect impacts of changes in freshwater provision, which include stress to existing water supply systems and increased risks to human health (Kaur et al., 2019).

7.7.7 Ecosystems Cultural Services

Overview

Ecosystem cultural services refer to outputs of ecosystems (biotic and abiotic) that affect physical and mental states of people; they support people's engagement with the natural environment in ways that are culturally enriching (Haines-Young and Potschin, 2017). Categories of ecosystem cultural services include nature-based recreation, educational value, aesthetic experience, physical and mental well-being, spiritual experience, culture heritage and sense of place associated with nature (TEEB, 2010), with these services available across all regions of Ontario. Spaces, such as shorelines and water of the Great Lakes, often supply multiple ecosystem cultural services at the same time, with the greatest delivery of services occurring near population centres or generally where people and supporting infrastructure are present to accrue benefits (Allan et al., 2015). Since Ontarians and people in Ontario derive the benefits from these ecosystem services directly, there is a direct link between investments in ecosystem quality and human activity and well-being. For example, improvements in water clarity in lakes generate additional visits, with people willing to travel further and spend more money to visit lakes with better water clarity (Keeler et al., 2015).

Ecosystem cultural services, like recreation in the outdoors, are a key part of Canadian culture. There is robust evidence linking the importance of nature-based recreation and health and well-being, with ecological integrity playing a major role in the restorative outcomes (Reining et al., 2021).

Current market trends indicate that travelers are interested in visiting wild and wide-open spaces in response to confinement experienced during the COVID-19 pandemic (Destination Canada, 2021). Ontarians' participation in hiking or backpacking (+40%), visiting a national or provincial nature park (+39%), boating (+36%), canoeing or kayaking (+21%), going to a beach (+19%) and camping (+7%) in the third quarter of 2020 increased significantly compared to the same time in 2019 (Q3 2019: (Statistics Canada, 2021d)).

Environmental stresses like coastal development and habitat modifications, non-point source pollution, and the spread of invasive species affect the enjoyment of ecosystem cultural services, such as recreational services, with climate change as an additional stressor (Allan et al., 2015). As reviewed in sections 7.7.3 to 7.7.4, change in climate have direct and cascading effects on ecosystems, which, in turn, can compromise people's access to ecosystem services flows, either preventing a desired activity (like snowmobiling) or requiring a shift in timing, as well as the quality of these services. For example, warming temperatures are likely to affect recreational activities by shifting the timing of historical seasons (e.g.., fishing seasons, camping seasons), location of activity, and their associated regulations since recreationalists will have to change their behaviours to suit these changing conditions (Hestetune et al., 2018; Browne and Hunt, 2007; Wall et al., 1985).

For the purposes of the PCCIA, two Level 2 categories were used to assess the direct impacts to ecosystem cultural services: recreational fishing and nature-based recreation (hiking, camping, skiing, and snowmobiling). The selection of Level 2 categories considered applicability across Ontario, evidence based on climate change impacts, and guidance from stakeholders. The lack of focus on less tangible services or those hard to measure using economics or visitation rates (e.g. spiritual experience and sense of place related to nature) does not diminish the importance of these types of ecosystem cultural services but is rather a call for more research on these topics (e.g. Knoll et al., 2019).

Direct Impacts

The following sections provide brief characterizations of each Level 2 category assessed for ecosystem cultural services across Ontario and related risk results. Risk scenarios for ecosystem cultural services were driven by climate hazards related to temperature, precipitation, and wildfire. Changes in severity and occurrence of these climate hazards could lead to environmental consequences of the following types:

- Change in access to services
- Change in availability of services
- Change in quality of services

Examples of risk scenarios assessed under this Level 1 category can be found in Table 7.21. Risk profiles for Level 2 categories by time period and region appear in Table 7.22, at the end of this section.

Table 7.21: Illustrative Risk Scenarios for Ecosystem Cultural Services

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Nature based recreation	Heavy downpours during peak camping seasons discourage weekend camping trips.	**Low**
Recreational Fishing (Angling)	Sportfish species' distributions and availability will change with increasing temperature, resulting in the loss of some important recreational fisheries. Shifts in species will potentially open up other angling opportunities. Anglers will have to employ spatial or temporal changes to their behaviors, potentially affecting angling success and the associated economic benefits.	**Medium**

Nature-Based Recreation

In the context of the PCCIA, nature-based recreation refers to the active enjoyment of nature through warm-season (hiking and camping) and winter-season (skiing, snowmobiling) activities. Opportunities for nature-based recreation exist throughout the province, in high population and remote locations, with parks, protected areas, and other types of designated spaces in Ontario offering ample opportunities for these types of nature-based recreation (Douglas and Pearson, 2022).

The COVID-19 pandemic heightened the positive health benefits of taking part in outdoor recreation and spending time in nature, with Public Health Units across the province often encouraging people to participate in activities such as camping, fishing, hiking, and other nature-based recreation activities.

Nature-based recreation is highly sensitive to weather and climate variation, because of a reliance on the resilience of key ecological processes and natural features, as well as desirable physical conditions. Shifts in access to and quality of recreation opportunity influencing decisions on i) whether, how, and when to participate, as well as ii) what to offer and how to regulate the offering.

Climate risks to nature-based recreation were assessed for five provincial regions, including Central, Southwest, Eastern, Northeast and Northwest regions. Risk scenarios under this Level 2 category are driven by temperature changes, specifically Extreme Hot Days and Growing Degree Days, extreme precipitation, winter precipitation and wildfire occurrence.

The current climate risk profile associated with the consequences from climate change impacts to nature-based recreation is rated 'medium' across Ontario, increasing to 'high' by mid-century in all regions of Ontario. By the end of the century, risk levels are anticipated to remain at 'high' in southern Ontario (Southwest, Central and Eastern), but increase to 'very high' in northern parts of the province (Northeast and Northwest). Risk profiles consider socio-economic projections and the assumed increase in demand for ecosystem cultural services.

Warming winters may lead to a decrease in snow-based recreation due to unsuitable snow conditions. Climate change is projected to lead to substantial reductions in both depth and length of the snow cover season (Scott et al., 2006). Warmer winters reduce the seasonal availability and quality of snow-based recreation such as downhill and cross-country skiing and snowmobiling (Browne and Hunt, 2007). This is also expected to impact ice fishing, which is anticipated to decline due to climate change (Browne and Hunt, 2007). Ski areas in southern Ontario are expected to be more heavily impacted than those in northern regions, as it is possible that ski areas in Northeast and Northwest may benefit by attracting more southern residents whose local ski seasons have been reduced (Wall et al., 1985). In addition, the reliability of a snowmobile season occurrence in certain regions by mid-century is questionable (McBoyle et al., 2007).

Warmer daytime temperatures and lengthened shoulder seasons have the potential to increase camping, hiking, canoeing, kayaking and overall visitation in parks, with cascading implications for biodiversity, human communities, and management effort. Daily maximum temperature is a predictor of park visitation in Ontario, with studies suggesting substantial increases in park visitation and changes in the timing of peak visitation with rising temperatures and warmer shoulder seasons (April-May; September-October) (Hewer et al., 2016). However, temperatures could increase beyond campers' thermal comfort levels. Survey research suggests that the range of ideal daytime temperatures for campers is 24 to 31˚C, with daytime temperatures over 34˚C unacceptably hot for at least 50% of the sample (Hewer, 2012).

Thermal limits vary by activity, with groups of campers focused on canoeing/kayaking/fishing less sensitive to weather at large than those focused on swimming and wading. At the same time, warmer temperatures can alter water quality, including conditions contributing to algal blooms, reducing the potential enjoyment of parks and waterways. Climate-driven changes to visitation rates and patterns could increase park revenues and confer economic benefits to local operators and services but may strain conservation efforts (Hewer et al., 2016).

Changes in the occurrence of extreme events can also influence participation patterns, with more frequent heavy rainfall events discouraging warm-weather recreation in parks or shortening trip length. Survey research in two Ontario Parks indicates that the absence of rain as one of top three weather factors contributing to visitor satisfaction, with the other two being sunshine and comfortable daytime temperatures (Hewer, 2012). Weekend campers and those engaged in beach-oriented activities (swimming / wading) place a greater level of importance on the absence of rain in relation to overall trip satisfaction than other types of campers (multi-day, inland activities). This survey research highlighted the preference sensitivity to the occurrence of downpours, including 70% of campers stating their intent to leave the park early if they experienced conditions of rainfall over 16mm/hour.

More intense forest fire regimes have the potential to limit access to parks or amenities within parks. Fire is essential in maintaining and enhancing ecosystems in many provincial parks and conservation reserves. Expected shifts in fire regimes in a changing climate will challenge parks and protected area managers' ability to balance protection of socio-economic (e.g. human safety, asset integrity) and ecological values (e.g. endangered species) and use of controlled burns to restoring ecosystem health. In contrast to many parks and protected spaces in southern Ontario that consist of fragmented and relatively small patches of continuous fuels in forests, savannahs and prairies, parks located in boreal forest ecosystems in northern Ontario are continuous and much larger in size. Increased severity, frequency, and spatial extent of forest fires in and around parks in Ontario can result in park closures, travel restrictions, trail and canoe route closures, impair public safety and cause natural and physical asset losses.

A longer-term risk to the quality and availability of opportunities for nature-based recreation in parks and other designated spaces relates to climate-driven displacements of ecosystems outside of stationary park boundaries (Suffling and Scott, 2002). Shifts in biomes within park boundaries create challenges for park managers and may result in "last chance" visits to parks, to witness changing landscapes or natural features in the near term with reductions in aesthetic appeal and decreased visitation in the longer term (Kovacs and Thistlethwaite, 2014).

Recreational Fishing

Recreational fishing is an important outdoor recreational activity in Ontario. In 2015, more than 1.5 million anglers fished in Ontario and spent 1.75 billion dollars to fish (Ontario Ministry of Natural Resources and Forestry, 2020a). Although I majority of anglers fish in the Great Lakes and lakes and waterways in southern Ontario, many northern Ontarians view recreational fishing as an activity central to their way of life, an important part of many local economies and a driver of tourism (Wall, 1985). Climate-driven shifts in the distribution and abundance of target fishery species, fish habitats, as well as changes in the length and quality of recreational fishing seasons have direct impacts on angling opportunities (Hunt et al., 2016; Hunt and Moore, 2006). Recreational fishing is a regulated activity in Ontario (Ontario Ministry of Natural Resources and Forestry, 2022), with climate-driven shifts such as these requiring adaptation by management agencies, anglers, and operators alike.

Climate risks to recreational fishing were assessed across Ontario's six PCCIA regions, focusing on risk scenarios driven by temperature changes, specifically Extreme Hot Days and Growing Degree Days, as well as drought (Moisture Deficit).

The current climate risk profile associated with the environmental consequences from climate change impacts to recreational fishing is rated 'medium' across Ontario, increasing to 'high' by mid-century in all regions of Ontario and staying at that level by the end of the century. The risk results consider socio-economic projections of population growth, urban and industrial development exacerbating both the likelihood of the environmental consequence and its likelihood over time since demand for the service is assumed to increase.

The primary climate variable group identified as a control on sports fishing in Ontario was temperature, both average changes and occurrence of Extreme Hot Days. Increased temperatures are expected to impact sportfish species' distributions and abundance resulting in lowered or adjusted angling participation, reduced fishing success due to species changes, and losses of some important fisheries (Van Zuiden and Sharma, 2016; Hunt and Kolman, 2012). Additionally, increased air and surface water temperatures are associated with greater post-release mortality in sportfish in both summer open water angling and winter ice fishing. Impacts on recreational fisheries will be regionally variable. In some cases, climate change may enhance angling opportunities in localized areas due to increases in abundance of highly desirable sport fish species like walleye, such as might occur in Northeast Ontario (Shuter et al., 2002). Nevertheless, the co-occurrence of smallmouth bass and walleye in the same lakes can temper gains in walleye abundance and therefore the development of this recreational fishery (Van Zuiden and Sharma, 2016).

Risks to recreational fisheries also relate to reduced access to fishing areas. In southern Ontario, the combined effects of warmer temperatures and drier conditions could reduce lake levels and opportunities for boat usage (e.g. reduced access to docks, inadequate channel depth for fishing watercraft). This will reduce lake access and therefore fishing opportunities (Jyrkama and Sykes, 2007). Shifting water levels can affect the quality of shoreline marshes that support fish production and recreational fishing (Wall, 1985). In addition, although not assessed quantitatively, warmer winter weather can compromise ice fishing viability and reduce the length of the ice fishing season. Accounting for these changes may require changes to fisheries including closures or shifting of fishing seasons.

Table 7.22: Risk Scores for Ecosystem Cultural Services Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Ecosystem Cultural Services	Nature based Recreation	Central Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Nature based Recreation	Eastern Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Nature based Recreation	Northeast Region	**Medium**	**High**	**Very High**
Ecosystem Cultural Services	Nature based Recreation	Northwest Region	**Medium**	**High**	**Very High**
Ecosystem Cultural Services	Nature based Recreation	Southwest Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Recreational Fishing (Angling)	Central Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Recreational Fishing (Angling)	Eastern Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Recreational Fishing (Angling)	Far North Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Recreational Fishing (Angling)	Northeast Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Recreational Fishing (Angling)	Northwest Region	**Medium**	**High**	**High**
Ecosystem Cultural Services	Recreational Fishing (Angling)	Southwest Region	**Medium**	**High**	**High**

Indirect Impacts

The indirect impacts of climate change on ecosystem cultural services will impact communities that rely on recreational fishing for their economy and will face pressures and stresses due to changed fish species ranges, habitat disruptions, fish mortality increases, and seasonal timing changes (Wall, 1985). For example, there is a significant tourism industry in northern Ontario for walleye fishing catering to clients from the United States; if walleye (cool-water) fish populations decline US anglers may stop coming to Canada to fish since warm water fishing (bass) opportunities exist south of the border. Business in northern Ontario could incur losses as a result.

Changes to nature-based recreation through alteration of temperatures, precipitation events and type (rain vs snow), and broad ecosystem shifts will also affect the business and economy Area of Focus through direct impacts on fishing, hunting, and recreation. Communities with strong cultural ties to these activities will also be impacted. Increased temperatures can lead to decreased ice coverage on lakes, which results in a change in recreational fishing strategies and creates potential safety issues and travel hazards for anglers' health and well-being. Finally increased temperatures and changes to snowpack lead to changes in snow-based recreation, causing users to change their habits and creating potential safety issues through thin ice conditions.

7.8 Climate Change Opportunities

In comparison to other Areas of Focus, the concept of opportunities from the impacts of climate change may be more complex for the Natural Environment. Climate-driven increases in range or abundance of select species or ecosystems are not automatically benefits, as these shifts also influence dynamics of ecological communities (e.g. food webs) and ecological function. Shifting thermal niches may contribute to availability of new climate refugia but may require human intervention to obtain such benefits.

For managed species, identifying opportunities is more straightforward because we can assume that increased abundance translates to increased opportunities for recreation (e.g. fishing, hunting) and economic income for operators. Although it should be noted that seizing on these opportunities may not be cost free (e.g. new infrastructure may be necessary). Climate-driven increases in the capacity of ecosystems to supply flows of ecosystem services can be opportunities for human communities, in that this can help meet societal goals (e.g. increased freshwater provision contributing to water security).

Within this assessment, risk scores across two Level 2 categories (under Fauna) decreased in risk under a changing climate. These were for reptiles in all regions, and warm-water fish in the Central region. Warmer temperatures can facilitate a range expansion of the common five-lined skink (reptile), increasing populations' genetic diversity. However, the species' occurrence in heavily modified landscapes and as small, localized populations counteract gains in thermally suitable habitat. For Eastern and the Northeast regions, declining risk in the 2080s denotes a potential upside for the lizard. But the potential advantages of warming temperatures for populations of common-five lined skinks may be counteracted with anthropogenic pressures linked to projected population growth, urban and industrial development (e.g. road run off, pollution). The opportunity here is to facilitate range expansions by preventing or reducing non-climate stressors through improved land use planning and consideration of cumulative effects.

Warm-water fishes may gain suitable habitat toward the latter half of the century. Warm-water fishes may benefit from climate change in Ontario. Specifically, the PCCIA supported the finding that warmer temperatures may increase habitat for warm-water fishes in Central Ontario. Research also states that warm-water habitat may increase across Northeast, Northwest, and Far North regions. Assuming habitat connectivity or introductions by humans, new thermal habitats for warm-water fishes may allow for range shifts greater than the approximately 13-17.5 km per decade that already occurred over the last 30 years in Ontario lakes, expanding northern range limits further (Chetkiewicz et al., 2018; Chu et al., 2005; Alofs et al., 2014). There may be opportunities for recreational fisheries, although these will be regionally variable. Climate change may enhance angling opportunities in localized areas due to increases in abundance of highly desirable sport fish species. Nevertheless, the co-occurrence of smallmouth bass and cold- and cool- water fish species in the same lakes can temper gains in cold- and cold- water abundance due to predation by smallmouth bass and inter-specific competition.

Other potential opportunities that may emerge for the Natural Environment Area of Focus, include:

- Warmer temperatures, shorter winters and decreased snow depth create favourable conditions for range expansion and increased abundance of species currently limited by low temperatures. It is expected that white-tailed deer (Level 1 Fauna) will increase in abundance, retain their existing range and expand northward, potentially as far as the modern-day treeline. This may increase hunting opportunities for this cervid species.
- Potential opportunities exist in some cases, such as increased forest biomass in the northern regions for timber production with uncertainty given stresses on the growth of coniferous tree species from disturbances.
- Warmer daytime temperatures and lengthened shoulder seasons may create opportunities for more camping, hiking, canoeing, kayaking and overall visitation in parks, but this places strain on park management.
- In northern regions of the province that are less densely populated, with less of a footprint of human activity, yet harbour significant biodiversity and ecosystem services (e.g. carbon sequestration and storage of peatlands), there is an unprecedented opportunity to create a protected area network that considers current and future climate change impacts and managed for a range of biodiversity and biocultural values.

7.9 Adaptive Capacity

7.9.1 Adaptive Capacity Summary

Ontario's natural environment is intrinsically adaptive. However, the pace of climate change in Ontario, combined with local and regional development and economic pressures, may exceed the capacity and resilience of species and ecosystems, affecting the supply of critical ecosystem services (Nantel et al., 2014). Consistent with other Areas of Focus, Adaptive Capacity for the Natural Environment Area of Focus was evaluated across four over-arching categories: 1) technology 2) availability of resources, 3) governance measures, and 4) sector complexity (see Section 2.4.3 for definitions).

Overall, the Adaptive Capacity for each Level 1 category across the Natural Environment Area of Focus is ranked as a 'medium' Adaptive Capacity (Table 7.23). Building Adaptive Capacity across these four categories will help to strengthen species' and ecosystem's ability to adjust and maintain resilience to changing conditions over time, protecting humans' ability to benefit from the services the natural environment provides for free.

Table 7.23: Level 1 Adaptive Capacity Ratings for the Natural Environment Area of Focus[23]

Level 1 Category	Technology	Resource Availability	Governance	Sector Complexity	Level 1 Adaptive Capacity Rating
Fauna	Medium	Medium	Low	Low	**Medium**
Flora	Medium	Medium	Low	Low	**Medium**
Aquatic Ecosystems	Medium	Medium	Medium	Low	**Medium**
Terrestrial Ecosystems	Medium	Medium	Medium	Medium	**Medium**
Regulating Services	Medium	Medium	Medium	Medium	**Medium**
Provisioning Services	Medium	Medium	High	Medium	**Medium**
Ecosystem Cultural Services	Low	Medium	Medium	Medium	**Medium**

[23] Note these scores do not consider geographic location within the province. Please see Appendix 11 for regional Adaptive Capacity ratings.

7.9.2 Technology

Adaptive Capacity within the Technology category is ranked at a 'medium' capacity across all Level 1 categories, except for Ecosystem Cultural Services, for which the score is 'low'. Technology to protect, conserve, restore, sustainably use, and manage species, ecosystems and ecosystem services includes, applications of genetic research in plant breeding to ensure the resilience of species; assisted migration trials targeting commercial tree species; implementation of nature-based solutions (NbS) – an umbrella concept inclusive of restoration, ecosystem-based management, ecosystem-based adaptation, area-based protection, natural infrastructure; and use of decision-support tools that incorporate climate change considerations to inform policy updates, planning, and siting decisions (e.g. the use of SeedWhere to update policies on tree seed transfer) (Dhital et al., 2015; Anderson and Song, 2020; Douglas and Pearson, 2022; Williamson et al., 2019). Physical technologies for resilience include wildlife overpasses and infrastructure solutions for some recreational services (e.g. snowmaking machines for ski operations) (Lemieux et al., 2007; Browne and Hunt, 2007).

Although technologies exist to support adaptation of species and ecosystems and, some application is occurring, the scale of implementation needed far exceeds resources currently allocated and available. An example of scaling can be seen in Ontario's Forest Policy Framework, which includes provisions for seed transfer that integrate adaptive management (Ontario Ministry of Natural Resources and Forestry, 2020b). Implementation needs are highly variable across management contexts and can require more than enabling policy to result in tangible action. For example, species-based plans, such as species-at-risk-recovery plans, result in practices that are challenging and costly to implement, involving multi-year commitments and funding from several sources. When it comes to adapting to climate-driven shifts in ecological cultural services (e.g. nature-based recreation), opportunities to enhance Adaptive Capacity are available but decision-making is distributed and, in some cases, market-driven. Users of nature will need to alter their behaviour (type and timing of activities) and preferences (e.g. fishing in different streams and lakes). Financial incentives in the forest industry and statutory requirements to deliver public services such as access to clean freshwater, are drivers to initiate adaptation planning for provisioning services. Finally, current regimes may be limited in their adaptation potential. For some regulating services, specifically water flow regulation, technological interventions are already highly optimized with limited options to make major improvements in Adaptive Capacity.

The Technology category of Adaptive Capacity also includes sectoral best practices and planning. Known strategies to address climate change adaptation of species, ecosystems and landscapes include maintaining intactness and connectivity, and expanding protected area networks (WCS Canada, 2017). Across all Level 1 and 2 categories, protected areas contribute to nature-based adaptation by providing protection of species, ecosystems, and ecosystem services from non-climatic pressures on the broader landscape, such as resource industries and urban development. The extent of protected areas across PCCIA regions varies significantly, with protected areas inversely proportional to population density and human activity (see Table 7.24). The number and extent of protected areas and conserved land continues to fall below national and international targets (Ontario Biodiversity Council, 2021). Organizational deficiencies within management agencies (e.g. staff capacity levels), among other factors, limit the effectiveness of the management and expansion of the province's protected areas network (Office of the Auditor General of Ontario, 2020b).

Table 7.24: Protected Area Coverage in Ontario's PCCIA Regions[24]

PCCIA Region	Area (km^2)	Federal protected areas (km^2)	Provincial protected areas (km^2)	Total area protected (%)
Southwest	40,647	219	203	1.0%
Central	14,078	19	67	0.6%
Eastern	51,816	55	2,237	4.4%
Far North	248,052	221	27,874	11.3%
Northeast	228,679	16	24,972	10.9%
Northwest	401,031	1,921	40,905	10.7%

7.9.3 Resource Availability

The availability of human and financial resources, as well as knowledge, skills and expertise on the natural environment and its management are essential components of Adaptive Capacity. Resource availability is ranked at a 'medium' Adaptive Capacity across this Area of Focus. With few exceptions, climate change adaptation of species, ecosystems and ecosystem services requires public-sector leadership. Within the provincial government, the Ministry of Environment, Conservation and Parks and the Ministry of Natural Resources and Forestry have primary responsibility over adaptation in this Area of Focus, although other ministries are also implicated (e.g. the Ministry of Municipal Affairs and Housing and provisions in the Provincial Policy Statement, a key land-use planning instrument), in addition to several other institutions operating regionally and locally (e.g. Conservation Authorities leading source water protection) (Government of Ontario, 2020f).

[24] The area of overlap of provincial and federal protected areas within each PCCIA region was used to determine total percentage coverage in each PCCIA region. Delineations of terrestrial provincial protected areas (provincial parks, conservation reserves, Far North protected areas) and terrestrial federal protected areas (national parks, national wildlife areas, migratory bird sanctuaries) were sourced from Ontario GeoHub. Other Effective Area-Based Conservation Measures are not included.

Provincial environment and natural resource managers are engaged in adaptation planning for parks, forests, water resources and other natural resources and have begun to mainstream climate planning in decision making (Ontario Ministry of Natural Resources and Forestry, 2011; Adaptation Platform - Forestry Adaptation Working Group, 2014). However, a lack of staff resources and capacity continues to limit the scope and scale of adaptation. Staff resources, in the way of science and planning staff, are already insufficient to deliver on core responsibilities for managing existing protected areas (Office of the Auditor General of Ontario, 2020b). Under these conditions, layering on responsibilities for integrating climate change considerations in strategic and operational decisions is understandably challenging even for a motivated and knowledgeable public service. The lack of succession planning in critical research and professional roles also hampers human resource availability (e.g. retirement of experts in southern forestry) (Johnston et al., 2010).

Funding and prioritization of adaptation actions are key challenges in the implementation of practices to enhance Adaptive Capacity of Ontario's natural environment. Currently, no provincial or cost-shared programs dedicated to adaptation in this Area of Focus exist, although practitioners, municipalities, and Indigenous Communities can compete for funding from federal programs such as the Nature Smart Climate Solutions Fund and the Natural Infrastructure Fund. Some financial markets support carbon storage (e.g. offsets) and public funds may help support water flow regulation, but additional financial resources would be beneficial to increase Adaptive Capacity for regulating services (Dhital et al., 2015). The Government of Canada, province of Ontario, Indigenous Communities, municipal governments, non-profit organizations, operators, and recreational users have interest in maintenance of ecological cultural services. Adaptive Capacity in this case could be increased by developing stronger coordination among user groups, decision makers, and funding bodies.

Information and guidance to support climate change adaptation in environmental and natural resource management is available but its influence in improving adaptation decisions is uncertain. Notably, the Ontario Ministry of Natural Resources and Forestry contributes to adaptation by, for example, undertaking and publishing ecosystem-focused climate change vulnerability assessment, modelling climate impacts on natural resources, and through focused research to support sustainable forest management in a changing climate, with topics including assisted migration, carbon storage pathways, genecology, and climate niches (Adaptation Platform - Forestry Adaptation Working Group, 2014). The effectiveness or impact of the Ontario Ministry of Natural Resources and Forestry efforts has not been assessed, however (WCS Canada, 2017). Further, improvements in monitoring and data management could bolster Adaptive Capacity. Ontario's formal biodiversity monitoring focuses on large, charismatic species, especially species that are harvested and thus provide economic benefit (Environmental Commissioner of Ontario, 2018). Monitoring of some less charismatic species does take place but not consistently at a large geographic scale (Environmental Commissioner of Ontario, 2018). The Ontario Ministry of Natural Resources and Forestry has reviewed its monitoring programs and identified gaps in climate change indicators, particularly for rivers, wetlands, and terrestrial wildlife (Furrer et al., 2014).

Extensive knowledge and data about plant responses to climate change exist, but these data are not consolidated, limiting the application of these resources. Similarly, but on a larger scale, research and data on Great Lakes ecosystems is voluminous, but fragmented. Importantly, Indigenous and Traditional Ecological Knowledge is underutilized in informing adaptation in this Area of Focus, with protocols increasingly available to support co-application of different knowledge systems, while respecting principles of ownership, control, access, and possession.

7.9.4 Governance

Governance is rated as 'medium' overall, with differences across Level 1 categories in this Area of Focus. Governance for flora and fauna is rated as 'low' and for provisioning services as 'high'. Several governance mechanisms, laws, policies, and planning frameworks exist to support management of species, ecosystems, and ecosystem services in Ontario. For example, 25 legal statutes directly consider biodiversity, including laws referencing special places (e.g. the *Greenbelt Act, Far North Act*, *Niagara Escarpment Planning and Development Act*); as elsewhere in Canada, biodiversity governance is shared between agencies primarily responsible for the environment or protected areas and those responsible for natural resource use (Ray et al., 2021).

Institutional attributes that facilitate adaptation include those supporting cross-sectoral and forward-looking planning, adaptive management, and coordination to address shared priorities in complex socio-ecological systems (Douglas and Pearson, 2022). Fragmented governance such as that present for biodiversity is challenged to meet these institutional attributes. The potential may be greater for forests and freshwater management. Ontario Ministry of Natural Resources and Forestry makes leadership and governance decisions about forests in the province (Wyka et al., 2018; Ontario Ministry of Environment, Conservation and Parks, 2011). Over the past 20 years, the Ministry has actively pursued research, partnerships, monitoring, and issued guidance to support sustainable forest management in a changing climate (Williamson et al., 2019). However, transparency about the effectiveness of those actions could be improved.

Policies for climate adaptation in freshwater systems are lacking, although multiple bilateral international agreements exist for water management in the Great Lakes region (Ontario Ministry of Environment, Conservation and Parks, 2011). The history of water resource planning facilitates adaptation governance, though decision-making and action is challenged by overlapping and disjointed authority, with coordination difficult to achieve in practice (Douglas and Pearson, 2022).

Naturally Resilient, a strategic policy framework guiding natural resource adaptation in Ontario, deserves special mention (Ontario Ministry of Natural Resources and Forestry, 2017). Issued by the Ontario Ministry of Natural Resources and Forestry in 2017, this strategic policy framework outlined five goals and actions to advance adaptation between 2017 and 2021, including those related to mainstreaming, building resilience, science and research, and outreach. It highlights actions such as the 50 million tree program, the Ontario Grasslands Stewardship Initiative, the Wetland Conservation Strategy, and the Far North Land Use Strategy as core instruments to deliver adaptation goals. This policy framework includes laudable goals, but some environmental non-governmental organizations have suggested it has limited actionable directives, lack of quantifiable targets for goals, lack of attention to cumulative effects of land use and climate change, the invisibility of ecosystem services, and actions to protect intact wetlands in the Far North as an approach to support both climate change adaptation and mitigation, among others (WCS Canada, 2017).

New regulations requiring municipalities across Ontario to adopt an asset management plan hold promise in advancing the mapping, measurement, valuation, and management of ecosystem services. By 2023, according to O. Reg. 588/17: Asset Management Planning for Municipal Infrastructure, Ontario local governments are set to incorporate green infrastructure assets in their asset management plans. Capacity constraints within small and medium municipalities in Ontario will challenge compliance with this regulatory requirement difficult, but if supports are in place significant progress in recognizing nature’s value is possible, including evaluating southern Ontario’s remaining wetlands at risk of being lost (Office of the Auditor General of Ontario, 2022).

7.9.5 Sector Complexity

The final category of Adaptive Capacity assessed for this Area of Focus was Sector Complexity. From an ecological perspective, complexity is generally a positive attribute that contributes to resilience. In the context of this discussion the greater the complexity (as measured by, for example, the number of stakeholders, decision makers present, agile decision-making capacity), the lower the capacity to adapt. Problem complexity tends to be inversely proportional to effective policy delivery (Kirschke et al., 2017). The complexities of governing climate change adaptation (Baird et al., 2016) can make environmental decision-making and action challenging, and this is not unique to Ontario. As this Area of Focus is complex, Adaptive Capacity is rated ‘low’ to ‘medium’ across Level 1 categories.

Understanding, conserving, and managing Ontario's natural environment involves numerous and diverse species, ecosystems, landscapes/waterscapes, stakeholders, rightsholder, and institutions, shaped by factors internal and external to Ontario. For terrestrial ecosystems, private actors, industry and provincial ministries have traditionally had jurisdiction or control over large land bases, streamlining decision-making. Freshwater systems also have complicated ownership structures, often intersecting jurisdictions, increasing complexity in decision-making. Each aquatic system is very different - from oligotrophic lakes to meadow marshes, rivers or flood lands and wetlands– increasing management complexity and resourcing required for assessment, intervention design, and performance monitoring. Ecosystems and habitats that cross national borders have even higher complexity (e.g. Carolinian forests, boundary waters).

Regulating services involve active participation from multiple levels of government, Indigenous People, and stakeholders, with network sophistication and strength variable depending on the service. Established partnerships and division of responsibility exist for provisioning services that are traded in markets (e.g. timber and potable water). These partnerships can be leveraged for adaptation planning. Decision making related to cultural ecological services is decentralized, which complicates coordination and collective action.

Meaningful collaboration with Indigenous governance systems is an evolving issue, adding to management challenges in the near term but with expected gains in Adaptive Capacity in the longer term. Indigenous Communities in Ontario have treaty rights over the species and ecosystem services that governments are mandated to conserve and manage (WCS Canada, 2017). Ecosystem and natural resource adaptation in the province consistent with commitments under the UN Declaration on the Rights of Indigenous People and treaty rights (e.g. creating Indigenous Protected and Conserved Areas) presents socio-cultural and governance complexity but the outcomes more equitable and durable.

7.10 Climate Adaptation Priorities

In the context of the PCCIA, an adaptation priority is defined as any Level 1 or 2 category in a given region that has an Adaptive Capacity of 'medium' or lower and a risk score of 'high' or greater (see Appendix 12 for combined Level 1 and regional Adaptive Capacity ratings)

Each of the seven Level 1 categories included under this Area of Focus have a 'medium' Adaptive Capacity, based upon considerations for technology, resource availability, governance, and sector complexity. When combining this with the regional Adaptive Capacity ratings, Central, Northeast, and Northwest regions are found to have the lowest capacity rating. This section provides further detail on current and emerging adaptation priorities for the Natural Environment Area of Focus, considering existing levels of capacity and current and future risk scores.

The level of risk varies significantly depending on the Level 1 and 2 categories being assessed and which region of province is considered. These differences exist due to many reasons, including habitat-specific tolerance thresholds, the extent to which ecosystems are intact and continuous versus fragmented, and the level of consequences a particular impact may lead to. For example, risks to fauna reach the highest levels by the end of century in the Central region, in part because of higher levels of expected development, exacerbating climate stresses to individuals and populations with high biodiversity. When considering risks to aquatic and terrestrial ecosystems, Ontario's Central region and all northern regions stand out as having highest risk levels by the end of the century, with much of the risk driven by the impacts of climate change on northern wetlands ecosystems, such as changes in community structure, matter, and nutrient cycling. Ontario's Far North contains vast swathes of ecosystems and related ecosystem processes of global significance (e.g. peatlands as natural carbon stores), with climate threats (combined with potential development) leading to risks that are not only extensive but also irreversible.

Current Adaptation Priorities

Looking at Level 2 categories under exhibiting 'high' risk under existing conditions, and relatively lower capacity levels ('medium'), the following adaptation priorities are identified in Table 7.25 for the current timeframe. Note that amphibian and mollusc Level 2 categories are currently scored as 'high' risk in the Southwest region. However, due to the capacity assessed for the Southwest region (see Appendix 12), these Level 2 categories are not listed as current adaptation priorities.

Table 7.25: Current Natural Environment Adaptation Priorities

Current Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[25]
Fish	Central, Far North	**High**	**Medium**
Waterfowl	Central	**High**	**Medium**
Bogs	Northeast, Northwest, Far North	**High**	**Medium**
Mudflats	Far North	**High**	**Medium**
Carbon Storage	Northeast, Far North	**High**	**Medium**

[25] See Appendix 12 for combined Adaptive Capacity ratings and associated scoring matrix.

Emerging Adaptation Priorities

Looking ahead to mid-century a number of additional areas of 'high' risk will emerge for Ontario's natural environment, adding to those already identified for the current timeframe, all of which continue to persist and even increase in risk. For instance, Bogs, Fish and Waterfowl risk profiles are expected to increase to 'very high' by mid-century. Emerging adaptation priorities for Natural Environment are summarized in Table 7.26.

Table 7.26: Emerging Natural Environment Adaptation Priorities by Mid-Century (RCP8.5)

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[26]
Birds	Central, Northeast, Northwest	**High**	**Medium**
Insect/Spider	Central, Northeast	**High**	**Medium**
Mammals	Central, Northeast, Northwest, Far North	**High**	**Medium**
Migratory songbirds	Central, Northeast, Northwest, Far North	**High**	**Medium**
Reptile	Northeast	**High**	**Medium**
Lichen	Northwest	**High**	**Medium**
Vascular plant	Central, Northeast, Northwest	**High**	**Medium**
Marsh	Central, Northeast, Far North	**High**	**Medium**
Coniferous Forest	Northeast, Northwest, Far North	**High**	**Medium**
Deciduous Forest	Central, Northeast, Northwest	**High**	**Medium**
Sand Barren and Dune	Central	**High**	**Medium**
Tallgrass Savannah	Central	**High**	**Medium**
Freshwater Provision	Central, Northeast, Northwest, Far North	**High**	**Medium**
Wood Supplies	Central	**High**	**Medium**

[26] See Appendix 12 for combined Adaptive Capacity rating and associated scoring matrix.

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[26]
Carbon Storage	Central, Northwest	**High**	**Medium**
Pollination	Central	**Very High**	**Medium**
Water Flow Regulation	Central	**High**	**Medium**
Coniferous Forest	Northeast, Northwest, Far North	**High**	**Medium**
Deciduous Forest	Central, Northeast, Northwest	**High**	**Medium**
Sand Barren and Dune	Central	**High**	**Medium**
Tallgrass Savannah	Central	**High**	**Medium**
Nature-Based Recreation	Central, Northeast, Northwest	**High**	**Medium**
Recreational Fishing (Angling)	Central, Northeast, Northwest, Far North	**High**	**Medium**

Advancing Adaptation

The PCCIA Adaptation Best Practices (ABP) Report (External Resource – 2) has been developed considering adaptation options for the natural environment. Ontario has the solutions and knowledge to act to lessen and avoid many of the climate risks facing the natural environment. A high-level summary is provided in Table 7.27, but specific adaptation options are available in the ABP Report.

Table 7.27: Adaptation Options for the Natural Environment Area of Focus

Adaptation Category	Examples of Adaptation Measures
Projects or Programs	- Fill gaps across Ontario's regions and develop formal partnerships, with funding, to manage natural ecosystems. - Ensure Indigenous Knowledge informs new and enhanced regulations and management practices. - Develop a provincial framework to study variation in species demographics rates to track trends and conservation goals. - Develop a policy to manage and monitor changing species ranges.
Research and Development	- Adopt international standards for the practice of ecological restoration. - Develop collaborations among communities and support Indigenous-led conservation. - Develop provincial policy for landscape management to support assisted migration and re-establishment. - Develop education resources for forest and urban forest managers.
Investment and Incentives	- Invest in research and Indigenous-led community-based monitoring and research programs. - Prioritize ecosystem restoration, and the protection and preservation of intact or high functioning ecosystems. - De-risk green infrastructure implementation and invest in education.
Policy and Regulation	- Protect and strengthen the Conservation Authorities Act (CAA) and Environmental Assessment Act (EAA). - Protect riparian zones along water bodies, wetlands and stream corridors. - Develop a policy for climate refugia protection and management. - Maintain, promote, and enhance ecosystem connectivity. - Protect and conserve peatlands and other carbon-dense ecosystems as intact ecosystems.

8.0 People and Communities Area of Focus

8.1 Overview

Climate change has already had significant impacts on the individuals, communities, and associated services in Ontario. These risks are expected to continue into the future. The assessment reveals that climate risks are highest among Ontario's most vulnerable populations and exacerbate existing disparities and inequities (e.g. unhoused population, Indigenous population) (see Table 8.1). Climate risks to Indigenous Communities and associated systems are found to be significant based on the additional layers of sensitivity and exposure related to their close relationship with the environment and its natural resources, and based on the dispersed nature of their communities noted in the far north region of Ontario.

The results of this impact assessment highlight the urgent need to limit key risks to Ontario's people and communities. Intervention is needed to limit and avoid outcomes that can become inter-generational and further drive inequities for marginalized populations. Adaptation efforts to address the underlying health and well-being inequities are critical for reducing population vulnerability and building climate resilience across Ontario communities.

Table 8.1: Summary of Climate Risks to People and Communities (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Most at Risk Regions Abbreviations[27]	
FN - Far North	E - Eastern
NE - Northeast	C- Central
NW - Northwest	SW - Southwest

People and Communities Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Population				SW, C, E
Health Care				SW
Social Assistance and Public Admin				E
Indigenous Communities				All

[27] 'Most at risk regions' are those that display highest risk scores operating under RCP8.5 (Appendix 9).

8.2 Ontario's People and Communities

Ontario's rapidly changing climate both directly and indirectly threatens the health and well-being, livelihoods, access to services, cultural practices, and ways of being for people and communities in a myriad of ways. In the recent past, the most acute climate events have garnered the widest coverage and attention, with flooding, heat waves and ice storms that have suspended societal activities and caused electrical and other critical infrastructure interruptions. While the physical impacts to property and infrastructure often receive the greatest focus and have consequential impacts for people, the direct impacts on human health and the systems that people rely on for their well-being have been significant.

It is critical to evaluate climate change impacts and risks against the backdrop of equity in society. Vulnerable populations and those who experience inequity in society have low levels of Adaptive Capacity and face a larger uphill battle to adapt to climate risks. Systems of oppression influence an individual's vulnerability to climate-related risks, with impacts being felt most by low-income residents, Indigenous Communities, and those with underlying health conditions. In undertaking an analysis of climate change risk to human health and well-being, the People and Communities Area of Focus provides a window into how climate change has and will continue to impact people as individuals, and the healthcare systems and social services relied upon by communities across the province.

In order to evaluate climate change impacts into the future, it is important to understand how settlement and population patterns have and will continue to evolve over the coming decades. Ontario is home to some of the fastest growing communities in Canada and is projected to continue to grow at significant rates over the coming decades. Several of the Province's rapidly growing municipalities are located in the Greater Toronto Area, including Milton, Oakville, Clarington, and Oshawa, as well as other communities further west in Kitchener-Cambridge-Waterloo and London. There are a number of suburban municipalities that have also recorded significant growth, including East Gwillimbury, New Tecumseh, and Bradford West Gwillimbury. In northern Ontario, growth is projected to remain relatively stable, with an increase in population since 2016 most prominent in Greater Sudbury and North Bay, attributed to the growth in non-permanent residents living in the Region (Ontario's Long-Term Report on the Economy, Ontario Ministry of Finance, 2020a; Stiebert Consulting, 2022). With differentiation in immigration patterns, there is a high degree of regional variability in population demographics and diversity, driven in large part by local job attraction and relative levels of housing affordability and supply.

The current population of Ontario is approximately 14.8 million people, excluding Indigenous residents on reserves (Stiebert Consulting, 2022). Historical annual population growth rates in

Ontario have ranged from between 0.75 to 2.75%, peaking in the late 1980's and hovering around 1.75% over the past five years (Stiebert Consulting, 2022).

Communities have grown significantly in Central, Eastern, and Southwest Ontario, where climate, economic conditions, cultural diversity, education and skills training, and healthcare investments are concentrated. While cultural enclaves have grown particularly in Toronto and surrounding communities, studies have shown that there is high diversity within these areas, and most are not dominated by a single ethnic community (Hiebert, 2015). However, rural populations have declined in many parts of the province, as urban areas have grown, resulting in a shifting urban-rural balance over the past 60 years (Ahmed, 2019).

Patterns of population growth and degree of urbanization are critical to an assessment of climate change impacts and adaptation (see Figure 8.1). The differential vulnerability of populations to climate change, even within a small geographic range, has been well documented (Thomas et al., 2018). Regional variability in climate risk as well as specific conditions that manifest through particular outcomes for communities across Ontario are important to explore. This impact assessment considers the particular region-specific circumstances that play a role in climate impacts and Adaptive Capacity, including access to health care, availability of social services and providers, proximity to food sources, reach of emergency services, and existing levels of socio-economic inequality, all of which are intertwined with population density and level of urbanization.

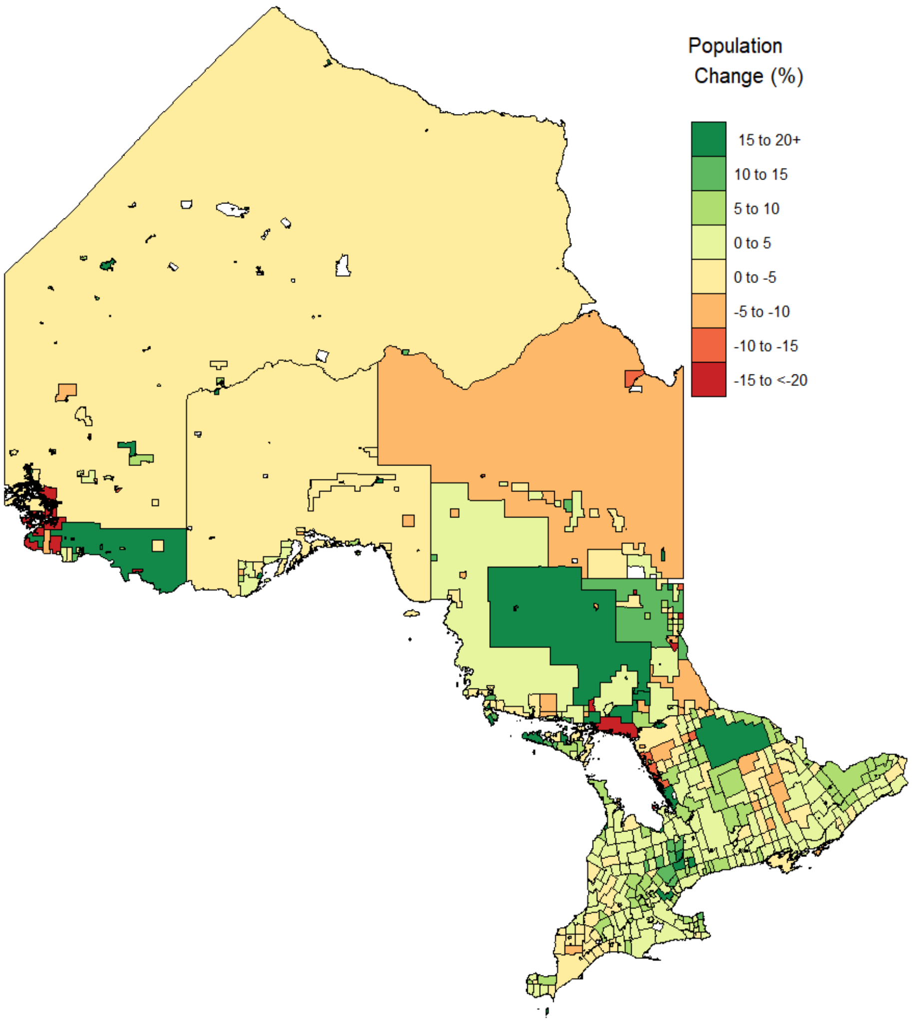
Current levels of regional population density vary considerably, as presented in Table 8.2. The Central region has by far the highest density, with approximately 625 people per square kilometre, compared to the Far North region with less than one person per square kilometre. This wide variability has distinct implications for how intensification of severe weather events and changing climate conditions manifest in different regions in the context of flooding due to limited permeable land surface, indirect impacts from infrastructure and building damage, urban heat island effect, and per capita availability of resources to support regional capacity (see Appendix 11).

Table 8.2: Population density in Ontario (Statistics Canada, 2022)

Region	Population Density (People per km^2)
Far North Region	0.08
Eastern Region	46.69
Central Region	625.49
Southwest Region	84.99
Northeast Region	3.07
Northwest Region	1.18
Total	**16.24**

Indigenous Peoples represent approximately 3% of the Ontario population, with over 406,000 people spread across the province, living both on-reserve and in urban areas. The majority (78%) of Indigenous Communities are located in Northern Ontario, with on-reserve members comprised of Métis, Inuit, First Nation, other Indigenous, and some non-Indigenous residents (Ontario Ministry of Indigenous Relations and Reconciliation, 2022). An oppressive history, (e.g. colonization), is a key influence on vulnerability of Indigenous People and communities, particularly in the context of climate change-related impacts and risks.

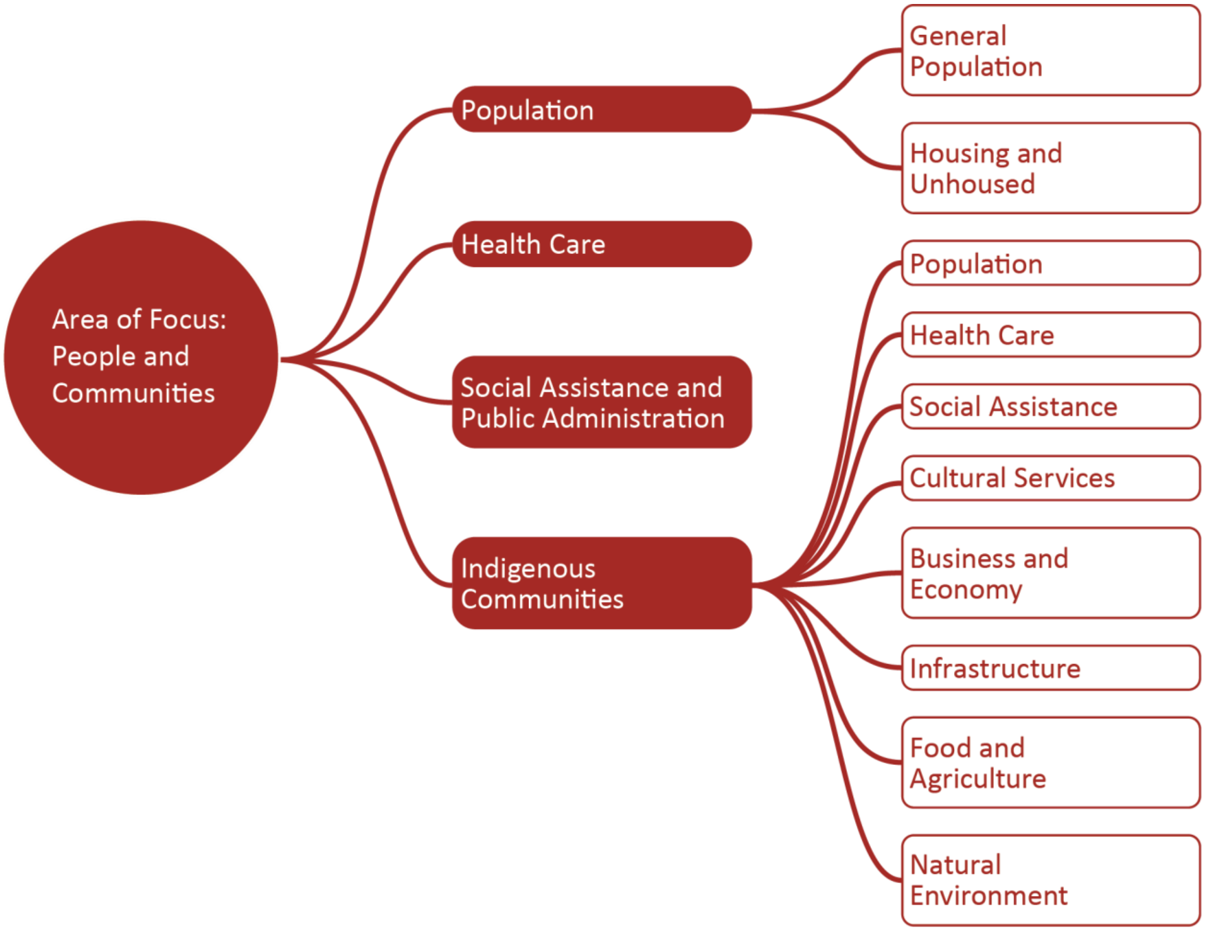
Figure 8.1: Population Change in Ontario between 2011 and 2016, based on Statistics Canada data (Ontario 360, Munk School of Global Affairs, University of Toronto)



8.3 Defining People and Communities in the Context of the PCCIA

The complexity and diversity associated with People and Communities, and its intimate connections to all other Areas of Focus for the PCCIA created challenges for its discrete analysis. As such, the climate change impacts were parsed to obtain direct impacts to people and systems. A total of four unique Level 1 categories were identified for the People and Communities Area of Focus, with the Population and the Indigenous Communities Level 1 categories further subdivided to include Level 2 categories (Figure 8.2). Appendix 1 provides a full summary of the Level 1 and 2 categories assessed as part of this Area of Focus, including a brief description of each.

Figure 8.2: Structure of the People and Communities Area of Focus in the Context of the PCCIA



The Level 1 categories are intended to capture direct impacts to the health and well-being of people as individuals and communities in Ontario. They also account for the multiple levels at which climate risks interplay and affect Ontarian's ability to meet their daily needs, and their capacity to adapt to acute and chronic climate change. The Level 1 and 2 categories are also designed to capture direct impacts to key services that are connected to the overall health and well-being of Ontarians. Indirect impacts that lead to damage to infrastructures, changes in natural ecosystems, infectious diseases and food and water-borne infections, worsening air pollution, disruptions to food and water supplies, and population displacement are also characterized throughout this Area of Focus.

Limited data availability, notably those data that could fully characterize impacts to Indigenous culture, impacts to educational services and specific segments of the population most vulnerable (e.g. incarcerated populations, newcomers to Canada, outdoor workers, migrant workers, and those in long-term care facilities) proved to constrain the assessment. Given some of the gaps in data, the quantitative analysis of risk was limited to people and communities. A fulsome consideration of climate-related risk would require deeper analysis into specific segments leading to a more fulsome characterization of climate risks to population. Indirect and other cascading impacts are further elaborated on through qualitative narrative in Section 8.7.

The Level 1 categories that were identified for the general (non-Indigenous) component, include population, health care, and social services and public administration. Each component of this Area of Focus, as well as the other Areas of Focus are assessed for Indigenous Communities under the Indigenous Level 1 category.

Population

Within the population Level 1 category, two Level 2 categories were assessed: general population and unhoused population. The two categories were developed to recognize the specific vulnerability of people without access to safe, secure shelter to climate change. Priority populations who are disproportionately impacted by climate change (e.g. children and seniors, disabled individuals, newcomers to Ontario or Canada etc.) are considered as a percentage of the general population, as further described in Section 8.7.1. The general population Level 1 category considered impacts to personal safety and well-being, integrating the influence social determinants have on health and well-being. Population vulnerability to the impacts of climate change considers the exposure and sensitivity to climate change impacts, and the existing capacity to respond to, or cope with them. The social determinants of health play a role in defining the way that individuals and communities respond to climate-related impacts, and the ways that their exposure and sensitivity to climate risks may be exacerbated based on their social, material and health conditions.

The Financial Accountability Office of Ontario (FAO) estimated that in 2021, over 179,000 households in Ontario live in housing that was “deeply unaffordable” and were at risk of homelessness (Financial Accountability Office of Ontario, 2021b). Disaggregated data from this work was not available for the inclusion in this impact assessment. Consequently, the analysis of the unhoused population Level 2 category primarily relied on a scan of municipal and regional data on homelessness counts. The connections between housing insecurity and insufficiency and vulnerability to climate change impacts are well documented, with several studies identifying homelessness, inadequate heating or cooling, and flood risk due to geographic location as key factors increasing exposure and vulnerability to multiple climate hazards (Bezgrebelna, 2021).

Health Care

The health care Level 1 category comprises establishments primarily engaged in providing health care by diagnosis and treatment and providing residential medical care. This includes ambulatory services, hospital care, nursing and residential care, and in-home health care.

For the purposes of this assessment, data on Ontario's health care sector were drawn from a number of sources, including the Local Health Integration Network (LHIN), comprised of 14 regional LHINs and 78 sub-regional units (Public Health Ontario, 2016). The LHINs are responsible for planning, funding health service providers, and integrating services through a coordinated effort. As the LHINs are structured in a way that allows for a regional analysis, this point of reference was integrated into Ontario Marginalization Index (2016) data, developed by Public Health Ontario. These datasets provided insight into the population size, ethnic diversity, and level of material deprivation in the populations served by each health unit.

Social Assistance and Public Administration

The Social Assistance and Public Administration Level 1 category comprises establishments primarily engaged in providing social assistance and activities of a governmental nature. These include counselling, welfare, child protection, community housing and food services, vocational rehabilitation and childcare, legislative activities, taxation, national defense, public order and safety, immigration services, foreign affairs and international assistance, and the administration of government programs.

Social and administrative services rendered by the Federal, Provincial, and Municipal governments are a key contributor to maintaining the health and well-being of Ontarians, including provision of support services for people with disabilities, food, housing, employment, family services, immigration and settlement, education, and various other essential services. The impact of closures of public administrative services can be difficult to quantify; however, close to 11% or over 1.5 million of Ontarians lived in poverty in 2019, and approximately 6.5%, or just under one million residents, received social assistance in 2019-2020 (Kapoor, 2022). These statistics provide some insight into the level of service provision necessary to maintain the basic necessities for a portion of the Ontario population and the consequences of service disruptions due to extreme climate-related events.

Indigenous Communities

The Indigenous Communities Level 2 category includes population, health care and social assistance and cultural services, in recognition of the integral aspect of cultural and spiritual practices on the land that is impacted by climate change. In addition, a set of Level 2 categories for each Area of Focus was assessed separately for Indigenous Communities, to capture the nuances climate impacts have on infrastructure, food and agriculture, business and economy, and natural environment, for Indigenous Communities.

The assessment of climate impacts and capacity considered how environmental justice and equity issues are directly related to how climate change disproportionately impacts specific segments of the population (Morss et al., 2011). The delineation of vulnerable populations is further discussed in Section 8.5, detailing the methodology and approach taken for this Area of Focus assessment.

8.4 Risk Snapshot across Ontario

Summary of Risks

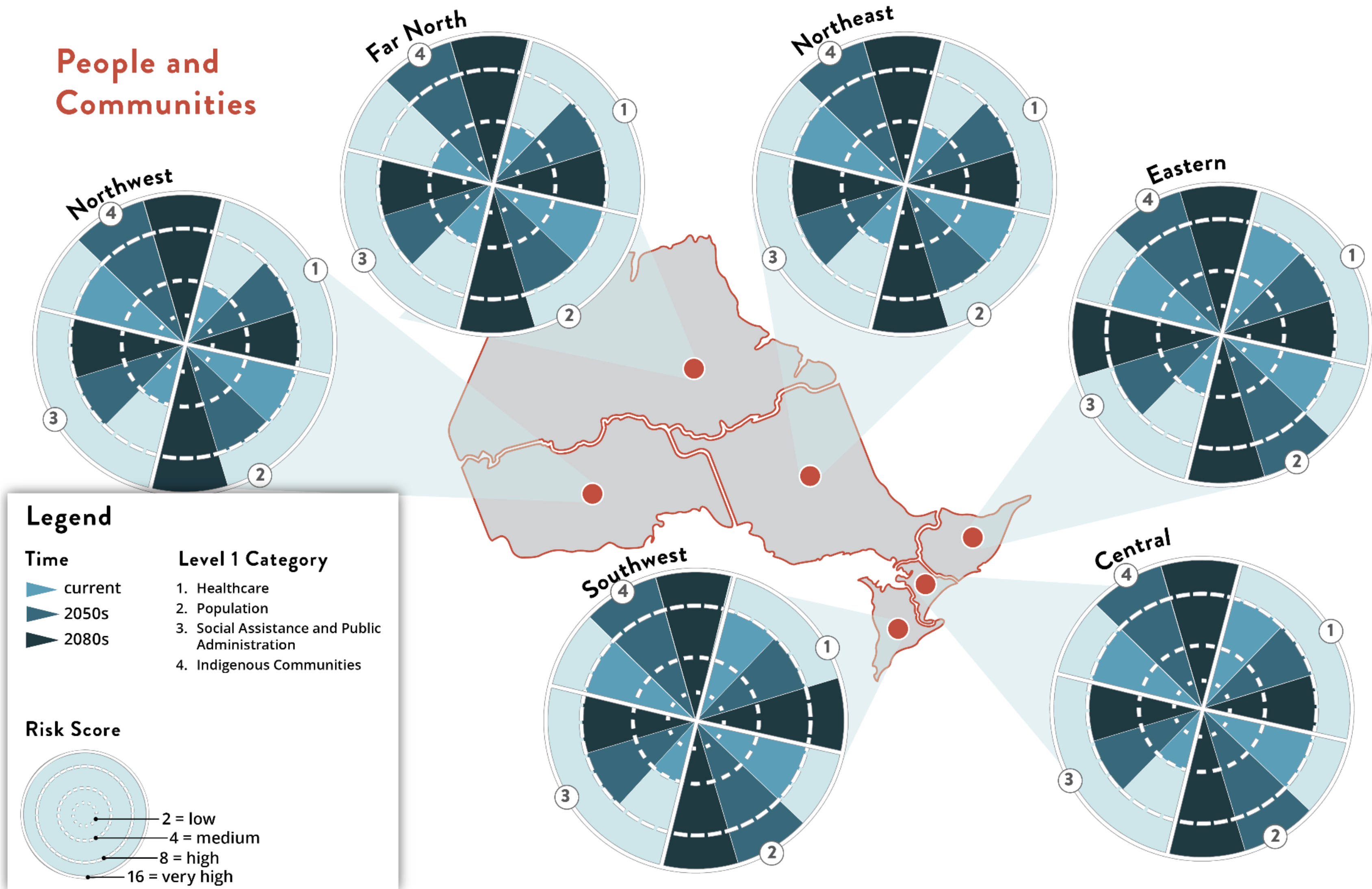
Under the People and Communities Area of Focus, a total of 576 unique risk scenarios were evaluated through each of the Level 1 categories and climate variable interactions. Risk profiles for all Level 1 categories within the regions are summarized in Figure 8.3 illustrating current risk, and the expected risks for 2050 and 2080 under a high-emissions scenario (RCP8.5).

Results from the PCCIA indicate that current risk profiles for this Area of Focus across all regions of Ontario range from 'medium' and 'high' risks, with no 'very high' risks reported. Population, health care, and Indigenous Communities Level 1 categories are found to have similar proportional distribution of 'medium' and 'high' risks, with social assistance and public administration risks assessed at the 'medium' level across the province.

Looking into the future, several Level 1 and 2 risk profiles increase to 'high' and 'very high'. The 'very high' risks largely emanate from the population and Indigenous Communities Level 1 categories, while health care risks average out to a 'high' level across most of the province. Social assistance and public administration risk profiles increase from 'medium' to 'high' risks across most regions of Ontario, with the Eastern region rising to 'very high'.

Generally, the PCCIA results indicate a considerable increase in risk across most categories and regions by mid-century (2050s). This increase is reflective of overall population growth and growth in vulnerable populations, in particular, increased unhoused populations, people with disabilities, and those in the low-income category. This shift towards 'very high' risks is further exacerbated by the 2080s for many Level 2 categories, reflecting considerable changes in the frequency of climate variables assessed under this Area of Focus (e.g. extreme precipitation and high temperatures).

Figure 8.3: Current and Future Risk Profiles by Region Assessed for People and Communities (RCP8.5)[28]



[28] Appendix 13 provides an alternative visual format of the presented risk results by Level 1 category and region for this Area of Focus.

The overall findings of the PCCIA suggest that some of the greatest climate risks across Ontario are for people and communities, both now and into the future. The highest risks for the population Level 1 category are present in the Central, Eastern, and Southwest regions, which are regions with the greatest population density and ethno-cultural concentration (Stiebert Consulting, 2022; Ontario Marginalization Index, 2016). Risks highlighted for health care, particularly in the Southwest and Central regions, also correspond to the extent of population density and exposure of hospitals and emergency services to potential flooding and extreme heat event, increasing risks related to electricity blackouts (Ness et al., 2021). The Southwest and Central regions of the province also exhibit existing strain on emergency services resulting in increased wait times for patients, caregiver and provider stress, which are exacerbated in a climate emergency, as well as the limited availability of per capita health resources to manage the demand (Ontario's Premier's Council on Improving Healthcare and Ending Hallway Medicine, 2019). Risks to population and health care Level 1 categories are anticipated to rise in future time frames as current capacity constraints are accentuated into the future.

Within the Indigenous Communities Level 1 category, the three main Level 2 categories with highest current risk exposure are Indigenous cultural services, Indigenous health care, and the general Indigenous population. The same categories also reflect the greatest risk by the end of century (2080s) time horizon, indicating that existing exposure of vulnerable populations will be exacerbated into the future. Currently the most densely populated regions (Southwest, Central and Eastern) exhibit the greatest risk across Indigenous Communities. By the end of century (2080s) risk profiles in Northeast, Northwest and Far North regions are anticipated to be 'very high', reflecting an accelerated rate of climate change and high rates of material deprivation in northern regions of the province.

The results of the PCCIA highlight priority areas for equity-based adaptation planning and implementation across Ontario communities. The consequences associated with climate risks for Ontario's most vulnerable populations are significant and present critical concerns, particularly in the context of rising income disparity and economic precarity.

Key Climate Drivers

The major climate variables impacting People and Communities are presented in Table 8.3. Extreme weather events are found to be the most impactful for this Area of Focus, including extreme temperatures and precipitation events. The greatest drivers of 'high' and 'very high' risks are extreme temperature climate variables (e.g. Extreme Cold and Extreme Hot Days) which accounted for half of all risk scenarios in this ranking. However, it should be noted that emerging research on the impacts of onset changes in average temperatures indicates that long-term, changes of 5°C can have equal or greater impacts on population health, compared to acute extreme temperature events (Chen et al., 2016). With this in mind, supporting adaptation interventions should address both acute and chronic temperature-related impacts, particularly for the unhoused population, who are most exposed and sensitive to smaller fluctuations in temperature.

Extreme precipitation events followed closely behind extreme temperatures, representing nearly 20% of risk scenarios. Winter precipitation (e.g. freezing rain) represented over 10% of People and Communities risk scenarios (included under 'other variables'). A full list of all major climate variables that are driving the highest risks to Ontario's People and Communities Area of Focus by Level 1 category is available in Appendix 8.

Table 8.3: Main Climate Variables Assessed for People and Communities

Climate Variable	Proportion (%) of Area of Risk Scenarios
Extreme Cold Days	**25%**
Extreme Hot Days	**25%**
Extreme Precipitation Event (shorter term)	**19%**
Other Variables	**31%**

8.5 Approach to Assessing Climate Impacts on People and Communities

The assessment of climate impacts on the People and Communities Area of Focus considers both acute and chronic events associated with climate change, including extreme weather events and wildfire, as well as slow onset changes to climate conditions. As with other Areas of Focus, both direct and indirect impacts on the Leve 1 and 2 categories were explored, with only direct impacts being reflected in the risk scores.

Based on data, research and literature, relevant climate variables were selected for each Level 2 category. For instance, extreme heat and extreme cold were selected given the evidence for related mortality and morbidity risk. An Ontario-wide study found that for the period between 1996 and 2010, each 5°C change in daily temperature was estimated to induce seven excess deaths per day in cold seasons and four excess deaths in warm seasons, with high-risk subgroups noted including unhoused populations and those with inadequate residential heating and cooling (Chen at el., 2016).

Key climate variables assessed for the general population Level 2 category include, Extreme Hot Days, Extreme Cold Days, extreme precipitation events, winter precipitation, and in certain regions, wildfire. These climate variables have the potential to create adverse health impacts including temperature stress, respiratory impacts, and threats to physical safety, leading to situations where Ontarians may require medical attention, relocation to a site equipped with the infrastructure to support their well-being, such as heating or cooling centres, or short-term evacuation or long-term displacement.

For People and Communities, the assessment of consequences was scoped to the portion (%) of population that is adversely impacted by the climate impact, where the higher the percentage of population affected, the greater the consequence score (see Table 8.4). A 'very high' consequence score reflected almost the entire population being affected by the impact, whereas a 'low' score reflected between 20 to 40% of the population affected. It should be noted that the percentage ranges provide a large band for each consequence score, potentially obscuring the changes from one time horizon to the next, especially when considering the projected increases in vulnerable populations from now until the end of century.

Table 8.4: Consequence Criteria Applied to the People and Communities Area of Focus

Consequence Score	Category	Definition – Portion of Population that is Adversely Impacted
16	Very High	>80% to 100%
8	High	>60% to 80%
4	Medium	>40% to 60%
2	Low	>20% to 40%
1	Very Low	0% to 20%

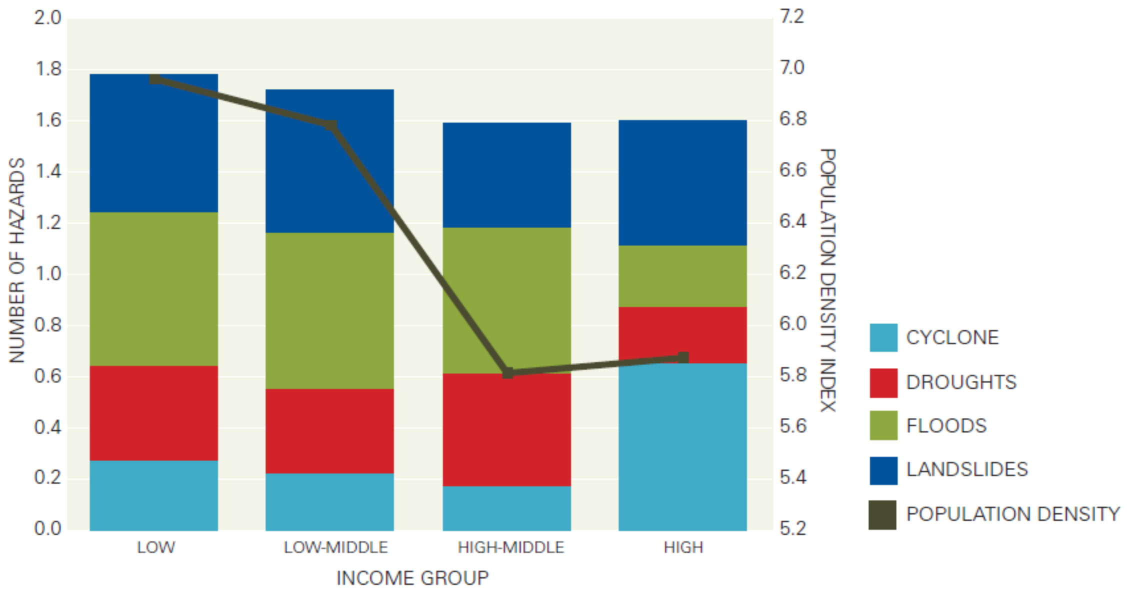
To update risk consequence scores for the 2050s and 2080s time periods, socio-economic projections were considered along with specific assumptions (see Box 14). In order to allow for a deeper analysis of each of the six provincial regions, a representative census area was selected that presented typical population characteristics for a given region, related to population size, growth, diversity, and density. The selected Census Subdivisions for each region are shown in Table 8.5.

Table 8.5: Representative Census Subdivisions for each Region

Region	Representative Census Subdivision
Far North	Kenora
Northwest	Thunder Bay
Northeast	Sudbury
Eastern	Peterborough
Central	Peel
Southwest	Essex

Box 14: Socio-economic Analysis for People and Communities Area of Focus

The socio-economic analysis conducted as part of this study was foundational to the review of climate variables for the People and Communities. In particular, the relationship between climate-related impacts and population density by income level clearly highlights the disproportionate exposure of low-income populations in more dense areas to a range of severe weather events and conditions, including droughts, floods, and landslides (see Figure below). Specific socio-economic indicators applied to this Area of Focus include population, population density, capital formation and low-income measure.



Source: Jiang and Hardee, 2009

Approach to Assessing Risks to Vulnerable Populations

There are significant segments of the Ontario population that are and will continue to be disproportionately impacted by climate change. Priority or vulnerable populations were identified based on a comprehensive review of provincial research and through consultations with subject matter experts over the course of the engagement process. In addition, the Ontario Marginalization Index (2016) and the Social Determinants of Health Map (2006, 2011, and 2016), both developed by Public Health Ontario were accessed to identify how severe weather events and conditions may overlap with materially deprived communities across the province (Public Health Ontario, 2022). Social determinants of health (SDOH) are social and economic factors that characterize and influence individual living conditions, such as income, education or employment, housing status, as well as the nature of the physical environment in which they reside. Experiences of discrimination, racism and historical trauma are important social determinants of health for certain groups including, Indigenous Peoples, people of colour and LGBTQ (lesbian, gay, bisexual, transgender, queer).

Given the broad nature of the PCCIA and the direction to take a data-oriented approach, the integration of an SDOH lens to understand how people and communities are impacted by climate change enables an intersectional approach to understand how intersecting layers of vulnerability can influence the proportion of the population that is disproportionately impacted, and therefore the overall level of climate risk to population groups across Ontario.

The effects of climate change will not be felt uniformly across sub-populations, with certain groups anticipated to be disproportionately impacted. Examples of these groups include (Public Health Ontario, 2022):

- Seniors
- Infants and children
- Socially disadvantaged people, including low-income populations
- People with disabilities, including pre-existing illnesses or otherwise compromised health
- People living in Northern communities
- Emergency response workers

Other factors also contribute to climate change vulnerability, and are difficult to quantify at the Ontario-wide population level. These include:

- People living in areas with poor air quality
- People working outdoors
- People without access to air conditioning

Socio-economic projections were applied and cross-referenced with the Ontario Marginalization Index to highlight vulnerable populations as part of this impact assessment. This approach allowed consideration of how segments of societal marginalization intersect with climate change impacts related to a given climate variable which ultimately informed the associated consequence rating.

Three distinct (non-overlapping) segments of the population who would experience greater levels vulnerability were identified. From here proportions of the identified population groups were analyzed across the six representative regions based on the PCCIA socio-economic analysis (Stiebert Consulting, 2022). The three distinct population groups include:

- Low Income (Prevalence of low income based on the Low-income measure, after tax (LIM-AT) (%), for the 18-64 age group)
- Youth (Proportion of the population aged 0-14 years)
- Older Adults (Proportion of the population aged over 65 years)

Analysis of the proportions of each of the three population groups resulted in a 'Total Base Vulnerable Population' for each provincial region. To further advance an assessment of intersectionality, an added layer of analysis was applied to consider the following groups:

- People with disabilities (Proportion averaged at 22% of the overall population over age 14)
- Women (averaged at 50.4% of the population)

Proportions of the population representing people with disabilities and women were multiplied with the 'Total Base Vulnerable Population' for each representative regional census tract. The resulting 'Total Vulnerable Population' number was then matched against the population ranges, to inform the consequence scores for the impact assessment. By applying this approach, the multiplicative impacts and cumulative impacts of overlapping aspects of marginalized identities and climate change could be included in the assessment of people and communities. For more information, please refer to the PCCIA Methodology Framework (External Resource – 1).

8.6 Limitations of the People and Communities Assessment

Engagement Limitations

Engagement is an important component of assessing climate change impacts on people and allows for the inclusion of experiences, risk tolerance and risk perception into the process. Engagement for the PCCIA were constrained due to the COVID-19 pandemic. Originally, in-person engagement was planned for throughout the assessment process but had to be changed to a fully virtual approach. This resulted in engagement limitations across the project, including

Indigenous engagement. Climate change knowledge and adaptation activity within Indigenous Communities, associations, and organizations is apparent and should be emphasized in future outcomes of this project and subsequent iterations of climate change assessment at a provincial scale.

Data Input Limitations

Within the People and Communities Area of Focus, certain impact elements could not be fully characterized due to lack of comprehensive province-wide data and information. For this reason, the strength of evidence for this Area of Focus was ranked mainly as low or medium. Examples of specific knowledge gaps include impacts on specific vulnerable segments of the population such as incarcerated populations, newcomers to Canada, outdoor workers, migrant workers, and those in long-term care facilities. Given some of these knowledge gaps, the quantitative analysis of risk to the People and Communities Area of Focus was limited for several categories.

Another example is data availability on the unhoused population in Ontario. Data applied to this category were somewhat generalized across the province, recognizing that unhoused individual counts, and shelter service records are maintained at a municipal level, and was beyond the scope of this assessment. Instead, the representative Census Subdivisions identified in the previous section were used to guide research on the unhoused population. There are some limitations to this approach, as it does not capture the 'hidden homeless' – those who may be living with relatives or friends in the community, who may be precariously housed or in situations with low security of tenure, and those who have recently arrived in Ontario and are in the process of securing accommodations.

Future more fulsome assessments of climate risk would require a deeper review of populations and vulnerable groups in Ontario. In addition, the quantitative data and robust methods to assess the cascading impacts for people and communities are limited. However, it is well known that cascading impacts from all sections stretch broadly across elements of health and well-being, both at individual as well as community level. Cross-sectoral impacts are discussed further throughout Section 10.0, considering cascading impacts on food, energy and water security, health and well-being, and overall community function.

8.7 Current and Future Risks

8.7.1 Population

Overview

The Population Level 1 category refers to all people present across Ontario, except for the Indigenous Peoples living on First Nation reserves (covered under Indigenous Communities), and relates to all members of a community, including those who have been residing in the province over multiple generations, newcomers, international students, temporary foreign workers, and visitors.

The two Level 2 categories identified within the Population Level 1 category are General Population and Unhoused Population, to recognize and capture the significant impacts of shelter on vulnerability to climate change as it relates to human health and wellness.

The Population Level 1 category forms the basis of our understanding of how communities and individuals are potentially exposed to changing climate conditions, and the need for an intersectional approach to assessing the proportion of the population that is classified as vulnerable. In considering the types of climate-related impacts that inform the risk scenarios within the population Level 1 category, the consulting team drew upon available research, news sources, and socio-economic data.

Direct Impacts

This section describes quantitative scores for direct risks assessed for Level 2 categories under the Population Level 1 category. As noted, Representative Census Subdivisions were assessed, considering how climate variables could lead to impacts on each Level 2 category under current and future timeframes. The consequences of climate risks for the broader population, including the unhoused population, revolve around increased proportions of the population requiring access to medical intervention in times of high demand for services, with potential for increased mortality and morbidity as a result of medical and emergency service capacity constraints.

Example risk scenarios are available in Table 8.6 for a fuller picture of the risk scenarios considered for the Population Level 1 category. Table 8.7 summarizes the risk profiles for each Level 2 category and region, operating under a high emissions scenario (RCP8.5).

Table 8.6: Illustrative Risk Scenario Examples Population Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
General Population	Extreme precipitation (shorter term) leads to widespread flooding. Due to the lack of permeable surfaces in Central Ontario and presence of aging infrastructure, stormwater drainage is overwhelmed in some areas. Recreational water or safe drinking water sources may be compromised due to runoff from heavy rainfall events. Vulnerable populations are exposed to mould especially in low-income housing. Food contamination and related illness can occur following flooding and associated power outages. Flooding worsens some physical health problems, personal loss, financial difficulty and mental health disorders among this group.	**High**
Unhoused Population	Extreme heat and cold events associated with mortality and morbidity particularly for unhoused populations. Extreme precipitation (rainfall) and Winter precipitation result in shelter damage and loss of property, prompting the need for evacuation or relocation.	**High**

General Population

The results of the impact assessment indicate that extreme heat and cold are key climate variables driving future risk for Ontario's general population. Extreme precipitation (rainfall) and winter precipitation are also found to be impactful on the general population, with risks to shelter damage and loss of property. Risk to the general population is found to increase from 'medium' to 'high' by the 2050s across all regions except the Far North where it remains 'medium'. By the 2080s, general population in all regions is expected to face 'high' risks, while those living in Southwest Ontario will experience 'very high' risks.

Extreme heat and high temperature associated with climate change are expected to have implications for the general population related to heightened exposure to daily high temperature that exceed 30°C. Those who belong to particular demographic groups deemed to have a higher vulnerability (e.g. low-income households, outdoor workers, seniors, those with chronic diseases) may be disproportionately impacted, with more cases of heat related illnesses and fatalities.

A previous study of four Canadian cities demonstrated that from 1954 to 2000, approximately 120 people died each year due to heat-related causes in Toronto (Pengelly et al., 2007). Extreme heat impacts will be further exacerbated in the absence of natural assets and green spaces (e.g. trees for shade) in urban areas of the province (Mohajerani et al., 2017). The PCCIA assessed impacts associated with the Urban Heat Island Effect, finding that Central and Southwest regions of the province, with the highest population densities (Stiebert Consulting, 2022) are more likely to be impacted than those in less densely populated regions (e.g. northern regions of the province) (Li et al., 2020).

Extreme precipitation is another climate variable that is driving risk for the general population, with vulnerable populations being disproportionately impacted, particularly in urban areas at greater risk of flooding (Hemmati et al., 2022). Vulnerability to extreme precipitation events can also stem from a lack of warning systems, stormwater management, and adequate infrastructure in neighbourhoods with a larger proportion of underserved communities. The resulting psychosocial and health effects of flooding can be long lasting and exacerbate social, economic, health, and other disparities, making it difficult to recover and build resilience (Glenn and Myre, 2022).

Impacts to the general population that relate to severe acute climate events, such as wildfire, are largely linked to community evacuation, food-, water- or vector-borne diseases, food or water shortages, exacerbation of cardiovascular and respiratory conditions, disruptions of health and emergency services, stress from community evacuations and population displacement and mental illness (Doyle et al., 2017).

The cascading effects of evacuation to health and well-being as well as the healthcare and social services systems are significant and require coordination between multiple agencies including Emergency Management Ontario, the Provincial Emergency Operations Centre, Local Health Integration Networks, municipal governments, and First Nations. In the Far North region in particular, fly-in communities are at greater risk if timely evacuation is not planned and prepared for, and operational limitations continue to be a high point of stress (Rall, 2020).

Unhoused Population

The impact assessment found that the unhoused population is affected by climate change in similar ways as the general population, but to a greater extent given the high potential that their living conditions are not protected or resistant weather and climate conditions (e.g. poorly equipped shelter, limited access to heating and cooling systems), creating greater levels of exposure. Extreme temperature (heat and cold) are the key climate variables driving future risk for this population category across Ontario.

Risk to the unhoused population is found to increase from a ‘high’ current risk score to a ‘very high’ risk score by the 2080s across all regions of Ontario. The southern regions of the province (Central Southwest and Eastern) are expected to see an increase in risk for the unhoused population by mid-century (2050s), reflecting increased exposure to extreme heat in the southern regions with greater population densities in urban areas.

The Southwest and Central regions of the province have greater unhoused population, particularly in urban centres (e.g. the Greater Toronto Area). Many of these residents are more likely to have pre-existing, untreated, or undiagnosed health conditions (Gomez, 2010). In addition, lack of secure tenure is also linked to lower access to crisis communications, making unhoused populations less likely to be forewarned about inclement weather or have access to information on emergency procedures and supports (Ramin & Svoboda, 2019; Gomez, 2010; Feng et al., 2021).

The risk results for the unhoused population in Ontario demonstrated the inherent vulnerability of this population. The intersectional approach applied to the assessment of this Area of Focus provides a clear picture of how additional health conditions within this population may further amplify climate vulnerability. For instance, in considering the risk scenario related to extreme precipitation, it was assumed that flash flooding would be localized within a particular geography. Due to the lack of permeable surfaces in some urbanized areas and presence of aging infrastructure, stormwater drainage may be overwhelmed (Kleerekoper et al., 2012). Recreational water or safe drinking water sources may be compromised due to run off from heavy rainfall events, creating limitations in access to potable water (Gomez, 2010). Unhoused populations who are exposed to these conditions are likely to experience increased mortality and morbidity, including the exacerbation of mental health issues and infectious diseases as a result of being forced to seek shelter in crowded facilities, and the stress accompanying the loss of personal belongings and displacement (Ramin & Svoboda, 2019; Pendrey et al., 2014).

Table 8.7: Risk Scores for Population Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Population	General Population	Central Region	**Medium**	**High**	**High**
Population	General Population	Eastern Region	**Medium**	**High**	**High**
Population	General Population	Far North Region	**Medium**	**Medium**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Population	General Population	Northeast Region	**Medium**	**High**	**High**
Population	General Population	Northwest Region	**Medium**	**High**	**High**
Population	General Population	Southwest Region	**Medium**	**High**	**Very High**
Population	Unhoused Population	Central Region	**High**	**Very High**	**Very High**
Population	Unhoused Population	Eastern Region	**High**	**Very High**	**Very High**
Population	Unhoused Population	Far North Region	**High**	**High**	**Very High**
Population	Unhoused Population	Northeast Region	**High**	**High**	**Very High**
Population	Unhoused Population	Northwest Region	**High**	**High**	**Very High**
Population	Unhoused Population	Southwest Region	**High**	**Very High**	**Very High**

Indirect Impacts

Ontario's general population may be indirectly impacted by climate change through macro-level shifts such as economic downturns or losses in major local employment sectors. This would have cascading impacts related to the number of people experiencing housing insecurity, and who would therefore be more vulnerable to being exposed to severe weather as a result of potentially being rendered homeless or finding accommodations in poorly equipped shelter, such as housing with inadequate heating or cooling systems (Falvo, 2020).

Climate change can also increase risks to mental health and well-being of Ontarians, with impacts being significant and long lasting. Mental health outcomes in relation to climate change can exacerbate existing conditions and introduce new illnesses, such as depression, post-traumatic stress, anxiety and grief. Mental health impacts have been found to be particularly pronounced in individuals who have experienced displacement, loss of housing and/or livelihood from climate-related impacts (e.g. flooding, wildfire) (Copes, 2017). General distress from climate change and related environmental degradation can also worsen existing or introduce new mental illnesses (e.g. ecoanxiety) (Hayes et al., 2022).

Infectious diseases as well as water- and food- borne illnesses are associated with a number of climate variables that impact air and water quality and create conditions for pathogens to spread, including extreme heat and extreme precipitation (Copes, 2017; Eyquem and Feltmate, 2022). Other indirect impacts of concern to the population include risk of injury or death from infrastructure damage, increase in insect and pest populations leading to potential exposure to new diseases and general discomfort outdoors, and quality of life and health impacts from increased exposure to solid waste and wastewater in the event of impacts to sanitation services (Eyquem and Feltmate, 2022).

Further analysis on the indirect and cross-sectoral impacts on human health, well-being and safety can be found in Section 10.4.

8.7.2 Health Care

Overview

The Health Care Level 1 category was designed to capture climate change impacts on the functioning and service delivery of health care services to Ontarians, including emergency services and hospital/clinic-based care. There is some disparity in the presence of and access to health care facilities across the province, particularly in growing communities and in less densely populated areas across northern Ontario. The types of care that are available and wait times to access urgent and emergent health care needs vary significantly across Ontario. In addition, access to timely and reliable health care is a key indicator of health and well-being, in particular for vulnerable populations who require more regular and consistent care.

In the context of climate change, impacts to service delivery arising from increased demand, limitations in access to ambulance and emergency services, as well as caregiver constraints and burnout are all potential factors that would impact the provision of healthcare during a climate emergency.

The risk scenario in Table 8.8 provides a description of the risk scenario considered for the under the Health Care Level 1 category. A summary of the risk profiles for health care across each region can be found in Table 8.9.

Table 8.8: Illustrative Risk Scenarios for the Health Care Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Health Care	Increased demand for health care services as a result of extreme climate related events (heat waves, extreme cold, extreme precipitation) result in longer wait times, caregiver/provider stress and potential burnout, leading to shortfalls in service provision.	**High**

Direct Impacts

The assessment of direct impacts to Ontario health care systems revealed that extreme climate related events (heat waves, extreme cold, extreme precipitation) are driving future risk. Increased demand for health care services as a result of acute climate events may result in longer wait times, caregiver/provider stress and potential burnout, and reduced quality of care and attentiveness, particularly to people with disabilities and with chronic illness. For instance, a study of Toronto neighbourhoods found that heat-related ambulance calls were 12.3% higher during extreme heat events than in the preceding or the following week (Graham et al., 2016). Health care employees at all levels are vulnerable to extreme weather conditions that could impact their ability to be available and overcome challenges related to increased service demands during emergency situations.

Risk to health care is found to maintain a ‘high’ score from the current timeframe to the 2080s, in Central and Eastern regions. In the Southwest region, the risk is found to increase to a ‘very high’ risk score by the 2080s. For the northern regions of the province (Northeast, Northwest and Far North), the current risk profile for health care is deemed to have ‘medium’ score and is anticipated to increase to ‘high’ in the 2050s and 2080s.

Winter precipitation, with rain and freezing rain falling during winter months may cause hazardous travel conditions and infrastructure damages, creating risk for a number of health care services, including for health care providers attempting to reach their place of work, emergency vehicles attempting to reach those in need, and potential for collisions and road accidents that create additional stress on the transportation and emergency services systems (Tsang and Scott, 2020). In this risk scenario, emergency and health care wait times would increase by as much as three times, with greater consequences in more densely populated and underserved communities (Coles et al., 2017; Tsang and Scott, 2020).

Table 8.9: Risk Scores for Health Care Level 1 Category

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	**Region**	**Climate Risk Scores**		
		Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Health Care	Central Region	**High**	**High**	**High**
Health Care	Eastern Region	**High**	**High**	**High**
Health Care	Far North Region	**Medium**	**High**	**High**
Health Care	Northeast Region	**Medium**	**High**	**High**
Health Care	Northwest Region	**Medium**	**High**	**High**
Health Care	Southwest Region	**High**	**High**	**Very High**

Indirect Impacts

There are several indirect impacts that can compound the identified direct risks or introduce additional climate-related pressures to health care services in Ontario. Infrastructure is a critical aspect of climate resilience for health care, as it is crucial for emergency services to be able to reach people in need or for them to be able to reach medical care. Climate impacts leading to power outages, road access disruptions, and damage to potable water systems can all have significant consequences for health that would result in greater numbers of people requiring emergency services care (Coles et al., 2017; Ramgopal et al., 2019; Tsang and Scott, 2020). As populations grow and population density increases over time, these impacts are likely to be further exacerbated.

In addition, impacts related to disruptions of supply chains and production systems for equipment, materials, medications, and supplies can be significant, as experienced throughout the COVID-19 pandemic. Impacts causing supply chain disruptions can have significant cascading impacts, particularly for quality of care and access to services which disproportionately impact people with disabilities or long-term conditions, as well as Indigenous Communities (Hahmann and Kumar, 2022).

8.7.3 Social Assistance and Public Administration

Overview

The Social Assistance and Public Administration Level 1 category is linked to, but distinct from the health care Level 1 category. While the health care category identifies impacts on the health care sector primarily in emergency situations, the Social Assistance and Public

Administration category considers both emergency as well as long term consequences of climate change on the population. This includes the need for ongoing, as well as acute situation supports, considering populations reliant on home care assistance, mental health supports, occupational therapy, family and child services, and employment services. These services are fundamental to health and well-being and are called into high demand as a result of both acute and chronic climate related events. The impacts on service providers and community-based organizations are considered under this category.

Direct Impacts

Similar to health care services, the assessment of social assistance and public administration services revealed that acute climate events (e.g. extreme temperatures and precipitation) are driving current and future risk. These types of events and conditions cause increased demands for services and for higher proportions of the population that are unable to access social supports. Impacts include increased demand for social worker assistance, emergency shelter space, and wellness check-ins on the most vulnerable in a community. Vulnerable groups include people with disabilities, seniors, and newcomers who may be experiencing communication barriers or lack of information on where to access services in a time of crisis.

Table 8.10 provides an example risk scenario for this Level 1 category. Notably, these are meant to be illustrative examples of the types of scenarios assessed and are non-exhaustive. A more detailed risk characterization and a description of risk drivers are provided in the section below.

Further details on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 8.11, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 8.10: Illustrative Risk Scenario for Social Assistance and Public Administration

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Social Assistance and Public Administration	Increased demand for social services as a result of extreme climate related events (heat waves, extreme cold, extreme precipitation) resulting in a reduction in availability of service providers and increased wait times in the system overall.	**Medium**

The risk profile for social assistance and public administration is found to increase from a current risk score of 'medium' to a 'high' risk score by the 2050s and remain there, in the

Southwest, Central, Northeast, Northwest, and Far North regions. For Eastern Ontario, risk is expected to increase further, to a ‘very high’ score by the 2080s.

An additional aspect of climate impacts for social assistance and public administration services relates to the increased demand for services during extreme climate related events. With a series of hot days, certain populations, particularly the most vulnerable, but also relatively healthy adults, could experience the physical and mental health strain of coping with extreme heat (Smoyer-Tomic et al., 2003; Paterson et al., 2014; Gough et al., 2016). Longer durations of heat waves would also have corresponding rates of increased mortality if wellness check-ins and home care visits are not possible due to the strain on the system and lack of resources, placing a sense of urgency in the system with respect to reaching community members who may be more isolated (Paterson et al., 2014).

Administrative as well as care workers involved in delivering social assistance are more likely to experience high stress and increased demand during prolonged extreme weather events, potentially leading to a reduction in availability of service providers and increased wait times in the system overall (Morss et al., 2011). Limitations in social assistance support for example through welfare programs including the Ontario Disability Support Program may result in reduced capacity for low-income residents to be able to afford shelter with adequate temperature controls, or to be able to afford the cost of regular use of heating and cooling. These impacts may lead to greater risk of temperature stress and mortality risk, which in turn impacts the demand for and availability of those tasked with providing care in emergency situations.

In a study on extreme heat impacts to workers in Ontario between 2004 and 2010, workers in government services accounted for nearly 15% of all heat illnesses, more than twice their share of all injuries. The ratio of heat illnesses to workers was the highest for government workers, including those providing essential services such as park maintenance, fighting forest fires, and sanitation (Fortune et al., 2013).

Table 8.11: Risk Scores for Social Assistance and Public Administrative Level 1 Category

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	**Region**	**Climate Risk Scores**		
		Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Social Assistance and Public Administration	Central Region	**Medium**	**High**	**High**
Social Assistance and Public Administration	Eastern Region	**Medium**	**High**	**Very High**
Social Assistance and Public Administration	Far North Region	**Medium**	**High**	**High**
Social Assistance and Public Administration	Northeast Region	**Medium**	**High**	**High**
Social Assistance and Public Administration	Northwest Region	**Medium**	**High**	**High**
Social Assistance and Public Administration	Southwest Region	**Medium**	**High**	**High**

Indirect Impacts

The longer-term implications of recurrent extreme events and greater climate variability can cause several indirect impacts. Indirect impacts of climate change on social assistance and public administrative services include impacts to overall mental health of service providers, greater demand for supports beyond the emergent care needs described above, and greater demand for long-term social supports (e.g. occupational therapy and physical care to manage the physical impacts of climate-related health outcomes).

Food insecurity is another indirect impact that would influence the need for social assistance, which may be impacted by changes in the Food and Agriculture sector, as well as overall increased cost of living as a result of impacts in the Business and Economy Area of Focus (Morss et al., 2011; Rosenthal et al., 2021).

8.7.4 Indigenous Communities

Overview

The Indigenous Communities Level 1 category includes all First Nation, Inuit and Metis living across Ontario. There is significant research to indicate that Indigenous Communities are disproportionately impacted by climate change, due to impacts that affect the natural environment, existing socio-economic disparities, remoteness of many community reserves, and lack of adequate infrastructure (water, wastewater, roads, etc.) (Centre for Indigenous Environmental Resources, 2006; Furgal and Seguin, 2006; Smith, 2016; Laduzinsky, 2019). As part of the People and Communities Area of Focus, it was important to therefore separate the assessment of climate risk and Adaptive Capacity between Indigenous and non-Indigenous Populations in Ontario, particularly in the context of supporting and respecting Indigenous rights to self-determination.

There are 215 Indigenous Reserves/Settlement/Villages in Ontario as identified by Crown-Indigenous Relations and Northern Affairs Canada, held by approximately 133 First Nations in Ontario. A large number of communities are located around or in close proximity to the Great Lakes throughout southern Ontario. Northern Ontario is home to 106 First Nations (Ontario Ministry of Municipal Affairs and Housing, 2019), many located adjacent to lakes and rivers. Over 30 First Nations communities in Ontario are located in remote areas of the Far North, accessible only by air or by winter roads (Hori et al., 2018a). There are several urban centers with considerable Indigenous Populations as well, particularly in Northern Ontario (Thunder Bay, Sudbury, Sault Ste. Marie, Timmins) and in Ottawa and Toronto. The total on-reserve population is estimated at approximately 57,700, noting that the statistics are dependent on self-reporting, and may represent an undercount (Stiebert Consulting, 2022).

Climate impacts on Indigenous Communities were assessed across several Level 2 categories, including, 1) Population, 2) Health Care, 3) Cultural Services and 4) Social Assistance. In addition, an assessment of the other Areas of Focus, 5) Infrastructure, 6) Food and Agriculture, 7) Business and Economy, and 8) Natural Environment.

The direct and indirect impacts of climate change on Indigenous Communities in Ontario are far-reaching and complex, from increased populations with a need for relocation or evacuation during extreme weather events, to disruptions in cultural and community land-based practices, and reductions in access to health care and social services during extreme events.

In comparison to the assessment of similar non-Indigenous sub-categories, the assessment of this Level 1 categories considers the additional layers of vulnerability and potential for increased risk for Indigenous Communities.

Direct Impacts

All of the aforementioned events, conditions and impacts to health and well-being are applicable to the Indigenous Level 2 categories, albeit in more acute ways given existing constraints in service provision and vulnerability. Climate change impacts on Indigenous Communities were assessed, with attention to how changes in magnitude and frequency of climate variables could lead to impacts on each Level 2 category. Each Level 2 category was evaluated under current and future timeframes, as described in the following sections.

Example risk scenarios are available in Table 8.12 for a fuller picture of the risk scenarios considered for the Indigenous Communities Level 1 category. Table 8.13 summarizes the risk profiles for each Level 2 category and region, operating under a high emissions scenario (RCP8.5).

Table 8.12: Illustrative Risk Scenarios for Indigenous Communities Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Indigenous Population	Extreme heat and cold events associated with mortality and morbidity particularly for vulnerable populations. Extreme precipitation (rainfall) and winter precipitation result in shelter damage and loss of property, prompting the need for evacuation or relocation.	**High**
Indigenous Health Care	Increased demand for health care services as a result of extreme climate related events (heat waves, extreme cold, extreme precipitation) result in longer wait times, caregiver/provider stress and potential burnout, leading to shortfalls in service provision and inaccessibility to services for remote communities.	**High**
Indigenous Social Assistance	Increased demand for social services as a result of extreme climate related events (heat waves, extreme cold, extreme precipitation) resulting in longer wait times, caregiver/provider stress and potential burnout, leading to shortfalls in service provision and inaccessibility to services for remote communities.	**High**
Indigenous Cultural Services	Extreme climate related events (heat waves, extreme cold, extreme precipitation) are associated with loss of resources for cultural services that result in decline in harvest, medicines and hunting.	**High**

Indigenous Population

Changing climate conditions present a range of direct and indirect health and well-being impacts on Indigenous Populations, threating their personal safety, water and food security, mental well-being, knowledge systems, ways of life and cultural cohesion. The impact assessment found that extreme heat and cold events, extreme precipitation (and associated flooding), and wildfire climate variables are driving the highest risks for Indigenous Populations. Specific vulnerability considerations for Indigenous Populations were applied to the assessment of climate impacts, including socio-economic disparities, social gradients in health, close relationships to sometimes rapidly changing environments, and other systemic barriers. Barriers to building resiliency to a changing climate and capacity constraints, as a result of colonial legacies are also important when considering climate impacts on Indigenous Populations.

Under current conditions, the risk profile for Indigenous population was determined to be 'high' for Southwest, Eastern and Northeast regions, and 'medium' for Central, Northwest and the Far North. The difference in current risk levels reflects differences in current climate hazard exposure (e.g. extreme heat and wildfire) and the distribution of Indigenous Communities. Risk to Indigenous Populations is anticipated to increase across all regions by mid-century (2050s), with Southwest and Eastern Ontario experiencing 'very high' risk (reflective of extreme heat related risks). Risk profiles increase to "very high' by the 2080s, across all regions of the province.

The direct health and well-being impacts to Indigenous Communities as a result of climate change have been well documented, including in a recent study from Health Canada which identified the exacerbation of existing health and socio-economic inequalities; air quality health impacts, including respiratory and cardiovascular diseases; mental health impacts including stress, anxiety, and post-traumatic stress disorder; increased injuries and deaths from extreme weather related accidents; and evacuation or displacement from traditional territories, disrupting lives, creating financial hardship and affecting mental well-being (National Collaborating Centre for Indigenous Health, 2022).

Extreme temperature (e.g. extreme heat and cold) is currently driving the greatest risks to Indigenous Populations. Extreme heat and cold events are associated with higher mortality and morbidity rates, particularly for vulnerable populations which includes Indigenous Communities. For instance, Indigenous urban residents are more than twice as likely to have experienced hidden homelessness as their non-Indigenous counterparts, increasing exposure to extreme temperature (Advocacy Centre for Tenants in Ontario, 2017).

Flooding conditions from extreme precipitation events is greater for Indigenous Communities compared to non-Indigenous Populations. Flooding is already creating significant impacts for Indigenous Communities (e.g. property damage and evacuation), with an estimated 27% of Indigenous residents in Ontario facing heightened exposure to residential flood risk, compared to 16% of non-Indigenous residents (Chakraborty et al., 2021).

Wildfire risk to Indigenous Populations creates deep emotional and psychological impacts for communities, not only from the loss of property but also from damage to sacred lands and loss of cultural heritage (Centre for Indigenous Environmental Resources, 2006; Furgal and Seguin, 2006; Smith, 2016; Laduzinsky, 2019; Graham, 2020; Belanger, 2021). Wildfire also has cascading mental health impacts, as events may leave residents feeling uneasy about future wildfire risk (Furgal and Seguin, 2006). Indigenous Communities located in areas of high wildfire risk (e.g. northern regions) may experience more frequent community evacuations under a changing climate.

Indigenous Health Care

Increased demand for health care services as a result of extreme climate related events (heat waves, extreme cold, extreme precipitation) may result in longer wait times, caregiver/provider stress and potential burnout, leading to shortfalls in service provision and inaccessibility to services. The implications of limited access to remote Indigenous Communities in northern regions (Northeast, Northwest and the Far North) may result in long delays of emergency service delivery and could have severe consequences for health in emergency situations. Impacts to critical transportation and communication infrastructure may also impact access to food, medication supplies, and other daily necessities. Extreme weather events may lead to restricted or delayed travel for health and emergency services and compromise patient safety in northern communities (National Collaborating Centre for Indigenous Health, 2022).

Risks to Indigenous health care are assessed at a ‘high’ score under current conditions, in all regions except the Far North. By the end of century (2080s), this risk profile is expected to increase to ‘very high’ across all provincial regions. Risk is anticipated to increase at an accelerated rate in the Southwest region as a result of extreme heat and high temperature exposure.

Indigenous Social Assistance

The direct impacts to Indigenous social services including employment, family and community services, education, housing, and supports for people with disabilities, are similar to those described for the health care sector. These include increased needs for social services as a result of extreme climate related events (heat waves, extreme cold, extreme precipitation) resulting in longer wait times, caregiver/provider stress and potential burnout, shortfalls in service provision and inaccessibility to services for remote communities particularly.

Climate impacts are expected to be felt differently across segments of the Indigenous population, with women, children, Elders, people with disabilities, and those living off-reserve experiencing a range of consequences that may be short or long term in duration (Warren et al., 2021). Existing social services to Indigenous Communities are already limited by availability of trained professionals, with knowledge of culturally appropriate practices (e.g. integrating Indigenous ways of being into their work) and understanding of the disproportionate socio-economic inequities and harms from colonization (Canadian Association of Social Workers, 2020).

Risk profiles for Indigenous social services are currently deemed as 'medium' across all regions of the province. However, future risk is anticipated to increase considerably to 'very high' by mid-century for southern regions of Ontario (Southwest, Central and Eastern). Northern regions (Northeast, Northwest) also see an increase in risk, with scores 'very high' by the 2080s. The Far North also is expected to experience 'high' risk under this sector for both future time periods (2050s and 2080s).

Indigenous Cultural Services

Indigenous culture, language, and livelihoods are tightly intertwined with the land, with deep investment in the well-being of all aspects of the natural world (NCCIH, 2022). Climate change has resulted in significant losses for Indigenous Peoples, including cultural practices and heritage, traditions and social fabric, as well as physical and mental health, identity and dignity, among others (Pearson et al., 2021).

Indigenous cultural services are currently assessed as 'high' risk across all provincial regions. Climate-related impacts are anticipated to compound risks to this category, with southern regions of the province (Southwest, Central, Eastern) experiencing an accelerated increase in risk by mid-century (2050s), and the northern regions (Northeast, Northwest and Far North) experiencing an increase by end of century (2080s).

This assessment found that extreme climate-related events (heat waves, extreme cold, extreme precipitation) are associated with loss of resources for cultural services, resulting in declining harvests, medicines, and hunting activities. Impacts from climate change have also resulted in decreased opportunities for transmission of Indigenous knowledges and land skills, particularly among youth, affecting sense of identity, mental well-being, and cultures (National Collaborating Centre for Indigenous Health, 2022). The risks extend to how Traditional Ecological Knowledge (TEK) is developed and shared, as climate change impacts have shifted the ways that communities interact with nature and create new concerns with the safety of past practices given the changing ecological conditions seen across the province (e.g. increased unpredictability of ice conditions for winter travel and hunting) (Charles-Norris, 2020). However, TEK remains one of the most crucial elements in understanding climate change impacts and advancing adaptation mechanisms for Indigenous Communities, further highlighting its value and cause for critical concern (Thomas et al., 2018).

Another key impact to Indigenous culture is the loss of archaeological and built heritage as a result of major climate events (e.g. wildfire, flooding etc.). Climate-related impacts, coupled with human activity, such as extractive industries and development can have devastating impacts to Indigenous culture and well-being (Pearson et al., 2021). Increasing occurrences of extreme weather events such as flooding and tornados, combined with gradual climate impacts such as erosion and rising water levels coastal sites present risks to these irreplaceable sites and non-renewable resources (Pearson et al., 2021; Sesana et al., 2021). These losses are difficult to quantify in the context of Indigenous knowledge and cultural values, with impacts cascading to the health and well-being of Indigenous People and communities in Ontario (CAA, 2022).

Indigenous Infrastructure

Indigenous Communities across Ontario face varying forms and degrees of infrastructure limitations, with historic underdevelopment. Infrastructure in Indigenous Communities is often multifunctional and integral to sustaining healthy community life, providing a range of services. The infrastructure gap between Indigenous and non-Indigenous communities across Canada is significant, with an estimated $30 billion in investment needed to close gap (Baird and Podlasly, 2020). These gaps include critical infrastructure, such as water, wastewater, waste management, roads, and stormwater management systems. As of October 2022, there are 22 boil water advisories in 19 communities across Ontario, the highest number in Canada (Indigenous Services Canada, October 17, 2022). Several First Nations have taken leadership to undertake infrastructure projects and programs, supporting self-determination and growing the capacity on Indigenous reserves (Indigenous Services Canada, 2022).

In addition to the deficits in critical infrastructure, climate change presents an additional dimension of capacity and servicing challenges. These include similar impacts facing off-reserve infrastructure, including risks from flooding causing damage to infrastructure assets, reduced efficiency during extreme heat or cold events, failure or impassability of transportation routes, and damage to buildings (see Section 6.0).

Damage to physical infrastructure in Indigenous Communities across the province can be impacted by several climate variables. This Level 2 category has been designed to encompass all relevant systems covered under the Infrastructure Area of Focus that Indigenous Communities rely upon. This includes but is not limited to buildings, waste management, stormwater management, utilities, and transportation infrastructure. Winter roads are an example of critical infrastructure that northern Indigenous Communities rely on and are particularly vulnerable to climate change. Warming winters and temperature variability are shortening the winter road season, resulting in construction and maintenance challenges and safety concerns related to road stability. Increasing unpredictability of winter road conditions is impacting the supply of critical supplies and emergency services for Indigenous Communities in northern Ontario. (Hori et al., 2018a; 2018b). The potential for increased exposure to water-borne illnesses as a result of changing temperatures and extreme heat is also a concern with inadequate water treatment infrastructure in place.

Risk profiles were derived from the Infrastructure Area of Focus and scores were increased for this Level 2 category, to reflect the increased susceptibility and disproportionate impacts on Indigenous community infrastructure. Levels of risk to Indigenous infrastructure are anticipated to increase from 'high' to 'very high' by mid-century across all provincial regions.

Indigenous Food and Agriculture

Many Indigenous Communities rely on the land and water for sustenance and food security. Under a changing climate, traditional food sources are being threatened as the distribution and abundance of species changes. Indigenous Communities who rely on harvesting traditional foods as their main food source will be greatly impacted, as access to certain plant, fish (e.g. walleye and brook trout) and mammal species (e.g. moose) from their traditional territories may be limited or entirely lost in some areas. These expected ecological changes compound risks to food security, resulting in declines to diet quality and nutrient access and accompanying impacts to mental health, cultural well-being and social cohesion (Harper and Schnitter, 2022). In addition, safety associated with winter hunting and fishing is increasingly compromised by thin ice during warmer winter weather, further exacerbating climate risks to indigenous food security (Hori et al., 2018a; 2018b).

Under the quantitative assessment of this Level 2 category, only Level 1 and 2 categories covered under the Food and Agriculture Area of Focus that Indigenous Communities rely upon were assessed (note that this Area of Focus does not includes hunting and gathering practices). However, climate-related impacts to primary food production can have cascading impacts for Indigenous Communities with pre-existing food security and access challenges (see Section 10.1 for further details) but is not included in the quantitative risk scoring of this Level 2 category (Harper and Schnitter, 2022).

With this in mind, the risk scenarios and profiles for this Level 2 category were derived from the Food and Agriculture Area of Focus but remain in line with the calculated risk scores under this Area of Focus.

Indigenous Business and Economy

As explored throughout Section 9.0, changes in frequency and magnitude of climate variables can cause several impacts and disruptions to business and economies across the province. This Level 2 category encompasses all relevant Level 1 and 2 categories under the Business and Economy Area of Focus that could impact Indigenous Communities directly. Due to the dependence on natural resource sectors under this Area of Focus for Indigenous livelihoods, current and future risk profiles were extracted and increased by one level from Business and Economy for this Level 2 category.

Indigenous People in Canada have tended to pursue a strategy of economic development with social entrepreneurship at its core. Examples of Indigenous socio-economic objectives include (i) greater control of activities on their traditional lands, (ii) self-determination and an end to dependency through economic self-sufficiency, (iii) the preservation and strengthening of traditional values and their application in economic development and business activities, and (iv) improved socioeconomic circumstance for individuals, families, and communities through social entrepreneurship (Anderson et al., 2006).

Ensuring Indigenous People are able to pursue economic development is inextricably tied to ensuring the land on which they live is not ravaged by the effects of climate change. From an Indigenous perspective, land is important for several reasons. First, traditional lands are the 'place' of the nation and are inseparable from the people, their culture, and their identity as a nation. Additionally, land and resources are the foundation upon which Indigenous Communities intend to rebuild the economies of their nations and so improve the socio-economic circumstance of their people (Anderson et al., 2006; Ford et al., 2020).

Indigenous Natural Environment

Natural systems are tightly linked to Indigenous culture, language, and livelihoods. Under the Natural Environment Area of Focus, several risk interactions found that the distribution and abundance of certain species will vary under a changing climate. Indigenous Communities will be greatly impacted by these changes, as access to certain plant, fish (e.g. walleye and brook trout) and mammal species (e.g. moose) from their traditional territories may be limited or entirely lost in some areas.

Overall research points to the devastating effects of forest fires, droughts, and permafrost, lake and sea-ice melt on the lives of Indigenous Peoples and communities across Ontario. These experiences support findings regarding the disproportionate impacts of climate change on Indigenous Peoples, including losses of biodiversity predicted to severely disrupt the traditional hunting, fishing and gathering practices (Indigenous Circle of Experts, 2018).

Water is also of utmost importance to Indigenous Populations, not only for physical need but also spiritual. Within many traditional belief systems among Indigenous Communities, water and the subsequent aspects are of paramount importance. Research from the Ontario Indigenous Women's Water Commission highlights that water in Ontario is threatened by hydro-fracking, deforestation around watershed areas, the emission of pollutants into the air, and the shipment of toxins across the Great Lakes (Indigenous Circle of Experts, 2018). Underpinning their work is the philosophy of honouring obligations to the seven generations to come, honouring teachings of women and Elders, and ensuring that all the information provided is respectful of Indigenous Knowledge. Now, these features are changing, becoming less predictable, and resources are at greater risk today from changing conditions, despite modern weather prediction methods, improved communication, and enhanced technologies (Mustonen et al, 2022).

Climatic changes compound risks to food security, mental health, cultural well-being, and social cohesion for Indigenous Communities. Risk scenarios and profiles, reflecting direct impacts, were extracted from the Natural Environment Area of Focus, with scores increased by one level to reflect deep alignment of Indigenous Peoples with the natural world.

Table 8.13: Risk Scores for Indigenous Communities Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Indigenous Communities	Indigenous Population	Central Region	Medium	High	Very High
Indigenous Communities	Indigenous Population	Eastern Region	High	Very High	Very High
Indigenous Communities	Indigenous Population	Far North Region	Medium	High	Very High
Indigenous Communities	Indigenous Population	Northeast Region	High	High	Very High
Indigenous Communities	Indigenous Population	Northwest Region	Medium	High	Very High
Indigenous Communities	Indigenous Population	Southwest Region	High	Very High	Very High

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Indigenous Communities	Indigenous Health Care	Central Region	High	High	Very High
Indigenous Communities	Indigenous Health Care	Eastern Region	High	High	Very High
Indigenous Communities	Indigenous Health Care	Far North Region	Medium	High	Very High
Indigenous Communities	Indigenous Health Care	Northeast Region	High	High	Very High
Indigenous Communities	Indigenous Health Care	Northwest Region	High	High	Very High
Indigenous Communities	Indigenous Health Care	Southwest Region	High	Very High	Very High
Indigenous Communities	Indigenous Social Assistance	Central Region	Medium	Very High	Very High
Indigenous Communities	Indigenous Social Assistance	Eastern Region	Medium	Very High	Very High
Indigenous Communities	Indigenous Social Assistance	Far North Region	Medium	High	High
Indigenous Communities	Indigenous Social Assistance	Northeast Region	Medium	High	Very High
Indigenous Communities	Indigenous Social Assistance	Northwest Region	Medium	High	Very High
Indigenous Communities	Indigenous Social Assistance	Southwest Region	Medium	Very High	Very High
Indigenous Communities	Indigenous Cultural Services	Central Region	High	Very High	Very High
Indigenous Communities	Indigenous Cultural Services	Eastern Region	High	Very High	Very High
Indigenous Communities	Indigenous Cultural Services	Far North Region	High	High	Very High
Indigenous Communities	Indigenous Cultural Services	Northeast Region	High	High	Very High
Indigenous Communities	Indigenous Cultural Services	Northwest Region	High	High	Very High

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Indigenous Communities	Indigenous Cultural Services	Southwest Region	High	Very High	Very High

Indirect Impacts

The indirect impacts to Indigenous Peoples across Ontario stem from a number of factors, including existing infrastructure deficits and socio-economic inequality that is further exacerbated by climate related risk. The inadequacy of current infrastructure is systemic, including drinking and boil water advisories, limited transportation infrastructure, and homes and dwellings that are three times more likely to need repairs than non-Indigenous communities (Chakraborty, et al., 2021; Ness et al., 2021). The disproportionate and significant impacts that Indigenous Communities face include financial, psychological, and social burdens associated with flooding and displacement (Chakraborty et al., 2021). Indigenous Communities have worked to adapt their activities and practices in response to changing climate conditions, and exhibit resiliency in face of structural and systemic inequities (Laduzinsky, 2019).

Additional indirect impacts can have long-term consequences for health, well-being, and resilience of Indigenous Communities including food and water insecurity due to decreased access to and quality of land, waters, and natural resources; spread of infectious diseases and water-borne illnesses (National Collaborating Centre for Indigenous Health, 2022). For northern Ontario communities in particular, transportation access is critical to the provision of services, food, products, and maintenance of livelihoods, and any restrictions or damage to road and rail networks can have significant implications (Belanger, 2021).

8.8 Climate Change Opportunities

Opportunities resulting from direct physical climate change impacts on people and communities are limited. As demonstrated throughout this assessment, changing climate conditions across different regions of the province can impact Ontarians and their communities in a variety of ways. Overall, the impact assessment found the risks climate change poses to the Level 1 and 2 categories assessed under this Area of Focus, significantly outweigh any potential positive impacts. In other words, climate interactions with increasing risk scores (e.g. extreme heat) outweighed any interaction that exhibited stable or even slightly declining risk scores (e.g. extreme cold) for all Level 1 and 2 categories under this Area of Focus

Specific interactions related to low temperatures (Extreme Cold Days) and general population indicate that in the long-term (2080s), Extreme Cold Days will decrease and in turn, population risks related to extreme cold exposure decline. With that said, the assessment finds that increasing temperatures and extreme heat exposure will lead to increased mortality and morbidity for general, unhoused, and Indigenous Populations across the province.

8.9 Adaptive Capacity

8.9.1 Adaptive Capacity Summary

Adaptive Capacity in the context of the People and Communities Area of Focus refers to the ways in which individuals and communities are able to address and withstand the impacts of climate change, both acute and chronic. As part of this assessment, consideration was given to capacity across a range of levels, taking an intersectional approach to considering how climate change plays out in the daily lives of Ontarians. This included housing affordability, accessibility for people with disabilities, communications, and other technologies to manage and anticipate impacts and protect the most vulnerable, and governance potential to institute actions needed to address climate risks.

The five key indicators of Technology, Equity, Resource Availability, Governance, and Sector Complexity were appraised with the regional demographic and socio-economic diversity in mind, as well as the unique context that applies to Indigenous Communities. In addition, it is important to recognize that the general population is highly reliant on the provision of services and resources from the government, and that income is a key indicator of ability to adapt, independent of government support.

Fundamentally, the People and Communities Area of Focus assessment provides a more generalized overview of the dynamics that may play out in unique and specific ways in different communities. This approach highlights the need for evidence-based, collaborative planning around equity-based adaptation, that centers those most vulnerable and therefore most impacted.

Furthermore, it is important that the voices of Indigenous knowledge-holders are centered in the effort to develop meaningful and effective climate adaptation programs for all Ontarians, and not only when focused on Indigenous Communities. This is particularly important given the need to apply an environmental and social justice-oriented approach to climate adaptation (Thomas et al., 2018).

The results from the Adaptive Capacity analysis are provided in Table 8.14. A regional analysis of Adaptive Capacity can be found in Appendix 11.

There are both specific and general elements to improving Adaptive Capacity that would have an immediate and lasting effect on protecting human health and well-being. Several capacity-building measures can help to address not only climate impacts to people and communities, but also strengthen the determinants of good health across priority populations. It is important the capacity-building efforts are inclusive of those who are experiencing climate impacts on health and safety disproportionately. As the understanding of health vulnerability under a changing climate evolves, the intersections of health inequities across Ontario are crucial to integrate into adaptation and response planning. For example, investments in housing and health care are important to prioritize as climate change is anticipated to worsen existing conditions and inequities.

Table 8.14: Level 1 Adaptive Capacity Ratings for the People and Communities Area of Focus[29]

Level 1 Category	Technology	Equity	Resource Availability	Governance	Sector Complexity	Level 1 Adaptive Capacity Rating
Population	Medium	Low	Low	Low	Medium	**Medium**
Health Care	Medium	Low	Low	Medium	Low	**Medium**
Social Assistance and Public Administration	Low	Low	Low	Low	Medium	**Low**
Indigenous Communities	Low	Low	Low	Low	Medium	**Low**

8.9.2 Technology

Technology was given a 'medium' rating for the population Level 1 category. Opportunities related to technology and capacity building for the general population overlap with governance. Examples include:

- Access to and availability of communications and warning systems
- Artificial intelligence to support modelling and identification of risk and vulnerability,
- Access to affordable residential heating and cooling systems

[29]Note these scores do not consider geographic location within the province. Please see Appendix 11 for regional Adaptive Capacity ratings.

- Green infrastructure systems to support mitigation of Heat Island Effects and provide comfortable outdoor spaces in hotter and wetter weather

Similarly, Technology was scored at a 'medium' level for the Health Care Level 1 category. An example of capacity under this category is advancements in telemedicine and increased accessibility to services to support longer-term management of the mental and physical health impacts associated with climate change.

With respect to social assistance and public administration Level 1 category, Technology was rated as 'low'. Digital equity has been identified as a key gap and area for improvement in order to support greater access to social services for marginalized communities. The methods and technology to support social assistance expansion and equity exist and can be further refined through enhanced planning and implementation. Technology was also rated as 'low' for the Indigenous Communities Level 1 category. Improving infrastructure and monitoring systems, particularly for water, wastewater, and road access improves ability to adapt to changing conditions and quality of life. Communications infrastructure enhances resiliency during emergency scenarios and supports social assistance and health care needs remotely.

8.9.3 Equity

Equity was rated as 'low' for the population Level 1 category and remains a critical concern for climate change adaptation planning, particularly with rapid urbanization. Over 85% of Ontario's population lives in an urban context. The disparities of climate change impacts that exist in cities today disproportionately affect Indigenous Peoples, people of colour, and low-income residents, particularly those with disabilities, youth, and older adults, who lack access to green space, cooling shelters, and resources to respond during and after extreme weather events. Ontario also has one of Canada's largest populations of migrant workers, who are particularly vulnerable to heat stress and infectious disease due to the nature of their work and precarity of employment. There is also a significant population of nearly 600,000 non-permanent residents overall (students, foreign workers, etc.) who lack capacity to respond to climate impacts and would benefit from additional supports to successfully adapt to climate-related risks. Additionally, projections indicate future instability of Ontario's housing stock, with the number of unhoused residents in Ontario increasing, along with their vulnerability to climate change due to lack of supports.

Equity was also scored at a 'low' level for health care, and social services and public administration Level 1 categories. A chronic lack of quality and availability in long-term care facilities indicates inadequate levels of capacity to build resilience and be better equipped to respond to the associated impacts. Some public health units, research institutions, and government are investing in planning and research, but overall funding and supports for vulnerable communities and further research to support climate vulnerability assessments for at-risk populations in Ontario appear to be limited.

For the Indigenous Communities Level 1 category, Equity was also scored as 'low' and is closely linked to Resources Availability, which received the same score. This rating was assigned due to the understanding that Adaptive Capacity is a significant challenge for the majority of Indigenous Communities which are deeply underfunded and where risks to population well-being from climate change are compounded due to existing socio-economic conditions. Indigenous Communities continue to have higher rates of unemployment, lower infrastructure quality, limited access to social supports, poorer health outcomes, and higher rates of exposure to environmental pollution, indicating severe equity challenges.

8.9.4 Resource Availability

Resource Availability was rated to be 'low' for the population Level 1 category, influenced by the evidence of growing social inequality fueled by education cuts, lack of healthcare equity (Xi et al., 2005), employment disparities, and a general uneven distribution of resources to support population health and well-being. Current wait times for subsidized housing in Ontario are as long as 7-10 years in larger municipalities, with the situation forecasted to worsen (Gibson, 2021).

While funding and data resources for climate change adaptation planning have been made broadly available at the municipal level through Provincial and Federal programs, funding for implementation can be a key constraint particularly in smaller communities and more remote areas of the province. At a granular level, the uneven distribution of wealth and income results in differential levels of access to the resources that can support Adaptive Capacity; thus, even when the technology, housing, food stores, relocation support, are generally available, they are not equitably shared, and more vulnerable segments of the population are less likely to be able to access them (Thomas et al., 2018). A study of health impacts from extreme heat in Toronto found that air conditioning access is directly correlated with income level, with higher annual income households over $80,000 being 25% more likely to have air conditioning compared to lower annual income households below $20,000 (Thomas et al., 2018). However, in-home air cooling is not a definite guarantee of indoor comfort during extreme heat events, and even those with residential air conditioning reported heat-related discomfort. The cost of energy to maintain air conditioning creates an additional barrier for low-income households, as well as other aspects such as the level of shading and tree canopy in low-income neighbourhoods and structure orientation to support passive cooling (Thomas et al., 2018).

Adaptive housing, modular housing, and sustainable construction methods to support increased diversity of housing stock, climate resilience, and accessibility for affordable options, have been proven in North America, and in Ontario specifically. Improvements to the supply of housing stock and adequate, safe, accessible shelters should remain a critical priority. As demonstrated within this assessment, unhoused populations are highly vulnerable to climate change, and do not have the capacity to cope with extreme weather or even moderate changes in temperature which can cause heat/cold stress. While many municipalities have undertaken housing strategies, funding for social housing remains low and wait lists for supportive and social housing continue to grow across the province.

With respect to health care and social services and public administration Level 1 categories, Resource Availability was also rated low, as planning and funding for the health care sector in Ontario has experienced significant instability, with funding cuts and a projected deficit that does not meet the needs of Ontario's growing population.

For many of the reasons noted above, Indigenous Communities was also assigned a 'low' rating for Resource Availability. In addition, lack of dedicated long-term funding for mental health services are additional complicating factors that further constrain the provision of health care and social service supports in Indigenous Communities (National Collaborating Centre for Indigenous Health, 2022).

8.9.5 Governance

Governance was rated as 'low' for the population Level 1 category. Public health and planning departments across Ontario municipalities are integrating a climate change lens to mitigate climate risk, however, political will to take action is not consistent across Ontario. Attention should be given to deeper systemic inequities around environmental racism, ableism, and income inequality that are linked to and exacerbate climate-related risks.

There are broad municipal coalition networks and spaces that enable knowledge transfer and training to advance climate action. Further investment in these networks can support shared capacity across regions and create resources that help to balance out the disparities in funding and access across regions.

Emergency response and institutional capacity to support unhoused populations in dealing with the impacts of climate change vary across the province, based on regional distributions of unhoused populations, local political conditions, and availability of resources. Overall, unhoused populations are particularly vulnerable to funding cuts and lack of economic stability, which continues to be a critical challenge in Ontario.

Governance for health care was scored as 'medium', given the strong academic, practitioner, not for profit, and research knowledge base to support climate change adaptation. For example, several Public Health Units have undertaken regional and local assessments of climate change vulnerability that include consideration of health equity provide a foundation for stronger and more widespread adaptation action (e.g. Peel Region, London Middlesex, Simcoe Muskoka and Grey-Bruce). Additional toolkits have been developed are established forums for discussion, networking, knowledge sharing, and capacity building.

Governance was scored as 'low' for social assistance and public administration. Poverty reduction, social inclusion and human rights are key areas that need to be improved upon to build capacity in this area. Approximately eight percent of Ontarians under the age of 65 rely on social assistance for their primary source of income, either through Ontario Works or the Ontario Disability Support Benefit (Maytree, 2022). Deep barriers exist to accessing needed services due to complexities in navigating different levels of social assistance, as well as lack of supports for single people and people with disabilities.

8.9.6 Sector Complexity

Sector complexity was rated as 'low' for the population Level 1 category, as planning for climate adaptation that directly impacts health and well-being of populations, entails a fair degree of complexity, with the requisite engagement of audiences and stakeholders. Capacity building is supported at the municipal level and is critical for building community-based response plans and undertaking meaningful engagement with vulnerable populations to inform adaptation strategies. The knowledge of how to conduct this engagement and create meaningful strategies exists and has been documented in the literature (Bednar et al., 2018; Eyquem and Feltmate, 2022).

Complexity also arises at the intersection of governance, resources, equity, and technology, such as in planning for long term adaptation responses. These include developing infrastructure to support timely evacuation in the event of wildfire or flooding, and in some cases relocation for communities that are in physically flood prone areas, such as in the case of Kashechewan First Nation in northern Ontario (CBC, 2022).

Complexity was rated 'low' for health care, recognizing the wide variability in conditions facing the LHIN units across the province, disparities in funding, and specific political and socio-economic conditions that impact how health care planning is undertaken. In contrast, social assistance and public administration received a 'medium' Complexity rating, considering how the social assistance sector is well connected with policy think tanks, academia, and practitioner knowledge. Sector complexity also stems from the wide range of needs of people who require social assistance, and the growing gap in funding.

For the Indigenous Communities Level 1 category, Complexity was scored as 'medium'**.** Climate change adaptation planning must be undertaken by Indigenous Peoples in an autonomous way, guided by local and traditional knowledge and community needs. There is a range of variability in institutional capacity to support implementation of adaptation plans and community-based engagement across Indigenous Communities in Ontario. However, there is shared institutional capacity in the form of the Indigenous Climate Hub and federally funded programs to support climate change adaptation across Indigenous Communities. There is also a deep commitment to climate change adaptation in Indigenous Communities that builds on traditional knowledge systems and practices.

8.10 Climate Adaptation Priorities

Results from the PCCIA can help to shed light on current and emerging adaptation priorities for the province, based on the anticipated magnitude of risk, and associated capacity levels to respond and cope with climate change impacts. As described in Section 2.4.5, an adaptation priority is defined as any Level 1 or 2 category in a given region that has an Adaptive Capacity of 'medium' or lower and a risk score of 'high' or greater (see Appendix 12 for combined Level 1 and regional Adaptive Capacity ratings)

As described in Section 8.9, the Population and Heath Care Level 1 categories included under this Area of Focus have a 'medium' Adaptive Capacity, and Social Assistance and Public Administration and Indigenous Level 2 categories have a 'low' Adaptive Capacity rating. When combining this with the regional Adaptive Capacity ratings, only Health Care in Southwest and Eastern regions are found to have a capacity rating greater than 'medium' (see Appendix 12). This section provides further detail on current and emerging adaptation priorities for the People and Communities Area of Focus, considering existing levels of capacity and current and future risk scores.

Current Adaptation Priorities

There were a number of priorities that emerged for the current timeframe with respect to Level 1 and 2 categories that are deemed to be 'high risk', with a corresponding 'lower' or 'medium' level of Adaptive Capacity. A summary of current adaptation priorities is provided in Table 8.15.

The first of these is health care, particularly in the southern regions (Central, Southwest and Eastern), where the population is growing at high rates. In the current timeframe, the health care risk in southern regions is high compared to more northern regions, largely due to the relative population density within this region and frequency of severe weather events and conditions including extreme heat and flooding, leading to higher rates of consequence and likelihood scores. The corresponding level of Adaptive Capacity was assessed as 'medium', given the clear potential to directly address population risks through improved funding and resources for emergency services and expansion of overall services, including mental health.

As noted, unhoused populations represent one of the most climate vulnerable groups in the province, with high-risk exposure highlighted in every region. Capacity limitations are attributed to the lack of significant action on housing programs from a governance and resource perspective, and the rising housing insecurity across the province.

Indigenous Communities were assessed to have a number of high risks across Level 2 categories, including cultural services, and health care. Adaptive Capacity across all categories was assessed to be relatively low, given the lack of funding and resources, existing environmental injustices, and lack of adequate existing infrastructure to combat the impacts of climate change. The Adaptive Capacity of Indigenous Communities, particularly in northern regions, is hindered by remote geographic conditions, food insecurity, and limited financial and technical resources (Human Rights Watch, 2020).

Table 8.15: Current Adaptation Priorities for People and Communities

Current Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[30]
Unhoused Population	Central, Far North, Northeast, Northwest	**High**	**Lower**
	Eastern, Southwest,	**High**	**Medium**
Health Care	Central	**High**	**Medium**
Indigenous Population	Northeast	**High**	**Lower**
	Eastern, Southwest	**High**	**Medium**
Indigenous Health Care	Central, Northeast, Northwest	**High**	**Lower**
	Eastern, Southwest	**High**	**Medium**
Indigenous Cultural Services	Central, Northeast, Northwest, Far North	**High**	**Lower**
	Eastern, Southwest	**High**	**Medium**

Emerging Adaptation Priorities

By the mid-century, a number of additional areas of high risk will manifest, adding to several of those already identified in the current timeframe, most of which continue to persist. A summary of emerging adaptation priorities is provided in Table 8.16.

The general population Level 1 category in all regions except the Far North emerges as a 'high' risk moving into the 2050s. The Adaptive Capacity for this category could be built through

[30] See Appendix 12 for combined Adaptive Capacity rating and associated scoring matrix.

interventions in the form of universal residential cooling, emergency warning systems, and improved collaborative planning to center the needs of marginalized populations. However, the socio-economic disparities and projected increase in vulnerable populations indicate that significant investments would be needed to build up Adaptive Capacity,

Risks to health care in the Northeast, Northwest, and Far North also emerged as a priority, indicating an increase in the proportion of the population most vulnerable to climate change in these regions. The existing strain on medical institutions and health care providers in these regions is anticipated to increase, affecting response times, delays in providing critical services, and longer wait times for specialized and mental health supports. The Adaptive Capacity in this category and throughout these regions could be strengthened through technological supports in telehealth and rural healthcare service provision, as well as decentralized emergency services and improved communications infrastructure.

Corresponding to the spike in health care risks, in the 2050s the risks to social assistance and public administration are also predicted to increase in all regions, owing to similar factors as the health care category around population change from rural to urban areas and an increase in vulnerable populations. In particular, support for people with disabilities, newcomers, and low-income populations are vital to improving Adaptive Capacity in these regions.

By the 2050s all categories of Indigenous Communities are labelled as adaptation priorities. Indigenous Communities were assessed to have a number of high-risk categories including, cultural services, and health care. This level of risk coupled with a relatively low Adaptive Capacity, given the lack of funding and resources and existing environmental injustices, highlights the requirement for urgent adaptation action.

Table 8.16: Emerging Adaptation Priorities for People and Communities by Mid-Century (RCP8.5)

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[31]
General Population	Central, Northeast, Northwest	**High**	**Lower**
	Eastern, Southwest	**High**	**Medium**
Health Care	Northeast, Northwest, Far North	**High**	**Medium**
Social Assistance and Public Administration	Central, Northeast, Northwest, Far North	**High**	**Lower**
	Eastern, Southwest	**High**	**Medium**
Indigenous Population	Central, Northwest, Far North	**High**	**Lower**
Indigenous Social Assistance	Eastern, Southwest	**Very High**	**Medium**
	Central	**Very High**	**Lower**
	Northeast, Northwest, Far North	**High**	**Lower**

Advancing Adaptation

Climate change has already had significant impacts on the individuals, communities, and associated services in Ontario. Without coordinated and inclusive adaptation efforts, climate change will continue to drive risks into the future. This assessment demonstrates that climate risks are highest among Ontario's most vulnerable populations, exacerbating existing disparities and inequities. Climate risks to Indigenous Communities and associated systems are significant based on the additional layers of sensitivity and exposure.

There is an urgent need to limit key risks to Ontario's people and communities, in order to avoid outcomes that can become inter-generational and further exacerbate inequities for marginalized populations. Adaptation efforts to address the underlying health and well-being inequities are critical for reducing population vulnerability and building climate resilience.

[31] See Appendix 12 for combined Adaptive Capacity rating and associated scoring matrix.

The PCCIA Adaptation Best Practices (ABP) Report (External Resource – 2) includes measures that are applicable to people and communities across Ontario. The province has the solutions and knowledge to act to lessen and avoid many of the climate risks Ontario's people and communities are facing. A high-level summary is provided in Table 8.17, with more specific adaptation options available in the ABP Report.

Table 8.17: Adaptation Options for the People and Communities Area of Focus

Adaptation Category	Examples of Adaptation Measures
Projects or Programs	- Provide funding and programming support for development of heat event response planning for municipalities. - Promote Indigenous-led adaptation projects and programs. - Provide consistently available and up-to-date emergency planning guidance to communities.
Research and Development	- Encourage the use of novel technology to increase capacity to respond to climate-related health crises (e.g. emergency response planning scenarios). - Advance research to fill remaining knowledge gaps on climate changes impacts to people and communities in Ontario.
Investment and Incentives	- Invest in early warning systems for climate hazard event. - Invest in the establishment and enhancement of extreme heat impact reduction strategies. - Build safety nets to protect vulnerable populations and retain community function.
Policy and Regulation	- Develop policies and tools to support respectful and meaningful incorporation of Indigenous knowledge systems into adaptation planning and decision-making. - Reframe adaptation policies to be culturally appropriate for Indigenous Communities. - Include a wide breadth of rights holders and stakeholders in public policy development and decision-making.

9.0 Business and Economy Area of Focus

9.1 Overview

Climate change is fueling more extreme weather, impacting local economies, driving up costs, and challenging economic growth. These impacts and the associated economic shocks will not be uniform across Ontario. The PCCIA finds that most Ontario businesses will face increased risks due to climate change, with the largest increases expected for businesses dependent on natural production systems and where historical infrastructure deficits exist (e.g. fishing, hunting and trapping industries, forestry and logging) (see Table 9.1). Local economies and businesses that subscribe to resilience as well as the transition to a low carbon future will have increased growth, prosperity and thrive in the context of climate change.

Table 9.1: Summary of Climate Risks to Business and Economy

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Most at Risk Regions Abbreviations[32]	
FN - Far North	E - Eastern
NE - Northeast	C- Central
NW - Northwest	SW - Southwest

Business and Economy Area of Focus				
Level 1 Categories	**Risk**			**Most at Risk Regions**
	Current	**2050s**	**2080s**	
Accommodation and Food Services	Medium	Medium	Medium	All
Arts, Entertainment and Recreation	High	High	High	Central
Construction	Low	Low	Medium	C, E, NE, NW, SW
Financial and Insurance	Medium	High	High	All
Forestry, Fishing and Hunting Economies	High	High	High	All
Information and Cultural Industries	Low	Medium	Medium	All
Manufacturing	Low	Low	Medium	All
Mining, Quarrying and Oil/Gas Extraction	Medium	Medium	Medium	All
Retail Trade	Low	Low	Medium	C, E, NE, NW, SW
Transportation Economy	Medium	Medium	High	C, E, NE, NW, SW
Utility Services	Medium	High	High	FN

[32] 'Most at risk regions' are those that display highest risk scores operating under RCP8.5 (Appendix 9).

9.2 Ontario's Business and Economy

Economic vitality is closely linked to managing climate risks and achieving resilience across communities (Bush, 2022). Through a solid understanding of climate-related risks and action on adaptation, Ontario has enormous opportunity to build strong local, resilient economies and to support in reducing greenhouse gas emissions and innovating more efficient business practices. A resilient Ontario economy has a competitive advantage and can enable businesses at all scales and across industries to thrive in the face of an uncertain and extreme future.

In the Canadian context, Ontario's economy is significant. As of July 2021, Ontario's economy contributed almost 39% of Canada's overall GDP (Government of Ontario, 2022f), which can be broadly understood as the value of goods produced and services provided throughout the year. Ontario's GDP can be further distributed into services (78%) and goods (22%), of which manufacturing contributes just over 10% of Ontario's GDP (Government of Ontario, 2022f). Other goods-producing industries include construction, utilities, and primary industries. Services-producing industry shares include real estate, rental and leasing, health and education, wholesale and retail trade, finance and insurance, public administration, transportation and warehousing, information and culture, and other services (Government of Ontario, 2021d).

With a population of over 14.8 million (Government of Ontario, 2022f), Ontario is the most populous province in Canada. Businesses and their economic operating conditions are undergoing a period of rapid change (OCC, 2019). In 2019, the Ontario Chamber of Commerce (OCC) identified that globalization, urbanization, and technological transformation are all challenging the status quo and particularly redefining what it means for Ontario businesses to be competitive. Climate change, both the pace at which greenhouse gas emissions are mitigated and the ability to adapt and foster resilient businesses and industries, is a crucial factor in the coming decades.

Ontario's economy does not exist in isolation. Economic success is contingent on businesses and industries remaining competitive in the international market. Evolving global conditions can impact businesses and the economy in Ontario through important external factors such as the Canadian Dollar exchange rate, the price of oil, and interest rates (Ontario Ministry of Finance, 2020b). Ontario relies upon imports, and benefits from importing and exporting goods to international markets, with the latter predominantly going to the United States. Significant Ontario exports include motor vehicles and parts, precious metals and stones, mechanical equipment, plastic products, and iron and steel. Significant imports to Ontario (largely from the United States, followed by China) include motor vehicles and parts, mechanical equipment, electrical machinery, precious metals and stones, and pharmaceutical products.

Given current and emerging pressures, Ontario's overall prosperity increasingly depends on the strength of its regional and local economies. However, regional economic and population growth have been remarkably imbalanced in recent decades (OCC, 2019). As an example, growth in Ontario's Greater Golden Horseshoe and Ottawa have far surpassed other areas in the province. In other words, Ontario's economy is composed of a multitude of smaller economies, such as rural and remote areas, small and large cities, Indigenous Communities, and border towns, each of which poses unique strengths, opportunities, and challenges. Regionally, these also differ significantly. For instance, Northern Ontario (Northeast, Northwest, Far North regions) encompasses nearly 88% of Ontario's land but only about five percent of its population, with an economy largely driven by natural resource industries such as forestry, fishing, mining, oil and gas. Tourism is also a significant contributor in Tourism Region 13 (covers Northeast, Northwest and Far North regions), with visitor spending in 2019 totaling $1.5 billion and generating $1 billion for the region's total GDP (Statistics Canada, 2021d) and in comprising seven percent of all businesses in the region in 2021 (Statistics Canada, 2021f). Rural areas in Ontario stretch across the province, with urbanization and consolidation in certain industries leading to workers and jobs leaving more rural communities that also pay more for energy than urban areas (OCC, 2019).

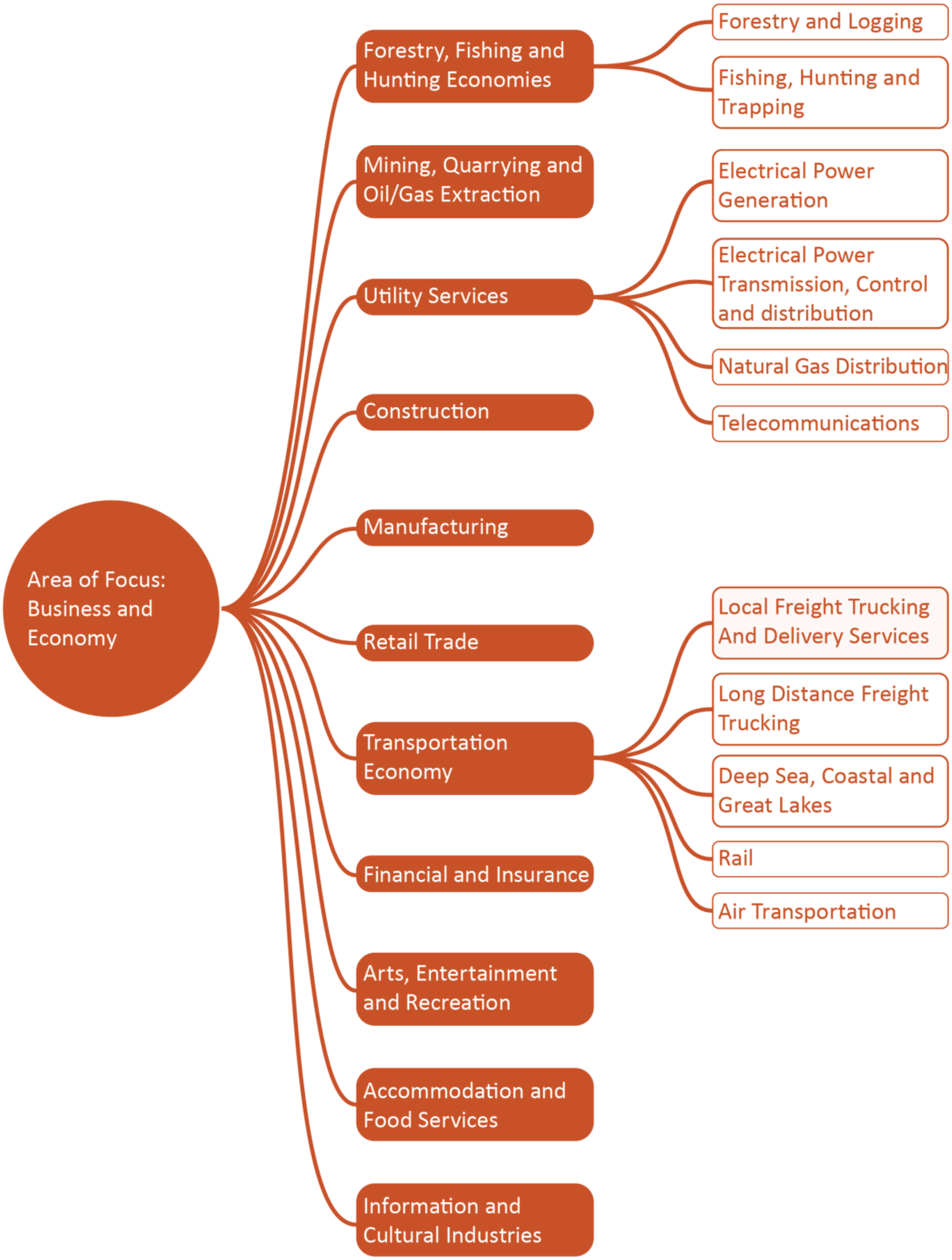
Economic shocks and stresses, including the climate impacts described in this report, are not (and will not be) felt uniformly across Ontario. This holds true for both climatic and non-climatic impacts. For example, the 2008 recession led to vastly different impacts across Ontario, with the Southwest region experiencing the largest impact and areas of Eastern Ontario the least impact. Regional variation in employment also indicates that employment growth has been concentrated in the Greater Toronto, Ottawa, and Greater Golden Horseshoe Areas, with little or declining employment in Northern regions (OCC, 2019). These differences indicate that non-climatic and indeed climatic impacts will not be uniformly experienced across the province. Similarly, the ability to recover from impacts is also not expected to be uniform by sector, by size of business, nor by region of Ontario.

9.3 Defining Business and Economy in the Context of the PCCIA

Ontario's Business and Economy Area of Focus is characterized as complex considering its diversity in size, location, industry, and relative contribution towards GDP. In scoping the PCCIA, numerous "categories" were defined to consider and were defined based upon national reporting standards and based on data availability. In some cases, certain types of businesses (e.g. healthcare and social assistance) were considered and included in other Areas of Focus contained in this report.

For the purposes of the assessment, the Business and Economy Area of Focus has been sub-divided into 11 Level 1 categories (see Figure 9.1), of which three were broken down into multiple Level 2 Categories (specifically, Forestry, Fishing and Hunting Economies; Utility Services; Transportation Economy). For additional details, Appendix 1 provides a characterization of the Level 1 and 2 categories for this Area of Focus.

Figure 9.1: Structure of the Business and Economy Area of Focus in the Context of the PCCIA



Each of these categories was identified with consideration given to relevant criteria and rationale, aligned with the scoping of the PCCIA. The following criteria were used in identifying the Level 1 and 2 categories:

- Alignment with relevant North American Industrial Classification System (NAICS) codes
- Relevance as it relates to Ontario's economic structure (e.g. major industry coverage, where possible)
- Consideration of other PCCIA Area of Focus categories where physical impacts on systems may be linked with inputs or supplies for businesses
- The ability to identify an appropriate "firm" representing a particular industry to be used as a proxy for quantitative risk evaluation

One notable industry in Ontario – real estate, rental, and leasing – was also considered in the development of Level 1 industries for quantitative evaluation. However, in the context of how the PCCIA has been scoped, real estate (e.g. buildings and assets themselves) has been included as part of risk evaluation for construction (see Section 9.7.4), whereas real estate investment trusts (REITs) or companies that own or finance income-producing real estate are included under the Finance and Insurance Level 1 category (see Section 9.7.5). Additional relevant content associated with real estate can also be found in the Infrastructure Area of Focus, in the characterization of buildings and other infrastructure components (see Section 6.0).

The Business and Economy Area of Focus is unique within the PCCIA as it links or plays a strong role in other Areas of Focus. As described in Section 2.0, Areas of Focus were identified as a means to assess the impacts and risks to systems and sectors in a systematic and scalable manner. In this regard, all other Areas of Focus quantitatively evaluated risks associated with direct impacts on the systems, commodities, or components themselves (e.g. the impact of extreme heat on an asset within the Infrastructure Area of Focus, or the impact of drought on commodity yield in the Food and Agriculture Area of Focus). To robustly evaluate risks within the Business and Economy Area of Focus, risk scenarios were developed and assessed based on the impact to service delivery associated with specific Level 1 or 2 category and financial loss based on annual revenue. In other words, risk scores reflect the ability of services to be continued or maintained in the event of a climate variable occurring, not the physical impact of the climate variable on the Level 1 or Level 2 category itself.

In many cases the impacts and risks characterized in other Areas of Focus may lead to cascading or indirect risks on Business and the Economy. For example, direct climate impacts on commodity yields (Food and Agriculture) may disrupt the supply chain for which manufacturing (e.g. food processing and manufacturers) relies upon. In another example, physical impacts to infrastructure assets may lead to asset failure or downtime that could cascade throughout the infrastructure system (e.g. if a culvert is blocked, leading to a road washout and exposed buried infrastructure) that could impact the transportation economy and the ability for local and long-distance freight to transport goods (Business and Economy). There are a significant number of these cross-sectoral impacts across Areas of Focus, and these have been qualitatively characterized across different themes under Cross-Sectoral Considerations (Section 10.0).

For the purpose of this section, however, these interdependencies were not distinctly quantitatively evaluated as part of Business and Economy, though some characterization is provided based upon each Level 1 category below.

9.4 Business and Economy Risk Snapshot across Ontario

Summary of Risks

Changes in physical climate risks are already impacting Ontario firms of all sizes, and these impacts are expected to continue (and potentially be exacerbated) into the future. The significance of climate risks to business performance and sustainability are anticipated to vary widely, depending on factors such as firm size, geographic location of business assets and activities (including supply chain relationships), and complexity of business arrangements (e.g. partnerships).

Climate risks and opportunities are numerous. Across the 11 Ontario business industries (Level 1 categories), many climate risk scenarios were identified – of these, a total of 350 unique climate risk scenarios were deemed potentially significant and subjected to assessment.

Most Ontario businesses are expected to experience increased levels of risk from current levels, exacerbated or influenced by projected changes in climate variables. However, these results are not homogeneous, and are highly influenced by the magnitude and intensity of change in climate variables, the size and unique details of specific firms, and the geographic location of business assets, activities, and supply chains. Additionally, Level 2 industry categories encompass a broader range of sub-industries that were not examined discreetly, and whose risk profiles may vary from that of the overall Level 2 category.

The most significant changes in risk profile are anticipated to belong to firms whose business models, services, markets, and products are dependent on natural production systems that are directly affected by severe weather events and changes in climate regime: 1) Arts, Entertainment and Recreation; 2) Forestry, Fishing and Hunting Economies. Public and private infrastructure system impacts are also a significant contributor to business risk, with firms in industries within Transportation Economy and Utility Services, anticipated to experience elevated risk over the coming decades.

Figure 9.2 illustrates risk scores for all Level 1 categories assessed, by region of Ontario under current, 2050s and 2080s time periods. Future time periods illustrate risk results associated with RCP8.5, a high emissions scenario.

The PCCIA methodology and assumptions made at the firm level were developed to represent industry risk and significant differences are not anticipated in the distribution of climate risk on a region-by-region basis. Additional investigation at the regional and local level could identify important regional differences, such as within the arts, entertainment and recreation industry where a broad range of summer and winter outdoor recreational activities are grouped together for the scale of this assessment. In this example, different climate variables may impact different outdoor activities in both positive and negative ways. More detailed characterizations and a description of risk drivers and risks for each industry are provided in Section 9.7.

Key Climate Drivers

The most prominent climate variables that drive risk in this Area of Focus are listed in Table 9.2, Extreme Precipitation Events, Extreme Hot Days, and Wildfire drive risks in 49%, 34%, and 7% of all risk scenarios, respectively.

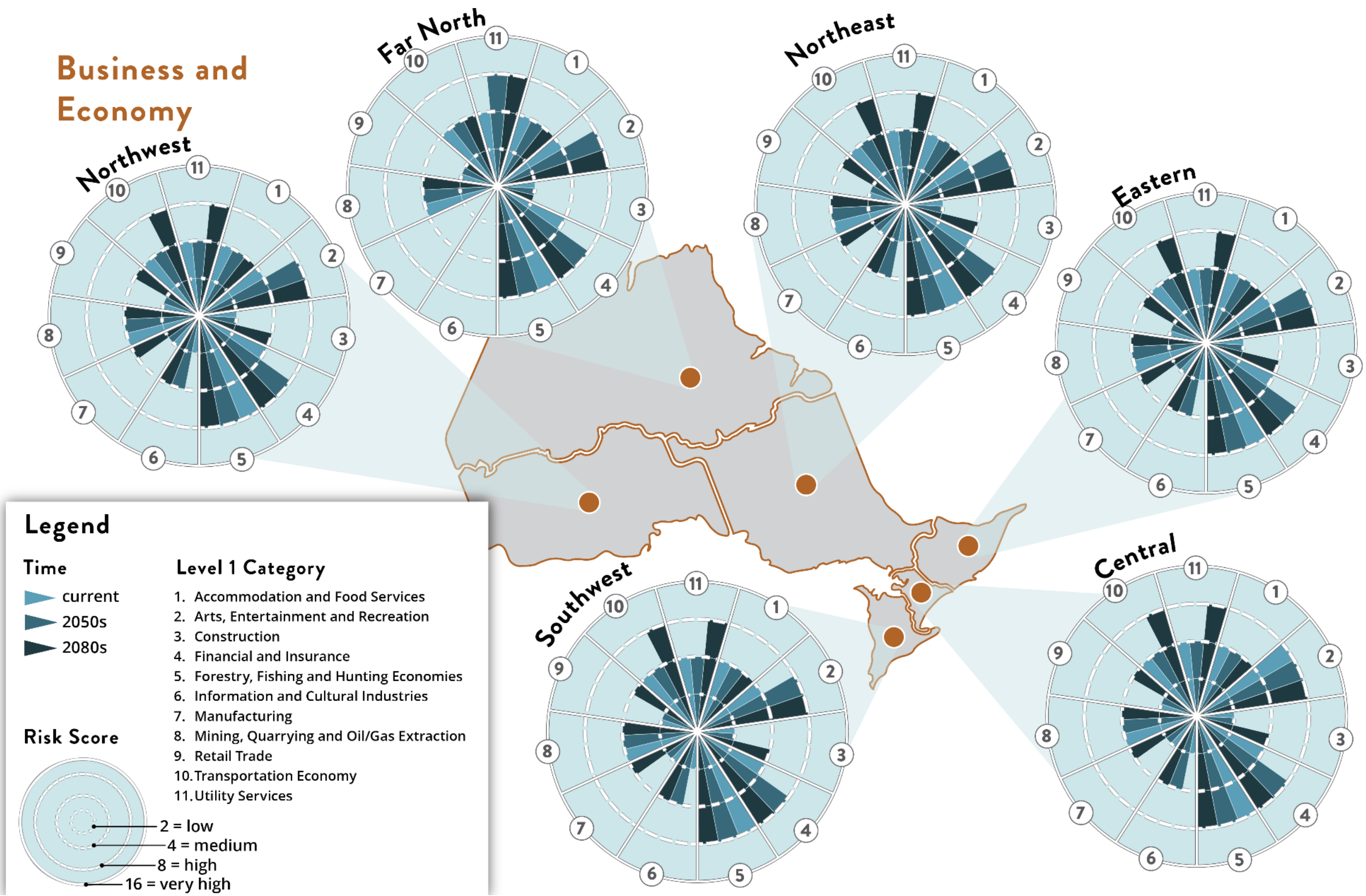
Table 9.2: Main Climate Variables Assessed for Business and Economy Area of Focus

Climate Variable	Proportion (%) of Area of Focus Risk Scenarios
Extreme Precipitation Event (shorter term)	**49%**
Extreme Hot Days	**34%**
Wildfire	**7%**
Other Variables	**10%**

A full list of all major climate variables that are driving the highest risks to Ontario's Business and Economy Area of Focus by Level 1 category is available in Appendix 8.

It must be noted that there are numerous other climate variables that were assessed and that impact Ontario's Businesses and Economy (e.g. changes in mean precipitation). The four identified above simply represent the greatest number of risk scenarios under this Area of Focus. One can consider these results in the context of managing and reducing risks from these climate variables. For example, where possible, reducing impacts associated with extreme precipitation (e.g. flooding) can be considered one effective adaptation option to reduce higher risks – particularly where Adaptive Capacity is limited.

Figure 9.2: Current and Future Risk Profiles by Region Assessed for Business and Economy (RCP8.5)[33]



[33] Appendix 13 provides an alternative visual format of the presented risk results by Level 1 category and region for this Area of Focus.

9.5 Approach to Assessing Climate Impacts to Business and Economy

Business climate risk was defined for each industry by assessing risk at the scale of an individual firm operating within the province, and then using an individual firm risk score as a proxy for industry risk. Industry risk scores do not depict overall industry, sector, or economy-wide climate risk, but rather present a view as to the nature of risk that an individual industry firm may face in a more extreme climate future. To describe with an example, a risk score for Utilities – Local Distribution represents the risk that a single Local Distribution Company (LDC) may be expected to face in relation to a single risk scenario (e.g. Most Probable Worst-Case Event). Thus, risk scores presented for the Business and Economy Area of Focus should not be interpreted as presenting the level of climate risk that the entire LDC industry or electrical system as a whole may experience.

Given the vast range of Ontario firm sizes (e.g. revenues, number of employees, number and range of products produced, and services delivered), geographic locations of assets and business activities, and value chain relationships, various assumptions regarding business resilience were used in this assessment in order to derive individual business risk scores. These assumptions are derived from the assessment scope, expert judgment and based upon available data to illustrate an “archetype” or “average” firm size. However, it is important that risks may differ significantly for varying sizes of business. For example, quarry operations are run by firms that vary greatly in terms of size. Many operations are small scale with very few employees and owned by a small business owner while others are larger, more sophisticated and owned by a large company. The smaller the firm's size and/or reserve funds, the greater the impact could be on service delivery and finances, thus varying risk levels. Additional assessments that dive deeper into these industries could produce more granular results.

The likelihood of a risk scenario and the associated consequence(s) for an individual firm were assessed for various climate variables and combined to form a risk score. Subsequently, each risk score was then combined to provide a risk score representing a firm as a proxy for its relevant industry.

Consequences were evaluated based on two criteria: 1) financial business loss, and 2) operational and service disruptions. These are summarized alongside all consequence criteria used in the PCCIA in Appendix 2.

Financial consequences were assessed based on the amount of business loss that a single firm might be expected to experience in relation to a single risk scenario (assessed as a % of annual company revenue). The Financial Consequences scale is presented in Table 9.3.

Table 9.3: Financial Consequence Criteria Applied to the Business and Economy Area of Focus

Consequence Score	Category	Definition – Amount of Business Revenue Loss due to Impact by Climate Variable. Measured as a % of annual revenue
16	Very High	>50% of annual revenue
8	High	25% to 49% of annual revenue
4	Medium	10% to 24% of annual revenue
2	Low	6% to 9% of annual revenue
1	Very Low	0% to 5% of annual revenue

Operational and service disruption consequences were assessed based on the degree to which an asset or service would no longer function at normal levels due to a single risk scenario (assessed as a % of loss of function of asset or service). The Operational and Services Disruption consequence criteria is presented in Table 9.4.

Table 9.4: Service Disruption Consequence Criteria Applied to the Business and Economy Area of Focus

Consequence Score	Category	Definition – Inability of Asset to Function Properly due to Impact by Climate Variable
16	Very High	>80% to 100%
8	High	>60% to 80%
4	Medium	>40% to 60%
2	Low	>20% to 40%
1	Very Low	5% to 20%

Ontario businesses are susceptible to both direct and indirect climate impacts – direct impacts being those that result when climate variables interact with a businesses' assets, operations, and service delivery, whereas indirect impacts are those that result when climate variables interact with systems (e.g. infrastructure, food, financial) that a business' assets, operations, and service delivery are dependent upon. Illustrative consequences for Ontario firms are provided in Table 9.5.

To robustly evaluate risks within the Business and Economy Area of Focus, direct and indirect impacts fall under the same type of evaluation based on the nature of evaluating impacts to industry, compared to other Areas of Focus assessing only direct physical impacts. In other words, risk scores reflect the ability of services to be continued or maintained in the event of a climate variable occurring, not the physical impact of the climate variable on the Level 1 or 2 category itself. Consequently, the characterization of direct and indirect impacts is presented together for this Area of Focus. In addition, this approach has resulted in a low strength of evidence ranking for all climate scenarios, given the methods and available data to illustrate an "archetype" or "average" firm size to represent each Level 1 or 2 category.

Table 9.5: Types of Consequences Evaluated for Businesses and Economy Level 1 Industries

Type of Consequence	Example	Level 1 Category
Operational/service disruption	Wildfire could result in stoppage of industrial/commercial logging operations, and potential loss of merchantable timber.	Forestry and Logging
Asset and infrastructure loss and damage	Extreme precipitation, wind-driven rain and fluvial/flash flooding could result in water infiltration (overland, roof, sewer backup) to buildings, leading to service disruption, content loss and infrastructure damage. These can also impact the road transportation/bridge infrastructure, subsequently disrupting business and industry (e.g. recent flooding in Northwest Ontario and highway infrastructure closure detours).	Construction; Transportation Economy
Change in availability and quality of inputs, as well as costs	Decreased average rainfall could result in decreased summer flow reducing hydro (run of river) or affecting water abstraction for generating stations, leading to derating/shutdown.	Electrical Power Generation
Legal liability and non-compliance	Drought could result in a decrease in water (groundwater & surface water) availability for mining and quarrying (use in production e.g. mineral dissolution in brining process, dust suppression, mine drainage, tailings covering). Decreased water availability could lead to water resource abstraction/discharge licenses being suspended or reduced and reduced ability to meet dust emission/suppression regulations.	Mining, Quarrying & Oil/Gas Extraction
Risk to worker and customer safety and well-being	Extreme temperature events could result in heat loading strains/exceedances of building HVAC system climatic design values, and cooling loads of mechanical cooling equipment leading to system underperformance/failure. Occupational heat stress	Retail Trade

Type of Consequence	Example	Level 1 Category
	could occur, affecting the health and well-being of workers, customers, and on-site visitors.	
Supply chain and distribution network interruption	Extreme temperature events (e.g. Daily Max, Heatwave) combined with humidity/moisture could affect the storage and shelf life of material inputs (e.g. resins, epoxies), semi-manufactured and finished products (plastic packaging).	Manufacturing

9.6 Limitations of the Business and Economy Assessment

Considerations and constraints for assessment of the Business and Economy Area of Focus are described briefly below.

Interconnections and Interdependencies

While there are examples in Ontario of interdependency mapping being conducted to advance understanding of the complexity of sectoral and industry interdependencies (e.g. electricity system; food system), there is little publicly available information about specific climate variables thresholds, and how these relationships translate into financial impacts at the firm-level. In many cases, this information is jurisdictional or context-dependent and may not translate into a province-wide assessment. To acknowledge the importance of the interconnections between Areas of Focus, cross-sectoral impacts are described and mapped across various themes in Section 10.0.

Socio-Economic Changes

Ontario's economy will evolve significantly over the mid to end of century. Demographic, technological, land-use, employment and other variables will change the socio-economic fabric of the province. Independent of climate change, these variables will undoubtedly shape the evolution of industries and the growth trajectory and risk profile of individual firms. Socio-economic projections and indicators assessed as part of this PCCIA (described in Section 4.0 of this report) did not warrant quantitative changes in risk scores at the firm level for the Business and Economy Area of Focus. More specifically, all socio-economic categories and indicators were reviewed for possible alignment to a firm-level risk evaluation, but it was ultimately determined that insufficient alignment existed at the appropriate scale to warrant increasing future scores from a quantitative perspective. However, socio-economic changes and transitions relevant to several Business and Economy industries are described qualitatively in Section 10.0 (cross-sectoral impacts) and later in this section regarding adaptation priorities.

9.7 Current and Future Risks

9.7.1 Accommodation and Food Services

Overview

Across Canada, there are over 117,000 establishments providing accommodation services and/or food services and drinking places, over 28,000 of which are based in Ontario and off employment. The vast majority of these businesses (e.g. 98.7% across Canada) have fewer than 100 employees (Government of Canada, 2022a). The labour productivity index, an indicator of labour trends and the extent to which labour is "efficiently used" within the sector compared to the Canadian economy overall, decreased 16.6% between 2019 and 2020, compared to a decline of 7.5% for the Canadian economy (Government of Canada, 2022b). This could be indicative of relative decreases in real income and/or standard of living in relation to inflation and other economic sectors.

Businesses involved in accommodation and food services are on the front lines, and this industry was one of the hardest hit by public safety measures put in place throughout the COVID-19 pandemic (Sood, 2021). For example, employment across Canada in this sector dropped over 55% from pre-pandemic levels and real GDP fell almost 40%. Over 85% of food services and drinking places experienced decreases in revenue in 2020 compared with 2019, with declines of 40% or more observed in Ontario, Quebec and Manitoba (Sood, 2021). Based on surveys conducted by Statistics Canada, the majority of businesses in this industry struggled to survive pandemic impacts and could not take on additional debt to stay solvent.

Accommodation and Food Services are also intrinsically linked to tourism, which employs a large number of workers, with many often required to work long shifts that require physical exertion. Many jobs in the sector also require employees to provide heightened customer service standards to ensure that consumers (tourists) have a positive experience. A key challenge faced by the industry is the shortage of labour, including difficulties in recruiting. In Ontario, job vacancies remain high for Accommodation and Food Service (and Arts, Entertainment and Recreation – see Section 9.7.2) businesses.

While total employment in Ontario has recovered to pre-pandemic levels, employment in Ontario's tourism-related industries remains well below 2019 levels. From January through December of 2022, employment in Ontario's tourism-related industries remained below 2019 levels (down 9% or 71,000 jobs compared to Jan-December 2019) (Statistics Canada, 2022i). Employees of tourism-related businesses in Ontario are diverse. In addition to being a top employer of youth and students, tourism businesses also employ a larger proportion of women, part-time workers, Indigenous Peoples, visible minorities, non-permanent residents, and persons with difficulties or long-term conditions. As the tourism industry changes and responds to more extreme weather and climate change, this could deter future travel and impact the Accommodation and Food Services industry. Similarly, it is possible that consumer patterns may shift based on the idea of “responsible travel” to lighten carbon footprints, support local economies and engage in activities enabling environmental conservation (Destination Canada, 2021).

Direct and Indirect Impacts

Accommodation and Food Service activities could be impacted by changes in extreme heat, higher average temperatures, drought, extreme precipitation, and wildfire. These weather events could lead to impacts in a variety of ways (Lucon et al., 2014; Zeuli et al., 2018a). Financial impacts to Accommodation and Food Service industries could lead to:

- Loss & damage and decreased serviceable life to assets or infrastructure, materials and equipment businesses rely upon
- Disruption and/or impairment to service productivity
- Supply chain and logistics delays
- Increased variability or reduction of key inputs and costs (e.g. materials, commodities, water, electricity, insurance) that can lead to higher operating costs or increased debt
- Changes and/or variability in consumer demand for indoor/outdoor accommodation and food services
- Health & safety impacts to staff and customers

An example risk scenario for accommodation and food services is presented in Table 9.6, to provide a fuller picture of the risk scenarios considered for this Level 1 category. Risk profiles for this Level 1 category can be found in Table 9.7.

Table 9.6: Illustrative Risk Scenario for the Accommodation and Food Services Level 1 Category

Level 1 Category	Example Risk Scenario	Strength of Evidence
Accommodation and Food Services	Impact to complex supply chain results in reduced availability of food commodities and financial effects for food service (quick serve and dine-in restaurants) companies. Interruption or failure of external power supply results in financial effects for both food service and accommodation industries, depending on duration of power interruption and existence of on-site back-up power generation capacity.	**Low**

Risk Results

The risk profile associated with the financial impact to Accommodation and Food Services is rated 'medium', and not anticipated to significantly increase or decrease over time. These results ('medium' risk) are consistent regardless of whether emissions follow a high emissions scenario (RCP8.5) or a moderate emissions scenario (RCP4.5). However, the cascading risk of loss of commodities (e.g. food) or physical loss of infrastructure (e.g. inability to access/occupy or use infrastructure) were not *quantitatively* evaluated as part of this risk rating. Food and Agriculture risks are described in Section 5.0 of this report, and Infrastructure risks are described in Section 6.0. Therefore, these results can be considered the risk profile of a typical business within Ontario, which does not lose total access to the building in which services are provided nor total ability to provide their services. In reality, financial implications may increase in the future for accommodation and food services businesses, but in the quantitative assessment completed as part of the PCCIA, this was not considered to exceed 50% of annual business revenue (recall the consequence criteria used in evaluation, identified in Section 9.5 and Appendix 2).

If a total supply chain disruption were to occur, or infrastructure completely failed, risks could be much more significant or amplified with recovery taking several years, particularly in the future. These cross-sectoral and cascading impacts are characterized qualitatively in Section 10.0 in the context of food security and impacts across the food system.

Table 9.7: Risk Scores for Accommodations and Food Services

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Region	Climate Risk Scores		
		Current	2050s (RCP8.5)	2080s (RCP8.5)
Accommodation and Food Services	Central Region	Medium	Medium	Medium
Accommodation and Food Services	Eastern Region	Medium	Medium	Medium
Accommodation and Food Services	Far North Region	Medium	Medium	Medium
Accommodation and Food Services	Northeast Region	Medium	Medium	Medium
Accommodation and Food Services	Northwest Region	Medium	Medium	Medium
Accommodation and Food Services	Southwest Region	Medium	Medium	Medium

9.7.2 Arts, Entertainment and Recreation

Overview

The Arts, Entertainment, and Recreation sector is one of the smaller services-producing industries in the Ontario economy. It is comprised of businesses and services related to: performing arts, spectator sports and related industries; heritage institutions (e.g. museums, art galleries); and amusement, gambling and recreation industries. The latter (amusement, gambling, and recreation) is the largest within this sector, accounting for 61.5% of employment in 2017 (LMSID, 2022). This sector employed 172,100 people, or approximately 2.4% of the provincial workforce in 2017 (LMSID, 2022). Businesses and services provided in this industry contributed 0.8% to Ontario's gross domestic product (GDP) in the same year. Across Canada, the vast majority of arts, entertainment and recreation sector businesses employed under 100 employees (96.9%) within 2021, bringing in an average annual revenue of $444,000 CAD (Government of Canada, 2022a).

The labour productivity index, an indicator of labour trends and the extent to which labour is "efficiently used" within the sector compared to the Canadian economy overall, decreased 12.5% between 2019 and 2020, compared to a decline of 7.5% for the Canadian economy (Government of Canada, 2022b). This could be indicative of relative decreases in real income and/or standard of living in relation to inflation and other economic sectors.

Throughout the COVID-19 pandemic, Ontario's performing arts sector was among the first and hardest hit by public health restrictions. For example, GDP for live performance in Canada fell 66.2% by quarter two of 2020 compared to quarter four of 2019, when it was $664 million.

Similarly, employment in the live performance sector in Canada declined through to mid-2021. In 2021 it increased to 37.7% of pre-pandemic levels, however, these gains were wiped out by the measures implemented to contain a wave of the pandemic. Ontario is home to 66,000 artists who live in all regions of the province, and this is an industry that is on the front lines in terms experiencing climate risks. Climate impacts in all regions of the province can impact Ontario's Arts, Entertainment and Recreation industry.

The Arts, Entertainment and Recreation sector has a higher ratio of employees who work part time compared to the Ontario average and is relatively unique in comparison to other industries. It has several types of businesses that are highly seasonal, such as amusement parks and golf clubs during the summer months, and ski resorts in the winter months. Tourism from within Canada and the United States also plays a significant role in its success and economic contribution to Ontario's overall economy. For instance, the strength of the U.S. economy and the exchange rate between the Canadian and the American dollar may help or hinder tourist expenditures, particularly due to U.S.'s proximity to Ontario (LMSID, 2022). Average household debt and disposable income, in many cases tied to the success of Ontario and Canada's economy more broadly, also influences the extent to which residents and tourists may be willing to spend on Arts, Entertainment, and Recreation-related activities.

Ontario is home to the largest volume of sport and recreation facilities in Canada (Canada Parks and Recreation Association, 2020) and extreme weather and climate impacts such as flooding (paired with aging building infrastructure) could result in damage to the interiors of a significant number of community sport and recreation facilities impacting the delivery of, and access to, sport and recreation services.

Regionally, certain areas of Ontario contribute particularly strongly to the Arts, Entertainment, and Recreation industry. For example, Southwest Ontario (e.g. Niagara) and central Ontario (e.g. Toronto) attract significant numbers of tourists due to cultural and heritage institutions, sporting events and casinos. Central Ontario also depends on business-related travel to a greater degree than other regions across the province, with 29% of visitor spending in Tourism Region 5 (Greater Toronto Area) in 2019 being generated by business travel compared to 19% in Ontario as a whole) (Statistics Canada, 2021d, Statistics Canada, 2022h). Eastern Ontario (e.g. Ottawa) attracts international visitors and tourists related to seeing Canada's capital and the parliament buildings. Northern Ontario tends to attract tourists from Ontario and the United States, with American visitors particularly important to businesses in the Northwest region (e.g. in 2019, US visitor spending accounted for 42% of total visitor spending in Northwest Ontario, compared to 17% in Ontario as a whole) (Statistics Canada, 2021d; 2022h). Key resource-based attractions in the North include boating, fishing, hunting, and camping. Resource-based tourism is described in further detail in Section 9.7.6 under the Forestry, Fishing and Hunting Economies for northern Ontario.

Direct and Indirect Impacts

Indoor and outdoor Arts, Entertainment, and Recreation could be impacted by changes in extreme and mean temperatures, Growing Degree Days, mean and extreme precipitation, Moisture Deficit or drought, and wildfire. These events and conditions directly and/or indirectly could lead to financial impacts in the Arts, Entertainment, and Recreation industries in numerous ways (Scott, 2003; Bruce, 2009):

- Loss & damage and decreased serviceable life to assets or infrastructure, materials and equipment businesses rely upon
- Disruption and/or impairment to service productivity
- Supply chain and logistics delays
- Increased variability or reduction of key inputs and costs (e.g. materials, commodities, water, electricity, insurance) that can lead to higher operating costs or increased debt
- Changes and/or variability in consumer demand for indoor/outdoor accommodation and food services
- Health & safety impacts staff, customers, sport and recreation participants.

These impacts may be particularly pronounced in certain regions of Ontario, or even occur in a different region of the province but lead to indirect impacts on Arts, Entertainment, and Recreational services. For example, increasing extreme heat may lead to a more difficult (and costly) process to create snow for ski hills in certain areas in Ontario, particularly in the mid to late Century. This warming may deter tourists and residents traveling to other regions of the province to enjoy recreational activities. Similarly, and as observed through the COVID19 pandemic, Ontario and/or Canadian-specific policies or health measures impact certain sectors more than others. Arts, entertainment, and recreation services may be particularly impacted given the importance of expenditures from tourists and consumers.

Climate change may also create additional pressures to maintain facilities resulting in increased costs, especially for outdoor fields. As climate change worsens and threatens to disrupt sports competitions, the suitability of regions to host large sport/recreation events may decrease further impacting tourism and the economy.

An illustrative risk scenario for arts, entertainment and recreation is presented in Table 9.8, to provide a picture of the type of scenarios assessed for this Level 1 category. Risk profiles for this Level 1 category can be found in Table 9.9.

Table 9.8: Illustrative Risk Scenario for the Arts, Entertainment and Recreation Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Arts, Entertainment and Recreation	Negative (or positive) impact to arts, entertainment and recreation organizations resulting from seasonal changes, such as shortening of winter outdoor recreation (e.g. skiing, snowmobiling, ice fishing) or lengthening of summer outdoor recreation and culture (e.g. golfing, hiking, boating, festivals). Disruption to indoor organized sport and recreation resulting from climate hazards can also reduce annual revenue for sport and recreation entities and organizations as they would no longer be functioning at normal levels.	**Low**

Risk Results

The Arts, Entertainment, and Recreation services category has current climate risks rated 'medium' in most regions of Ontario and these are expected to increase to 'high' by mid-century (2050s) and end of century (2080s). These increases in risk occur regardless of how fast greenhouse gas emissions are mitigated (e.g. RCP4.5 and RCP8.5 both indicate increasing risks for this industry). Regionally, a slight difference was determined for Central Ontario, which is already rated a 'high' risk. This elevated risk currently in Central Ontario may be indicative of the significant contribution that the Greater Golden Horseshoe and Greater Toronto Area has in relation to this industry (e.g. sporting events, concerts, amusement services, gambling institutions and racetracks, etc.). In other words, if a weather event or a change in a climate variable were to lead to an impact in Central Ontario in the short term (e.g. in Toronto), the financial consequence of that impact may be greater than if it were to occur in Eastern Ontario due to the increased density of Arts, Entertainment and Recreational services.

Table 9.9: Risk Scores for Arts, Entertainment and Recreation

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Region	Climate Risk Scores		
		Current	2050s (RCP8.5)	2080s (RCP8.5)
Arts, Entertainment and Recreation	Central Region	High	High	High
Arts, Entertainment and Recreation	Eastern Region	Medium	High	High
Arts, Entertainment and Recreation	Far North Region	Medium	High	High
Arts, Entertainment and Recreation	Northeast Region	Medium	High	High
Arts, Entertainment and Recreation	Northwest Region	Medium	High	High
Arts, Entertainment and Recreation	Southwest Region	Medium	High	High

9.7.3 Information and Cultural Industries

Overview

Information and Cultural Industries comprise establishments primarily engaged in producing or distributing information and cultural products, the value of which is contained in their information, educational entertainment, or cultural content (Statistics Canada, 2021g). Major components of these industries include publishing, motion picture and sound recording, broadcasting, telecommunications and data processing and hosting services. In 2021, there were over 48,000 businesses across Canada considered a part of these industries, with an average revenue of $389,000 CAD (Government of Canada, 2022c).

In 2020, these industries saw a decline in growth by 3.5% over the previous year, in comparison to the Canadian economy which decreased 1.8%. Notably, these numbers, in part, reflect the impact of COVID-19, which was particularly significant on information, culture, arts, entertainment and recreational activities in 2020 (Bernard and McMaster, 2021). As an example, motion picture and video exhibition businesses lost 69% of their operating revenue in 2020 due to restrictions from COVID-19, one of the most significant losses across all industries in Canada at that time. Similarly, book publishing in Ontario lost 5.7% of their operating revenue, though this impact was much more significant in other provinces and territories of Canada.

Ontario has the largest cultural industries sector in the country, accounting for almost half of all cultural industries GDP in Canada (Ontario Ministry of Tourism, Culture and Sport, 2022a). Ontario is also among North America’s top entertainment and media economies, ranking third in employment (behind only California and New York) (Ontario Ministry of Tourism, Culture and Sport, 2010).

The economic activity generated by the cultural industries reflects the shift from industrial-based to knowledge-based economies in Ontario. The majority of Information and Cultural Industries are small enterprises, many of which lack access to capital to grow their businesses.

Direct and Indirect Impacts

From a climate change perspective, information and cultural activities could be impacted from various climate hazards, including changes in extreme temperatures, extreme precipitation, and wildfire. These changes could lead to financial impacts on the Information and Cultural Industries in several ways:

- Loss and damage and decreased serviceable life to assets/infrastructure that is used by businesses within the industry – particularly if those are unique (e.g. movie film sets) that could be challenging to find alternatives for
- Changes to availability or decreased lifespan of materials and equipment and disruption or impairment to service productivity
- Supply chain and/or logistics delays in support of Information and Cultural Industries
- Reduction or increased variability of key inputs and costs (e.g. materials, commodities, water, electricity, insurance) that Information and Cultural Industries rely upon
- Increased variability in consumer demand for indoor/outdoor cultural services and entertainment, which in turn could cause financial impacts (e.g. music venue revenue loss in the event of shutdowns due to extreme weather or need for infrastructure repair)
- Health and safety impacts to staff and customers

An illustrative risk scenario for information and cultural industries is presented in Table 9.10. Further detail on the risk profiles relevant to this category, with more information on how the magnitude of the risks vary by region and timeframe (operating under RCP8.5) is provided in Table 9.11, at the end of the section. Appendix 7 provides risk scores for both RCP4.5 and RCP8.5 emission scenarios.

Table 9.10: Illustrative Risk Scenario for the Information and Cultural Industries Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Information and Cultural Industries	Interruption or failure of external power supply results in financial impacts for information/cultural companies. The extent of impact is dependant on the duration of power interruption and availability of on-site back-up power generation capacity.	**Low**

Risk Results

Climate change risks to Information and Cultural Industries were evaluated from the perspectives of a) financial loss and b) disruption to businesses continuity. In many cases, businesses within this sector rely on infrastructure, buildings, venues, studios, and numerous other assets to sustain operation. For example, if an extreme precipitation event (short or one of longer duration) were to occur in the spring season and lead to flooding and subsequent infiltration of water into the industrial building, the risk scenario would also include loss of all basement and ground-level contents. Under a scenario with significant loss of contents and access/ function disruption (but not failure), disruption to services will be significant for a period of time – potentially for weeks to a month - to allow for drying, mould treatment and repairs where needed. Some important assumptions were made in scenario evaluations. For instance, it was assumed that most buildings in use by Information and Cultural Industries are not located within a floodplain or have implemented maintenance and condition assessments, and that municipal sewer infrastructure is designed to withstand significant precipitation events.

Under current conditions, climate risks have been evaluated as 'low' for these industries, regardless of region of Ontario. In the future, it is expected that climate risks will increase to 'medium' across all regions of the province – regardless of how quickly greenhouse gas emissions are mitigated. This increasing risk profile reflects extreme weather events and/or impacts to businesses within this sector where financial losses or service disruption may become more frequent due to climate change.

Table 9.11: Risk Scores for Information and Cultural Industries (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	**Region**	**Climate Risk Scores**		
		Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Information and Cultural Industries	Central Region	**Low**	**Medium**	**Medium**
Information and Cultural Industries	Eastern Region	**Low**	**Medium**	**Medium**
Information and Cultural Industries	Northeast Region	**Low**	**Medium**	**Medium**
Information and Cultural Industries	Northwest Region	**Low**	**Medium**	**Medium**
Information and Cultural Industries	Southwest Region	**Low**	**Medium**	**Medium**

9.7.4 Construction

Overview

Construction is a pivotal industry across Canada, employing more than 1.4 million people nationwide, and contributing 7.5% of Canada's GDP. As defined by NAICS, Ontario's construction industry comprises any establishment *primarily* engaged in constructing, repairing, and renovating buildings, including engineering works and developing land. There are three subsectors, including 1) construction of buildings, 2) heavy and civil engineering construction, and 3) specialty trade contractors. A significant number of construction work is performed by enterprises primarily engaged in businesses other than construction – and these are not typically considered or reported upon in statistics surrounding this industry (Statistics Canada, 2021g).

As economic conditions were challenged in 2020, the construction industry was one of the few in Ontario that continued to grow. Ontario's construction industry grew by 0.3% compared to 2019, which represents approximately $50.9 billion or 7.2% of the province's GDP in 2020 (Building, 2021). As of 2021, construction employment was comprised of 29% residential renovations and maintenance, 26% new housing, 17% engineering, 16% industrial, commercial, and institutional (ICI) construction, and 11% non-residential maintenance (Build Force Canada, 2021). However, as recovery is ongoing, the construction industry is still hampered by the rising costs of raw materials, labour shortages, and schedule and price increases brought on by the widespread disruption to global supply chains (Dentons, 2021).

Following a modest decline in 2020 (e.g. due to supply chain and COVID-19 impacts), construction is expected to recover and continue growing in Ontario. The disruptions brought on by the COVID-19 pandemic have moderated the anticipated rapid rise in construction demand over the short term, but it did not reduce labour market challenges, which are a material risk moving forward for this industry. Driven by significant demand for infrastructure, housing, public transit, utility, mining, and ICI construction is expected to continue to grow and peak in 2026. Associated with this demand, employment is Ontario's construction industry is expected to rise by almost 24,000 workers (up 6%) over 2020 levels (Build Force, 2021). An aging labour force is also important to note, as over the next decade Ontario is expected to see more than 92,500 workers retire, representing 21% of the current labour force.

Regionally, Southwest Ontario is facing increasing recruitment challenges, due in part to large infrastructure projects underway such as refurbishment work at the Bruce Power nuclear plant, upgrades to the Gordie Howe International Bridge in Windsor, and the Nova Chemicals plant in Sarnia. Central Ontario is expected to grow significantly to meet residential and non-residential construction demands such as transit projects and work at the Ontario Power Generation Darlington nuclear refurbishment project. Construction activity in Eastern Ontario is expected to pick up pace due to the second phase of Ottawa's light rail transit (LRT) project and the redevelopment of Parliament Hill's Centre Block. In Northern Ontario, major mining and utility construction projects and a moderate increase in residential construction indicate a rising employment peaking in 2023, then declining as projects reach completion and weaker renovation demands drive residential activities lower. All together across Ontario, competing demands for construction are expected to limit potential for intra-provincial labour mobility to meet peak requirements in the short term (Build Force, 2021). An example risk scenario for construction is presented in Table 9.12. Risk profiles for this Level 1 category can be found in Table 9.13, at the end of this section.

Table 9.12: Illustrative Risk Scenario for the Construction Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Construction	Impact to complex supply chains results in reduced availability of construction inputs/materials and subsequent financial effects for construction and engineering companies.	**Low**

Direct and Indirect Impacts

Ontario's construction industry is confronted with several challenges. There is a need to rapidly decrease greenhouse emissions on a global and local scale which has translated into increased pressure on this sector to adopt low carbon resilience principles. At the same time, the construction industry is exposed to climate hazards leading to physical impacts– such as extreme weather impacting construction sites, water shortages, and deteriorating environmental conditions with increasing temperatures (Muller et al., 2020). Construction activities can also be impacted by changes in extreme heat, mean and extreme precipitation, drought, and wildfire (CMIC, 2017; Naude, 2020).

These changes which could lead to financial impacts in the construction industry in the following ways:

- Loss and damage to materials and equipment or rising prices for materials
- Supply chain and logistics delays
- Disruption and/or impairment to service productivity and schedule delays
- Changes, reduction or variability of key industrial inputs and costs (e.g. materials, water, electricity, insurance)
- Health & safety impacts on staff

Supply chains are complex and climate-related impacts to one or more chain components could result in reduced availability of construction inputs or materials and small to moderate short-term financial effects for construction and engineering companies. Interruption or failure of external power supply could also result in small to moderate short-term financial effects for construction industries, depending on duration of power interruption and existence of on-site back-up power generation capacity.

Risk Results

Based upon the PCCIA methodology, financial consequences were evaluated within the risk scores (described previously in Section 9.5). For example, in the event of a climate variable's magnitude or frequency leading to an impact, business service could be impaired for a short period of time and consequently lost revenue. This example and these results reflect the level of risk associated with one firm in the construction industry, and do not incorporate quantitative considerations associated with cascading impacts across supply chains. In other words, these can be considered a baseline risk for companies that could be exacerbating by systems-level impacts and interdependencies. Thus, it would be beneficial to undertake a systems-level assessment focused on the amplification of risks to Ontario's construction industry, and other businesses described in this Area of Focus.

Risk results for construction across Ontario are currently rated as 'low' across every region. In the future, it is anticipated that these risks will increase in every region of the province except the Far North where risks remain consistent (e.g. reflecting limited construction activities in that region and differing rates of change in climatic conditions). In every other region, climate risks are expected to increase to 'medium' by the end of century under a high emissions scenario (RCP8.5). In contrast, if greenhouse gas emissions are able to be mitigated to be in line with the RCP4.5 scenario (moderate emissions), climate risks are expected to remain somewhat similar to their current levels for companies in Ontario's construction industry. See Appendix 7 for risk scores under RCP4.5

Table 9.13: Risk Scores for Construction Level 1 Category (RCP8.5)

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Region	Climate Risk Scores		
		Current	2050s (RCP8.5)	2080s (RCP8.5)
Construction	Central Region	2	2	4
Construction	Eastern Region	2	2	4
Construction	Far North Region	2	2	2
Construction	Northeast Region	2	2	4
Construction	Northwest Region	2	2	4
Construction	Southwest Region	2	2	4

9.7.5 Financial and Insurance

Overview

Financial and Insurance Level 1 category broadly covers any establishment primarily engaging in financial intermediation. NAICS describes these activities as raising funds by taking deposits and/or issuing securities, and, in the process, incurring liabilities, which they use to acquire financial assets by making loans and/or purchasing securities. In this case, financial establishments expose themselves to risk, and channel funds from lenders to borrowers and transform or repackage the funds with respect to maturity, scale, and risk (Government of Canada, 2022a). Finance and Insurance also include establishments involved in pooling risk by underwriting annuities and insurance, and those charged with monetary control (e.g. monetary authorities).

Across Canada, the Finance and Insurance sector has outpaced growth averages in all other industries between 2011 and 2020 (The Conference Board of Canada, 2021b). A report released by the Conference Board of Canada identifies that the 10-year average GDP growth rate was roughly 3.6% for Finance and Insurance, compared to about 1.5% for other industries, and that the City of Toronto is leading in this industry across the country (The Conference Board of Canada, 2021b). In 2020, Finance and Insurance was the third largest contributor to Canada's GDP, after real estate and manufacturing.

In Ontario, the financial services industry generates approximately $63 billion in GDP and employs roughly 365,000 people (Invest Ontario, 2022). Concentrated in the City of Toronto, North America's second largest financial services hub, financial services are provided by 12,000 financial services firms. Canada's four largest banks, three of the top five largest Canadian insurers, two of the top 20 global pension funds, eight of the 10 largest Canadian asset managers, and the Toronto Stock Exchange (TSX) are all located within Toronto and represents the significance this industry to Ontario and across Canada.

From an insurance perspective, property and casualty insurance is particularly relevant considering their exposure to physical climate risks. Over 192 private property and casualty insurers compete across Canada. The Insurance Bureau of Canada identified that property insurance claims have risen over the last decade, as a percentage of total claims (from 28% in 2010 to almost 34% in 2020) (IBC, 2021a). Home insurance rates have also grown more than the rate of inflation, with Ontario home insurance premiums rising 64%, possibly tied to increasing extreme weather events and climate change (Berkow, 2021).

In Central Ontario, Toronto accounts for the most significant share (68%) of employment in Ontario's Finance and Insurance industry, driven by growing technology clusters and subsequent employment needs. In Southwest Ontario, Kitchener-Waterloo also has high employment in this sector due to high presence of large insurance companies. However, some indications suggest that restructuring and consolidation of large financial institutions may lead to weakening employment or a somewhat smaller footprint in this region (LMSID, 2022).

Illustrative risk scenarios for finance and insurance industries are presented in Table 9.14. Risk profiles for Level 2 categories assessed under finance and insurance can be found in Table 9.15, at the end of this section.

Table 9.14: Illustrative Risk Scenarios for the Finance and Insurance Level 2 Categories

Level 2 Category	Illustrative Risk Scenarios	Strength of Evidence
Insurance Carriers and Related Activities	Indirect financial risks on a single event basis impact a proportion of a single insurers overall financial exposures. This amount of exposure may vary depending on the type of financial peril, geographic concentration of policy holders relative to spatial location of the single climate risk event, and the degree of final exposure resulting from risk sharing/transfer contracts in place between insurers and re-insurers.	**Low**
Monetary, Credit, Securities, Funds and Other Financial Vehicles	Single-event indirect financial risks impact a proportion of a single financial institution's overall financial holdings. Flow-through financial risk exposure may or may not arise depending on the complexity of risk sharing and transfer arrangements in place with financial counterparties.	**Low**

Direct and Indirect Impacts

The impacts associated with climate change are particularly nuanced and complex in the Finance and Insurance industry, in part because companies consider, model and price risk as part of their products. The extent to which current physical climate risks have been factored into financial products, markets, and financial portfolios varies. An international survey conducted in October 2019, focused on integrating climate risk into institutional portfolio management, identified that only 38% of respondents had translated climate risk impacts into financial valuation of assets, and those that undertook a materiality analysis to determine if climate risk influences asset performance largely identified flooding, sea level rise, drought, wildfire, and windstorms as key hazards (Moudrak et al., 2020). A study focused on U.S. real estate identified that future perception of risk has a major role in determining the extent to which climate risk will influence real estate pricing, depending on belief systems (Baldauf et al., 2020).

What is clear, however, is that companies spanning most financial industry sectors will experience disruptions to the continuity of their operations due to physical climate impacts (Feltmate et al., 2020). For example, extreme precipitation resulting in flooding and cascading impacts to the supply chain could subsequently impact a company's cash flow, and the disclosure of this information would be required as part of a company's fiduciary duty. While best practices to integrate climate risk into investment management are not yet well established, some studies are beginning to identify the direct financial impacts of extreme weather on valuation. Addoum et al., (2019) have shown that extreme temperatures can adversely affect corporate earnings, and Kruttli et al., (2019) document that extreme weather can be reflected in stock and option market prices.

From a residential real estate perspective, impacts of flooding on housing were evaluated across several Canadian municipalities by the Intact Centre on Climate Adaptation (Bakos et al., 2022). The authors found that, on average, sales prices dropped by 8.2%, days on the market increased by 19.8% and 44.3% fewer houses were listed for sale comparing those impacted by a flood to those not impacted. As a practical example, a house that would sell at a price of $713,500 would be sold for $55,507 less at $654,993 if it were to be catastrophically flooded. Mortgages, on the other hand, are more complex and no material or consistent impacts were found comparing pre- and post-flood impacts on arrears and deferrals (Bakos et al., 2022).

Evidence also suggests that borrowers (e.g. municipalities in Ontario) likely to be impacted by climate change are going to be paying more in underwriting fees and initial yields in issuing long-term municipal bonds (Painter, 2018). This is particularly important for issuing long-term securities, rather than short-term bonds, implying that future climate risks have not factored into pricing, products, and other services. This is particularly important for Ontario municipalities as there will be higher issuance costs for bonds with lower credit ratings, and credit ratings are increasingly being tied to risk disclosure and demonstration of resilient investments.

Insurance Carriers and Related Activities

Insurance carrier activities could be impacted by changes in climate variables (e.g. extreme events and mean conditions) that directly affect financial counterparties (insurance policyholders). These changes could lead to financial impacts on the insurance industry in the following ways (Kovacs, 2020):

- reduced financial institution returns and underwriting performance due to counterparty climate -related risk and loss (e.g. increasing insurance claims paid out which is expected to double over the next 10 years from $2.1 billion to $5 billion)
- loss and damage associated with physical impacts to infrastructure
- increased costs and decreased serviceable/economic life of owned assets (e.g. office buildings)
- health & safety impacts to staff and customers

Indirect financial risks from single extreme event basis may apply to a relatively small proportion of a single insurer/’e-insurer's overall financial exposures, though this amount of exposure will vary significantly depending on the type of financial peril, geographic concentration of policy holders relative to spatial location of the single climate risk event, and the degree of final exposure resulting from risk sharing/transfer contracts in place between insurers and re-insurers.

The ability of insurance providers to change coverage, underwriting policy and pricing based upon their exposure (now and in the future) enables a higher degree of flexibility to recover financially from climate impacts. For example, the Insurance Institute of Canada identify that the property and casualty insurance industry has already adapted its underwriting practices and response to sustained high severe weather damage claims, as well as lower interest rates, and now consistently reports a modest overall underwriting profit (Kovacs, 2020). The industry has also adapted to the sustained increase in the volume of claims by increasing its response capacity.

Monetary, Credit, Securities, Funds and Other Financial Vehicles

Monetary, credit, securities, funds and other financial vehicle activities can be impacted by changes in various climate variables (e.g. extreme events and mean conditions) that could directly affect financial counterparties (credit, equity, debt). These changes could lead to financial impacts in the monetary, credit, securities, funds & other financial vehicle industry in the following ways:

- Reduced financial institution returns and credit performance due to counterparty climate-related risk and loss
- Loss & damage associated with physical damage to buildings and infrastructure
- Increased utility and insurance costs
- Decreased serviceable life to owned assets (e.g. office buildings)
- Health & safety impacts to staff and customers

The complexity of risk sharing and transfer arrangements in place with financial counterparties also suggests that flow-through of financial risk exposure to banking and fund managers could be lower than in an unmitigated exposure scenario. To an extent, the ability of financial institutions to change, update and increase pricing and products based upon their exposure (now and in the future) enables the ability for this industry to recover from climate impacts.

Risk Results

Based upon the PCCIA methodology, risks were quantitatively evaluated for a single climate event or scenario leading to financial loss for one typical firm. The results of this analysis indicate ‘medium’ risk now and increase to ‘high’ in future time periods across all regions. It is critical that these results not be interpreted that the finance and insurance sector will not be facing increasing physical risks. This is because quantitative scoring in this case do not reflect increasingly impactful tipping points, cascading impacts, and systemic risks posed to the Finance and Insurance industry.

It is very plausible that in the future, increasing frequency and continued exposure of the Finance and Insurance industry results in year-over-year losses that continue to mount resulting in a loss of confidence, devaluation, or other financial implications. This may lead to shifting product pricing or coverage in certain geographic regions or depending upon the policy context. In an *Insurance Regulator State of Climate Risks Survey* conducted by Deloitte, more than half of the United States insurance regulators indicate that climate change is likely to have a high or extremely high impact on coverage availability and underwriting assumptions, and that risks will likely increase over time due to liability risks, transition risks and physical risks (Deloitte, 2019).

An industry-wide systemic risk assessment would evaluate other categories of consequence as well as the interdependences between the Finance and Insurance industry and other sectors in the face of a climate change (e.g. coverage, policy assumptions, equitable coverage, and pricing of premiums).

Table 9.15: Risk Scores for Finance and Insurance Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	**Level 2 Category**	**Region**	**Climate Risk Scores**		
			Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Financial and Insurance	Insurance Carriers and Related Activities	Central Region	**Medium**	**High**	**High**
Financial and Insurance	Insurance Carriers and Related Activities	Eastern Region	**Medium**	**High**	**High**
Financial and Insurance	Insurance Carriers and Related Activities	Far North Region	**Medium**	**High**	**High**
Financial and Insurance	Insurance Carriers and Related Activities	Northeast Region	**Medium**	**High**	**High**
Financial and Insurance	Insurance Carriers and Related Activities	Northwest Region	**Medium**	**High**	**High**
Financial and Insurance	Insurance Carriers and Related Activities	Southwest Region	**Medium**	**High**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Financial and Insurance	Monetary, Credit, Securities, Funds and other Financial Vehicles	Central Region	**Medium**	**High**	**High**
Financial and Insurance	Monetary, Credit, Securities, Funds and other Financial Vehicles	Eastern Region	**Medium**	**High**	**High**
Financial and Insurance	Monetary, Credit, Securities, Funds and other Financial Vehicles	Far North Region	**Medium**	**High**	**High**
Financial and Insurance	Monetary, Credit, Securities, Funds and other Financial Vehicles	Northeast Region	**Medium**	**High**	**High**
Financial and Insurance	Monetary, Credit, Securities, Funds and other Financial Vehicles	Northwest Region	**Medium**	**High**	**High**
Financial and Insurance	Monetary, Credit, Securities, Funds and other Financial Vehicles	Southwest Region	**Medium**	**High**	**High**

9.7.6 Forestry, Fishing and Hunting Economies

Overview

Forestry, Fishing, and Hunting Economies is comprised of two distinct sub-sectors and will be described separately for the purpose of this report.

Fishing, Hunting and Trapping

The Fishing and Hunting Economy is comprised of activities and establishments primarily involved in hunting, trapping, fishing, and sport-shooting. These activities are an important part of culture, tradition, and personal identity for many residents and Indigenous Communities across Ontario and Canada, as well as provide a source of sustenance. A recent survey and report by the Conference Board of Canada quantified the economic footprint of fishing, hunting, trapping and sport-shooting activities. Their analysis estimated that these contributed $4.7 billion to Ontario's GDP in 2018 and supported 36,900 jobs (Lombardo, 2020; The Conference Board of Canada, 2019). It should be acknowledged that the values from this study have been suggested to be overestimated as a result of study design and methods applied.

Based on 2018 data for Ontario, Fishing and Hunting expenditures account for almost 90% of total spending across the four activities. Ontario also has 37% of all anglers in Canada, 33% of the country's hunters, 21% of the country's trappers and 26% of all Canadian recreational sport shooters (Conference Board of Canada., 2019).

Fishing, Hunting, and Trapping activities were all impacted by COVID-19 restrictions and were exhibited by the closure of access to natural areas and provincial parks as well as loss of non-resident licence fees border restrictions between Canada and the U.S. The Ontario Federation of Anglers and Hunters identifies that it will be a long road to recovery for this industry, and that there continues to be a need for promotion of fishing and hunting to encourage domestic participation and tourism, investments in natural and green infrastructure to support sustainable activities and removal of regulatory barriers for sustainable fishing and hunting opportunities to maximize participation and support conservation-related jobs (Lombardo, 2020).

Forestry, Fishing and Hunting Economies play a key role in tourism across Ontario, and particularly in northern regions. Resource-based tourism relies upon crown lands, waters, and natural resources to attract domestic and international visitors to enjoy activities such as hunting, fishing, camping, hiking, visiting reserves and parks, and viewing wildlife (Ontario Ministry of Tourism, Culture and Sport, 2022b). In northern Ontario, tourism generates approximately $1.6 billion annually and the region welcomes approximately 9.2 million visitors each year (Destination Northern Ontario, 2022). Sustainable and continued access to these resources is critical for the success of resource-based tourism. However, climate change is expected to impact terrestrial and aquatic ecosystems, and thereby lead to cascading impacts on the resource-based tourism sector. Risks are characterized in further detail in the Natural Environment section of this report. For example, if wildfire were to impact significant areas of crown lands where camping, hiking and other activities occur, revenue would be reduced or lost if access and safety concerns lead to closure of natural areas. Similarly, climate change could lead to changes in distribution and ranges of species, which may change the ability of visitors to participate in hunting or enjoy other resource-based activities in northern Ontario.

Recreational Fishing and Hunting are discussed more in depth in the Natural Environment section of this report (Section 7.7.7) as part of ecosystem cultural services and nature-based recreation. Indigenous food and agriculture, including fishing, hunting and trapping, is further described in the People and Communities Area of Focus (Section 8.7.4) of this report.

Forestry and Logging

This subsector comprises establishments primarily engaged in managing and harvesting timber on a long production cycle (generally 60-90 years). Long production cycles use different production processes than short production cycles and are much more dependent on long-term planning and multi-purpose investments in infrastructure. Ontario's forests consist of a variety of species such as spruce, pine, poplar, birch, oak and maple that support a broad range of in-demand products such as lumber, pulp, furniture, flooring, oriented strand board, plywood, veneer and wood pellets (Invest Ontario, 2019).

In 2021, over 12,000 establishments were primarily engaged in Forestry and Logging activities, bringing in an average revenue of $490,000 CAD, but ranging from $30,000 to $5 million CAD (Government of Canada, 2022a). The Forestry and Logging industry also contributed significantly to Canadian exports. On average over the past five years, Ontario exported almost $6.5 billion (CAD) in forest products around the world, accounting for over 96% of the province's total wood product exports (Invest Ontario, 2019; Watkins, 2022). Between 2019 and 2020 in Ontario; however, the gross domestic product (GDP) associated with Forestry and Logging declined by 2.7% (Government of Canada, 2022a). Approximately 20,000 kilometres of primary and secondary forest roads are maintained, and approximately 4,000 kilometres of new road systems (mainly operational roads) are constructed each year to provide access to the province's forest resources.

Forestry road infrastructure (e.g. roads, bridges, and culverts on Crown land) plays a critical role in the forestry and logging industry, with primary roads, branch roads and operational road access providing critical access and enabling economic development in Ontario's forests (Ontario Ministry of Northern Development, 2022b). While primarily used by industrial vehicles engaged in forestry, mining, oil and gas or agriculture operations, these infrastructure systems also provide a portion of rural infrastructure across Ontario that can be used in emergency preparedness and response. Other uses can also include tourism operators, utility and railway companies, Indigenous Communities, hunters, anglers, campers, trappers, cottagers, and the general public (Ontario Ministry of Northern Development, 2022b). Typically, forest roads are maintained by Sustainable Forest Licence Holders through obligations set out in Forest Management Plans (FMPs).

Forestry road infrastructure not only enables the transportation of harvested trees but also provides for forestry renewal – replacing forests after they have been harvested with new species, maintaining and caring for forests and planted species, and enabling adaptive management (Ontario Ministry of Northern Development, 2022c). For example, forest roads are used for technicians to assess newly planted trees and to move in tending crews to enable species diversity, health, and success in a changing climate (Steer, 2021).

Illustrative risk scenarios that were assessed for this Level 1 category can be found in Table 9.16. Table 9.17 provides the risk profiles for each Level 2 category assessed under Forestry, Fishing and Hunting Economies, at the end of this section.

Table 9.16: Illustrative Risk Scenarios for the Forestry, Fishing and Hunting Economies Level 2 Categories

Level 2 Category	Illustrative Risk Scenarios	Strength of Evidence
Fishing, Hunting & Trapping	Changes in climate regime lead to changes in terrestrial and freshwater species distribution and also timing of biological events (spawning, larval life cycles, zooplankton availability) that impact commercial fishing, hunting and trapping companies (e.g. introduction of new species, disease proliferation, non-native species displacement of native species). Extent of an individual business' financial exposure may depend on the nature of ecosystem changes, geographic location of changes, timing (annual, seasonal) and duration/persistence (temporary/permanent).	**Low**
Forestry and Logging	Changes in climate regime can impact forestry and logging companies due to changes in the abundance and distribution of coniferous and deciduous tree species (forest extent) resulting in increase/decrease in volume and quality of potential supply of timber products (impacts to tree health). Wildfire could result in stoppage of industrial/commercial logging operations, and potential loss of merchantable timber.	**Low**

Direct and Indirect Impacts

Ontario's forestry, fishing and hunting economies have significant exposure to climate hazards, and the impacts from climate change on these economies will be wide-ranging. In some cases other Areas of Focus (e.g. Natural Environment, Infrastructure) have assessed physical impacts and risks that are relevant to this industry. For example, climate risks to cold water fish are evaluated to be currently high and rising to very high by mid-century. Likewise, risks to wood supplies are rated medium currently but rising to high risks by 2050. Coniferous and deciduous forest risks are also characterized in the Natural Environment Area of Focus, and additional details are provided in Section 7.7.4 of this report. For the purposes of Business and Economy risk characterization, risks are evaluated based upon possible financial loss associated with the economies of forestry, fishing, and hunting.

In many cases, these economies produce goods upstream of other businesses that then develop or manufacture products for consumer use downstream (e.g. pulp and paper manufacturing rely upon raw materials provided through forest harvesting).

Climate change is anticipated to lead to changes to businesses in these industries in the following ways:

- loss and damage to assets, infrastructure, materials, and equipment
- disrupt or impair companies' ability to produce goods or services and schedule delays,
- create supply chain or logistics delays
- reduction or change key industrial inputs and costs (e.g. materials, commodities, water, electricity, insurance)
- cause health and safety impacts to staff

Climate impacts are characterized briefly for each of the Level 2 industries below.

Fishing, Hunting and Trapping

Changes in climate could lead to changes in terrestrial and freshwater species distribution and shifts to the timing of biological events (spawning, larval life cycles, zooplankton availability) that could affect the commercial fishing, hunting, and trapping industries (Browne and Hunt, 2007). These changes could include, for example, the introduction of new species, disease proliferation, non-native or invasive species and displacement of native species). The extent of financial exposure would be dependent on the nature of ecosystem changes, geographic location of changes, timing (annual, seasonal) and duration or persistence of the impacts (temporary/permanent).

Forestry and Logging

Changes in climate may have a highly uncertain impact on the abundance and distribution of coniferous and deciduous tree species (e.g. forest extent) resulting in increase/decrease in volume and quality of potential supply of timber products (impacts to tree health) (Goetz et al., 2015; Natural Resources Canada, 2020b). Each of these are further described and characterized as part of the Natural Environment Area of Focus in Section 7.7.4. Warmer temperatures (including increase in average winter temperature) could lead to reductions in cold-associated mortality of insect and other pest populations and increase in damaging effects of pests and disease (tree damage and mortality, loss of timber quantity and quality). Warmer temperatures could also lead to an increase in invasive flora and fauna, resulting in threats to native woodland and forest ecosystem. Drought could affect tree health, growth, and productivity - potentially further exacerbated by pest and pathogen stresses. Lastly, change in wildfire extent or the frequency of forest fires could affect volume of supply of timber products. In both cases, impacts may slow the growth rate of timber products, reduce supply across Ontario's forests and elevate prices based on rising demand for domestic and international exports.

Climate impacts can also impact forestry road systems that underpin the ability for companies to harvest, transport, plant, maintain and manage forests across Ontario. Forest roads are not built or maintained to the same level of service or standard as paved public roads (e.g. gravel surfaces, only one lane wide, brush limiting visibility, tight curves, etc.). For example, extreme precipitation can lead to flooding of forest roads, resulting in undermining surfaces, erosion or washouts and the inability to access certain forest management units (Government of British Columbia, 2021). Wildfires can prevent visibility of forest roads if smoke is heavy or may pose hazardous conditions for operations if nearby. In these cases, impacts may result in a delayed access, or total loss of access to certain areas of forests for harvesting and management activities, which can result in a loss of revenue for businesses, as well as cascading impacts to businesses downstream and reliant upon forest products.

Forestry management practices and risks to Ontario's terrestrial ecosystems are described in more detail in Section 7.7.4 of this report.

Risk Results

The risk profile associated with financial impacts to forestry, fishing, and hunting economies both for Forestry and Logging, and Fishing, Hunting and Trapping, are rated 'high'. Risks are already considered 'high' across every region of the province, in light of the exposure these industries have to climate conditions and the possible proliferation of widespread or particularly significant impacts. Risks are anticipated to remain 'high' regardless of how quickly greenhouse gas emissions are mitigated, and this is reflected in these industries having 'high' risk under RCP8.5 (high emissions) and RCP4.5 (moderate emissions) scenarios in future time periods.

A 'high' risk is associated with climate impacts that drive significant loss and/or impairment of business activity in these sectors for an extended period of time (e.g. months or seasonal implications). Furthermore, impacts may lead to a medium to high proportion of annual revenue loss, especially if impacts to the species for which these economies rely upon are impacted (e.g. availability or distribution). The forestry, fishing, and hunting economies are strongly dependent on the state of Ontario's natural environment as well as built infrastructure, which are addressed in Sections 6.0 and 7.0, and provide additional information about types and scale of risks these industries will face.

Table 9.17: Risk Scores for Forestry, Fishing and Hunting Economies Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Forestry, Fishing and Hunting Economies	Fishing, Hunting and Trapping	Central Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Fishing, Hunting and Trapping	Eastern Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Fishing, Hunting and Trapping	Far North Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Fishing, Hunting and Trapping	Northeast Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Fishing, Hunting and Trapping	Northwest Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Fishing, Hunting and Trapping	Southwest Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Forestry and Logging	Central Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Forestry and Logging	Eastern Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Forestry and Logging	Far North Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Forestry and Logging	Northeast Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Forestry and Logging	Northwest Region	**High**	**High**	**High**
Forestry, Fishing and Hunting Economies	Forestry and Logging	Southwest Region	**High**	**High**	**High**

9.7.7 Manufacturing

Overview

Manufacturing in Ontario refers to any establishment primarily involved in the physical or chemical transformation of materials or substances into products, which may be finished for consumption or semi-finished for use in further manufacturing (Government of Canada, 2022a). Manufacturing in Ontario is vital to the economy and provides significant employment for residents in the province. The Canadian Manufacturers and Exporters identified in 2018 that this sector contributed more than 12% of provincial GDP and accounted for more than 80% of Ontario's exports to other markets (Wilson and Greco, 2018). Manufacturing businesses employ more than 770,000 Ontarians, which indirectly supports another 1.5 million residents working in subsequent industries and services. Relative to the rest of Canada, Ontario employs roughly half of the country's manufacturing workers and generates about half of the country's total value of production.

Ontario's manufacturing industry has been facing intense global competition, decreasing investment, and stagnant output and exports (Wilson and Greco, 2018). In the last decades of the of 20th century, for example, an increasing number of manufacturing firms moved operations offshore or to locations with cheaper labour or more lax regulation (e.g. textiles and clothing experienced significant declines in activity and employment in Ontario) (Ontario 360, 2021). As some more labor-intensive manufacturing plants moved offshore, others have remained competitive such as those involved in providing transportation equipment, fabricated metals and other high value manufacturing industries.

As it relates to Ontario's economy, manufacturing also plays a critical role regionally and is a source of economic growth in small to mid-sized communities. Regionally, economic growth has been uneven across Ontario, with areas around Central Ontario (Toronto) and Eastern Ontario (Ottawa) growing quite quickly, and Southwest Ontario and Northern Ontario experiencing slow growth (Ontario 360, 2021). For example, roughly 55% of all employed residents in Ontario live in the Toronto or Ottawa areas, and many of the jobs in these cities are professional, scientific, and technical services (74.5%), or associated with finance and real estate (69.5%). Only 45% of the province's manufacturing workers live in the Ottawa and Toronto area, with the remaining majority living across the rest of the province.

Major manufacturing industries in Ontario include (Wilson and Greco, 2018):

- Motor vehicles and parts
- Food and beverage products
- Chemical products
- Machinery

- Plastics and rubber products
- Fabricated metal products
- Petroleum and coal refining
- Computers and electronics
- Paper products
- Other non-durables and miscellaneous goods

The Canadian Manufacturers and Exporters (CME) undertook a survey to identify challenges faced by companies within this industry. The top three challenges identified by businesses included 1) skilled labour shortages; 2) uncertainty in international trade agreements; and 3) cost increases imposed by government policies such as energy prices or minimum wage increases. Companies also identified that to foster growth in manufacturing in Ontario, the top factor in determining investment location is the availability of skilled labour and proximity to markets (Wilson and Greco, 2018). In 2022, CME released its net zero industrial strategy (Wilson and Arcand, 2022), indicating that many Canadian manufacturers have already made commitments to be net zero, but that transitioning toward those commitments will be very expensive. The strategy identifies that trends in the manufacturing industry continue to shift and transform due to geopolitical pressures, COVID-19, and is expected to lead to more localized production and supply chains to improve resilience and flexibility. Moving forward, there is a need to support small to medium enterprises with net zero transition, to develop effective energy solutions that recognize existing supply needs and the reality that supplies need to vastly increase while investing in new, low carbon resilient technologies (Wilson and Arcand, 2022). CME emphasizes the importance of consistency among climate policies and collaboration to ensure manufacturers remain competitive globally as businesses respond to climate change.

An illustrative risk scenario for manufacturing is presented in Table 9.18. Risk profiles for this Level 1 category can be found in Table 9.19, at the end of this section.

Table 9.18: Illustrative Risk Scenario for the Manufacturing Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Manufacturing	Impact to complex supply chains results in reduced availability of manufacturing inputs/materials and financial effects for manufacturing companies.	**Low**

Direct and Indirect Impacts

Climate change can lead to several impacts to manufacturing, both direct and indirect. Manufacturing companies can be impacted by increases in extreme heat, extreme precipitation and dry conditions or drought. This led to financial impacts to manufacturers in the following ways:

- Loss and damage to assets/infrastructure, materials, and equipment
- Disruption/impairment to service productivity and schedule delays
- Supply chain or logistics delays
- Timing, reduction or changes in variability of key industrial inputs and costs (e.g. materials, commodities, water, electricity, insurance)
- Health & safety impacts to staff

The manufacturing industry is organized around a complex system of interdependent supply chains, which facilitate input materials (e.g. commodities such as crops) and products that are manufactured (e.g. food products). Severe weather events and climate change are already posing risks to global supply chains and are likely to evolve over the coming decades (McKinsey Global Institute, 2020). However, not all supply chains are the same. For example, the more specialized the supply chain, the more severe a climate impact could be for a downstream organization (e.g. if only one source supplies a critical input and has been disrupted). On the other hand, climate impacts on supply chains that have become highly commoditized may affect a larger number of downstream organizations (e.g. by increased prices due to supply shortages) (McKinsey Global Institute, 2020).

Climate impacts could also limit key inputs to manufacturing such as water, timber, or energy, which could negatively impact production. The industry may face additional challenges due to disruptions in supply chains or impacts to supporting infrastructure and services such as energy or communications. For example, the Thailand floods and Japanese tsunami in 2011 resulted in significant losses for Ontario automobile manufacturers due to part shortages and delivery delays (DFAIT, 2012). Supply chain disruptions due to COVID-19 impacted the movement of several products such as lumber and steel, which led to cascading impacts and delays in real estate construction and other sectors (Ontario Construction, 2021).

Extreme weather may further disrupt operations by creating unsafe work environments for employees. Rapid changes in consumer demand could occur with significant changes in climate (e.g. increases in energy demand during extreme heat events) (OCCIAR, 2015).

Risk Results

Manufacturing risks were evaluated based on financial loss and possible disruption to the ability of businesses to continue to deliver the services they provide. The risks that were assessed can be considered as those that affect continued operation, rather than an evaluation of the tactical capacity of manufacturing to absorb climate impacts or adopt technologies and automation designed to improve process efficiency and climate impacts. Manufacturing inputs and outputs could be quantified based on possible financial loss if that information were available and as part of a more detailed risk assessment. For the purposes of the PCCIA, it is important to recognize this dimension of manufacturing, and the fact that processes tend to be more energy-intensive and waste intensive (and therefore costly) compared to building materials and the building envelope. In other words, risk scores should be considered a minimum amount of risk that businesses may face particularly in light of mounting financial costs.

In most cases, businesses within this sector rely on critical inputs from other systems and the supply chain to deliver and manufacture products. For example, in an extreme heat event, a worst possible scenario would be increased heat loading strain, which could exceed a building's HVAC system climatic design values (e.g. envelope component thermal glazing units, thermal breaks and seals; cooling loads of mechanical cooling equipment). This could then lead to cooling system underperformance or failure. The more strain, the higher chance of complete failure. The result would be potential closure of the facility, interruption of business services, and costs of equipment repair and/or replacement. Based on the PCCIA Methodology Framework (External Resource – 1), impacts were evaluated for the most probable worst-case event, which is considered to be the underperformance of a building's HVAC systems in the event of extreme heat, such as a 10% decrease in system efficiency resulting in increasing volume/cost of energy consumption.

Similarly, in the event of a drought, an example risk scenario could be a time-limited (e.g. several days) stoppage of manufacturing activity in the event that the water supply is disrupted. In this case, depending on the volume required, water from another source could be used but at the cost of its purchase and transportation.

Climate risk, or the risk profile for a typical manufacturer in Ontario, was determined to be currently 'low'. However, risk is expected to rise to 'medium' by the end of century under the high emissions scenario, RCP8.5. In this case, the extent and pace at which we reduce greenhouse gas emissions matters in the context of how impacted manufacturers in Ontario will be. If emissions are mitigated and a more moderate emissions scenario (RCP4.5) is achieved, climate risk is expected to remain lower for this industry (see Appendix 7).

Interdependencies with the global supply chain will likely have significant future risks to manufacturing in Ontario (e.g. climate impacts to sources and supplies elsewhere in the world leading to disruptions or shortages). These cascading impacts are not quantitatively factored into these scores. Furthermore, the manufacturing industry is uniquely positioned in the context of climate resilience such that companies with emissions-intensive operations have an opportunity to reduce greenhouse gas emissions though the adoption of skills and tools linked first to efficiency and automation, but also to the potential for circular recovery of waste or underutilized resources. In doing so they may reduce the climate impacts experienced in the future. Essentially, a global operation could ensure resilience to their own supply chain by considering sources and supplies they rely upon and reducing the carbon-intensity of their operations. In so doing, future significant disruptions to their manufacturing business may be mitigated.

Table 9.19: Risk Scores for Manufacturing Level 1 Category

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Region	Climate Risk Scores		
		Current	2050s (RCP8.5)	2080s (RCP8.5)
Manufacturing	Central Region	Low	Low	Medium
Manufacturing	Eastern Region	Low	Low	Medium
Manufacturing	Northeast Region	Low	Low	Medium
Manufacturing	Northwest Region	Low	Low	Medium
Manufacturing	Southwest Region	Low	Low	Medium

9.7.8 Mining, Quarrying and Oil/Gas Extraction

Overview

This industry refers to establishments primarily engaged in extracting naturally occurring minerals, whether they are solids (e.g. coal, ores), liquids (e.g. crude petroleum) or gases (e.g. natural gas). This industry also includes businesses involved in quarrying, aggregate extraction, well operations, milling and exploration of minerals (Government of Canada, 2022a). Ontario is one of Canada's largest mineral producers, generating $11.1 billion worth of minerals in 2021 and representing 20% of the country's total mineral production value. As of December 31, 2021, there were 317,426 active mining claims in Ontario that include those for gold, copper, nickel, zinc, platinum group metals, salt, and structural materials (LMSID, 2018). In 2021, mining in Ontario contributed an estimated annual total of $8.0 billion to GDP (Ontario Mining Association, 2021), with a large presence of mining companies publicly listed on the Toronto Stock Exchange (TSX) resulting in equity capital to be financed within Ontario and having a spillover effect on the province's financial sector (see Section 9.7.5).

Production in the non-metal industry largely includes stone, sand, gravel, and diamonds and was valued at $2.3 billion in 2017, lagging behind metallic production valued at almost $7.5 billion. This is an industry that also relies upon external and international market pricing for commodities like oil, copper, nickel, and gold, all of which are important to employment in Ontario. Evidence suggests that movements in nickel and copper prices are most dependent on demand and business cycles, but supply levels are challenging to predict in part because of their dependence on government policy and the world economy. Oil and gas extraction is a relatively small subsector in Ontario and thus a decline in oil prices and investment has had minimal employment impact in the overall industry (LMSID, 2018).

Like the construction industry (see Section 9.7.4), the Mining, Quarrying, Oil and Gas Extraction Industry also faces significant challenges in the near future with an aging labour market and subsequent need to replace retiring workers and transfer specialized skills to different generations of staff. These challenges are particularly pronounced in the north where the activities are concentrated and where recruitment can be challenging.

Regionally, Northeast Ontario employs the greatest numbers of workers in this sector – almost 50% of employment, with concentration around Sudbury and Timmins. Central Ontario, namely the Toronto region, employs the second greatest number of workers at just over 15% of the industry. These companies largely support mining operations and employ workers in management, financial auditing, and geology. In Northwest and the Far North, gold production dominates the industry in this region, with just over 10% of industry employment. These regions are broadly considered the key to future Ontario mining due to economic potential based on significant critical mineral deposits including nickel, copper, platinum and chromite (LMSID, 2018).

Ontario has identified several pillars in developing and expanding this industry (Ontario Ministry of Northern Development, 2022a):

- Enhance geoscience information and supporting critical minerals exploration
- Grow domestic processing and create resilient local supply chains
- Improve Ontario’s regulatory framework
- Invest in critical minerals innovation, research and development
- Build economic development opportunities with Indigenous partners
- Grow the labour supply and develop a skilled labour force.

Illustrative risk scenarios for this Level 1 category are presented in Table 9.20. Risk profiles for Level 2 categories assessed under mining, quarrying and oil/gas extraction can be found in Table 9.21, at the end of this section.

Table 9.20: Illustrative Risk Scenario for the Mining, Quarrying and Oil/Gas Extraction Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Mining, Quarrying and Oil/Gas Extraction	Interruption or failure of external power supply, disruptions to water available for industrial processes or operational disruptions from extreme weather and wildfire impact mining, quarrying and oil & gas extraction companies.	**Low**

Direct and Indirect Impacts

The Mining, Quarrying and Oil/Gas Extraction Industry have unique context in that there is a need to reduce the carbon intensity and/or emissions associated with activities to mitigate climate change, as well as reduce the impacts and risks to businesses and their operations at the same time. Furthermore, activities in these industries typically result in changing land use and tend to leave lasting remediation works or sites with tailings present that require long-term management, containment, and treatment to avoid health and environmental impacts adjacent to sites and/or downstream (Rodgers and Douglas, 2015). Approaches and frameworks to manage risks related to mining activities have been developed and these provide an excellent opportunity to consider climate change impacts and risks at the site level. The National Orphaned/Abandoned Mines Initiative (NOAMI) also provides a suite of resources where sites have been orphaned or abandoned, often with decades-long implications.

This section describes impacts and risks to mining businesses themselves and their activities. Mining, Quarrying and Oil and Gas Extraction businesses could be impacted by changes in extreme heat, mean and extreme precipitation, and drought conditions. This could lead to financial impacts in Mining, Quarrying and Oil & Gas Extraction Industries in the following ways: asset/infrastructure loss & damage, disruption/interruption of key business processes, changes/ reduction/variability of availability of key industrial inputs and costs (e.g. materials, water, energy, insurance), decrease in asset serviceable lifespan, and health and safety impacts to staff.

Risk Results

Based on the identified risk scenarios for this Level 1 category, risk scores for a typical company in this industry are expected to be 'medium', and do not increase or decrease significantly in the future. The illustrative examples above indicate some of the rationale behind this risk level, which represents a single event occurring and the impacts to annual revenue and service disruptions.

If a wildfire event were to occur, this could result in the stoppage of Mining, Quarrying and Oil/Gas Extraction operations. There would be clear and direct health and safety impact to company staff, possible disruptions to electricity supply and transportation or supply chain networks (e.g. shipment of commodities). Based upon the assumption that commercial and provincial government wildfire suppression and abatement practices are in place, a risk scenario could be a stoppage in industry functions lasting up to one week. Financial implications of this scenario would be expected for a short duration of time, representing a low proportion of annual revenue.

As a second illustrative example: drought conditions are driven by a decrease in water (both groundwater and surface water) availability for mining and quarrying (which would be used in production such as in mineral dissolution in brining processes, dust suppression, mine drainage and tailings covering). This decreased availability of water could lead to insufficient process water for operations as well as water resources abstraction or discharge licenses being reduced or revoked, with companies unable to meet dust emissions or suppression requirements. Under this risk scenario, shut down of company operations could occur for weeks to months during a hot, dry summer season. Financial impacts would be expected to be significant, but for a short period of time resulting in a moderate proportion of annual revenue loss.

A third example of a scenario evaluated for this industry includes extreme precipitation conditions. Extreme precipitation or changes in groundwater flow regimes could lead to increased contaminant transport (e.g. acid mine drainage) due to increased runoff of untreated water to adjacent watercourses to mine sites. Changing precipitation conditions could also reduce the number of options available for hazardous chemicals and pollutant disposal. For Oil and Gas infrastructure specifically, extreme precipitation conditions could lead to soil saturation, movement or undermining of pipes and buried assets, and increased maintenance requirements to ensure operational safety. All of these risk scenarios could result in reputational issues, regulatory non-compliance, and legal liability for businesses in this industry. A risk scenario could be a time -limited overtopping of a retention pond prior to applying mitigation measures, leading to discharge of contaminants in excess of permitted approval levels. The financial impacts associated with this scenario, for a single discharge of contaminants, could be up to three million dollars based on historical precedent and “typical” fines levied for similar effluent discharge.

Table 9.21: Risk Scores for Mining, Quarrying and Oil/Gas Extraction

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Region	Climate Risk Scores		
		Current	2050s (RCP8.5)	2080s (RCP8.5)
Mining, Quarrying and Oil/Gas Extraction	Central Region	Medium	Medium	Medium
Mining, Quarrying and Oil/Gas Extraction	Eastern Region	Medium	Medium	Medium
Mining, Quarrying and Oil/Gas Extraction	Far North Region	Medium	Medium	Medium
Mining, Quarrying and Oil/Gas Extraction	Northeast Region	Medium	Medium	Medium
Mining, Quarrying and Oil/Gas Extraction	Northwest Region	Medium	Medium	Medium
Mining, Quarrying and Oil/Gas Extraction	Southwest Region	Medium	Medium	Medium

9.7.9 Retail Trade

Overview

The retail trade sector broadly refers to businesses primarily engaged in retailing merchandise and rendering services associated with the sale of merchandise. This sector includes both store and non-store retailers. Store retailers operate fixed point-of-sale locations, designed to attract walk-in customers. Non-store retailers are organized to serve the public but use different methods such as publishing of infomercials, direct-response advertising, electronic catalogues, door-to-door sales and distribution by vending machines (Government of Canada, 2022a). Retail Trade can include various types of stores, such as motor vehicle dealers, furniture stores, electronics and appliance stores, food and beverage stores, gas stations, clothing stores, sporting goods, bookstores, among others.

Spending within the retail sector is broadly used as one indicator of economic growth and activity, particularly on a monthly or quarterly basis (Sondhi, 2022). In so doing, retail sales are often used as a narrative of disposable income and the ability of residents across Ontario to afford products and consumer goods. For example, in May of 2022, a report by TD bank states "higher prices and interest rates will begin to weigh on household budgets in the second half of the year, prompting consumers to tighten their purse strings." (Sondhi, 2022). However, this is a sector that was significantly impacted due to COVID-19 restrictions and public health measures. The Ontario Chamber of Commerce identifies that Retail Trade revenues remain well below pre-pandemic levels due to labour shortages and is one of the most pessimistic sectors within Ontario for confidence (OCC, 2021).

Retail Trade across Canada represents just under 11% of Canada's entire workforce, with about 66% of jobs in the sector being full-time as of 2019 (Retail Council of Canada, 2019). It is a significant part of the Canadian economy, with revenues exceeding $636 billion (Sarra, 2022).

In 2020, wholesale and Retail Trade made up just over 10% of Ontario's nominal GDP (Government of Ontario, 2021d). In a similar manner to some other industries described in this Area of Focus (e.g. manufacturing in Section 9.7.7), the presence or types of retail sales can vary widely depending on the size and location of municipalities. The Retail Council of Canada identifies that while municipalities may differ as agricultural hubs, mining towns, manufacturing centres, among others, retail is the critical link in the supply chain process and connects producers to households (Retail Council of Canada, 2019).

Regionally, in Central Ontario, retail and wholesale trade remain significant components of Toronto's economy with the sector employing over 400,000 individuals (TWIG, 2021). The Ontario Chamber of Commerce reported on regional employment changes (%) in 2021 and 2022 more generally in their 2022 Economic Report (OCC, 2022). The authors indicate that all regions, except Northeast Ontario, saw positive employment growth in 2021 and moderate to strong rebound from the pandemic in Windsor-Sarnia and Kingston-Pembroke, with Northwest Ontario seeing a milder rebound (OCC, 2022). As regional employment and economic activity continues to rebound, spending and growth in Retail Trade has a more positive outlook, recognizing that inflation and interest prices may impact consumer spending in the future.

An illustrative risk scenario for retail trade is presented in Table 9.22. Risk profiles for this Level 1 category can be found in Table 9.23, at the end of this section.

Table 9.22: Illustrative Risk Scenario for the Retail Trade Level 1 Category

Level 1 Category	Illustrative Risk Scenario	Strength of Evidence
Retail Trade	Interruption or failure of external power supply results in financial effects for retail trade companies, depending on duration of power interruption and existence of on-site back-up power generation capacity.	**Low**

Direct and Indirect Impacts

Climate change poses a variety of risks to retailers across Ontario and includes direct physical risks, transition risks and systemic risks. The increasing frequency and intensity of acute events such as flooding and wildfires are destroying retail assets, disrupting supply chains and distribution channels, creating uncertainty in availability and pricing of raw materials, and increasing insurance costs (Sarra, 2022). Furthermore, retailers are increasingly experiencing rising litigation related to companies failing to mitigate the impacts of climate change, failure to adapt, insufficiency of disclosure regarding material financial risks, and 'greenwashing' with substantial fines being levied for retail misrepresentation.

Extreme temperature changes can damage retail, storage, and distribution premises and prevent access. Extreme weather events can disrupt operations and supply chains and create employee safety concerns (Sarra, 2022). The Insurance Bureau of Canada reports that flooding in Canada causes annual average economic losses of over CA$1.2 billion, of which CA$800 million are uninsured (IBC, 2021b). If acute events continue to rise pace, insurance will become prohibitively expensive for some retailers and there is risk that it may become unavailable in some high-risk areas in the future. A report in 2019 by S&P Global identified that weather is already a significant swing factor in a retail company's results (Shoeb and Yoshimura, 2019).

Retail businesses also face significant indirect impacts from supply chain disruption, uncertainty in the availability and pricing of raw materials (particularly those at risk), and changes in water quality and availability. Risks facing Canadian retailers are exacerbated when suppliers are in countries that are feeling climate impacts even more, as it alters the availability of raw material (Sarra, 2022). Depending on the region of Canada or globally from which retailers purchase their products, there are risks from drought and rising costs of inputs such as agricultural production and clean water for manufacture of food, drink, and apparel.

Retail Trade activities could be impacted from climate change and lead to financial impacts in the Retail Trade industry in the following ways:

- Loss and damage to assets/infrastructure, materials, and equipment
- Disruption and/or impairment to service productivity
- Supply chain or logistics delays
- Changes or reduction of key industrial inputs and rising costs (e.g. materials, commodities, water, electricity, insurance)
- Increased variability in consumer demand for seasonal goods and services
- Health & safety impacts to staff and customers

Risk Results

The risks associated with a typical retail company have been determined to be currently 'low' but increasing to 'medium' by the end of the century under a high emissions scenario (RCP8.5) in all regions except the Far North. It is anticipated that under a scenario with significant loss of contents and access or function to a retail company (but not total failure), disruption to services would be significant but for a short duration of time. Financial loss within one year could be considered relatively low compared to total annual revenues. Recall that these risk scores only reflect the risk of a climate scenario occurring for one typical–business - not cascading impacts between companies, supply chains across the entire industry. Under a scenario where electricity supply is disrupted and building performance is reduced to 0% (e.g. no service) from one climate event, this could result in a significant reduction in business service activity for a short period of time (e.g. a few days).

More broadly speaking, evidence suggests that physical climate risks to retail trade are expected to grow in the future and retail companies will have to engage in adaptation strategies in addition to reducing greenhouse gas emissions. In many instances, the long term chronic physical impacts on the retail market are not yet known, particularly longer-term changes in the availability of key inputs for supply chains (Sarra, 2022).

One illustrative example of impacts and opportunities for a sub-sector within retail trade is food and beverage retail, which is where food production, distribution and consumption intersect. This is a sub-sector not only reliant upon supply chain systems to distribute commodities to market, but also one of the most energy intensive in the retail sector due to refrigeration and cooling needs (Putnam, 2021). Opportunities exist for the food and beverage retail industry to undertake corporate and supply chain risk assessments that focus on supply chain reliance and opportunities for resilience food systems. For example, the ice storm of 2003 resulted in power interruption of up to three days. Evidence suggests that most food retail stores in Toronto may only have three days of fresh food and up to 17 days of all food products in stock (Zeuli et al., 2018b). There is therefore a need to examine food systems and food security across sectors and systems (see Section 10.1 for a discussion regarding food security). Ontario's Food Terminal in Toronto, for instance, is the largest wholesale fruit and produce distribution centre in Canada, and the third largest in North America, supporting local farmers, independent and chain food retailers, restaurants and many others (Ontario Food Terminal Board, 2021). The reliance upon, or opportunities from, critical distribution centres, could be an important next step in characterizing increasing climate risks over time.

Table 9.23: Risk Scores for Retail Trade

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	**Region**	**Climate Risk Scores**		
		Current	**2050s (RCP8.5)**	**2080s (RCP8.5)**
Retail Trade	Central Region	**Low**	**Low**	**Medium**
Retail Trade	Eastern Region	**Low**	**Low**	**Medium**
Retail Trade	Far North Region	**Low**	**Low**	**Low**
Retail Trade	Northeast Region	**Low**	**Low**	**Medium**
Retail Trade	Northwest Region	**Low**	**Low**	**Medium**
Retail Trade	Southwest Region	**Low**	**Low**	**Medium**

9.7.10 Transportation Economy

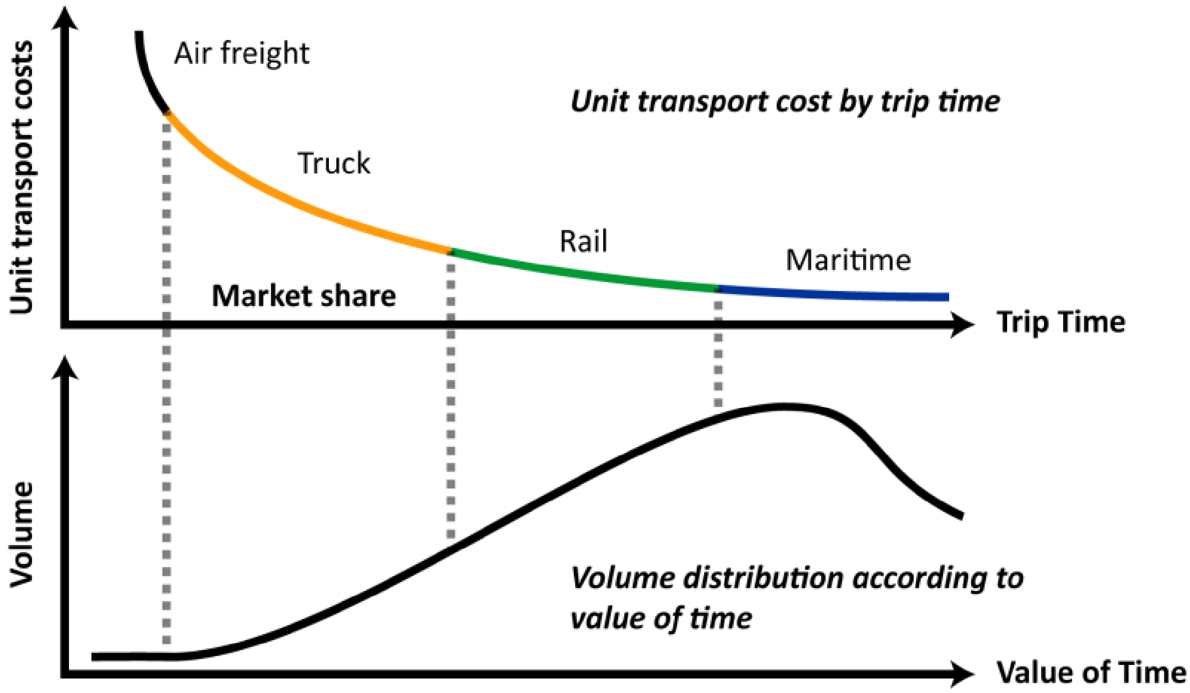
Overview

The Transportation Economy broadly refers to the movement of people and products both within and across Ontario, as well as external to the province to international markets. The Transportation Economy can refer to movement by trucking on roads (both long distance and local freight), on rail corridors, through air transportation, or by water.

Across Canada, there are three primary trade routes: the Western Corridor, the Atlantic Corridor, and the Continental Corridor. The latter, also referred to as the Ontario-Quebec Corridor, is the busiest of Canada's three major transportation corridors, with primary modes of transportation being road, rail and water transportation. Air transportation is also a significant mode with Toronto Pearson International, Montreal-Mirabel International and Montreal-Pierre Elliott Trudeau International Airports accounting for 54% of Canadian air traffic cargo in 2016 (TAC, 2021).

The selection or rationale for the movement of goods depends on numerous factors (e.g. size and type of cargo, time, costs of shipping, destination, distance, availability of services, among others). Figure 9.3 illustrates considerations for which mode of transportation is best based on costs, volume, and value of time (TAC, 2021). As illustrated in the figure below, cost, value, and distance are interdependent. For example, time sensitive goods and low-volume goods such as medical equipment or precious gems will most likely be shipped by air, since their cost per unit is higher. These costs can be absorbed by the sale value of the cargo. On the other hand, the value of un-refined crude oil or iron ore will be lower per unit-weight and less time-sensitive but higher in volume, hence the use of the slower but higher-capacity transport modes (TAC, 2021).

Figure 9.3: Modal Choice in the Transportation Economy: Modal Choice based on Cost, Volume and Value of Time



The transportation economy not only underpins numerous other sectors, but its infrastructure is in a deficit position and in need of maintenance, upgrades, and bolstered investment (see Section 6.7.5). Infrastructure ownership also varies, depending on the mode of transport: generally, roads are owned by governments, railways are private, airports are run as not-for-profit, and ports have mixed ownership/operation. From a business perspective, half of the businesses in Ontario consider transportation infrastructure critical to ensuring their competitiveness within the market, but 58% rate the ability of transportation infrastructure as fair or poor in meeting their needs (OCC, 2018).

Air Transportation

Goods shipped by air are typically high-value and time-sensitive merchandise such as pharmaceuticals, medical and electronic equipment, and precious metals (TAC, 2021). This mode of transportation is also used to supply cargo to remote communities. Air transportation in Canada is managed by NAV CANADA, one of the largest air navigation service providers in the world by total instrument flight rules (IFR) flight hours, which manages the world's third-largest aerospace sector, at over 18,000,000 kilometers (TAC, 2021). Airport authorities, as non-share and not-for-profit entities, have organizational structures that place the responsibility locally, rather than on the federal government. For instance, in Central Ontario, the Greater Toronto Airports Authority (GTAA) operates Toronto Pearson International Airport, and it has a board of directors comprised of community members such as local boards of trade, Professional Engineers Ontario, municipal representatives, among others. For commercial passengers using air transportation, Toronto Pearson is the busiest airport across Canada, handling over 47 million passengers per year (Toronto Pearson, 2021).

Deep Sea, Coastal and Great Lakes

The Ontario-Quebec Corridor also provides critical connection points to the Great Lakes and St. Lawrence Seaway, providing direct access from the Atlantic Ocean inland and creating the shortest route between Europe and part of the U.S. Midwest (TAC, 2021). Approximately 30,000 tonnes of freight originates in or is destined for Ontario by domestic waterways annually (Woudsma and Towns, 2017). Major ports within the Ontario-Quebec corridor include the Port of Montreal, Port of Thunder Bay, and Port of Sept-Iles. These ports compete with the Port of New York, as well as other Canadian ports for business in order to be the port of call in a specific corridor for the commodities that the specific port is capable of handling, since ports will vary based on the type of port (gateway, local, or transshipment), and commodities (container or liquid bulk) (Notteboom and Yap, 2018).

From a regulatory perspective, water transportation often requires binational or international coordination and commitments to ensure safety, security and environmental protection of shipping within the vicinity of international coastlines (e.g. as per International Maritime Organization (IMO, 2022), the International Joint Commission (IJC, 2022), and/or the Great Lakes Water Quality Agreement between the U.S. and Canada). Hundreds of other lakes and rivers in Ontario, particularly in the Northwest, Northeast and Central regions, also provide shipping, tourism, recreation, and subsistence benefits (Woudsma and Towns, 2017).

Local and Long-Distance Freight Trucking and Delivery Services

The majority of goods transported by road in North America are moved by heavy-duty trucks (Wiginton et al., 2019). As described above, the Continental Corridor between Ontario and Quebec includes transportation via Highway 401, which is the busiest highway in North America. Highway 401 serves as the primary route for east-west travel within Ontario and serves as critical connection points to intermodal terminals, the four largest facilities are located within the Greater Toronto Area (GTA) and Montreal and serve as key hubs for the efficient movement of goods (TAC, 2021). Road networks and freight trucking also connects Ontario and Canada to the U.S. Midwest and Northeast.

Goods movement by truck is critical to Ontario's economy but contributes significantly to greenhouse gas pollution. A total of 38% of Ontario's economy comes from freight-intensive industries, but heavy-duty trucks alone are now responsible for just under 10% of Ontario's emissions. From 1990 to 2014, the volume of road freight activity in Ontario grew by 242% (Wiginton et al., 2019). As demand for goods increases and truck activity increases, it is anticipated that fewer vehicle efficiency gains will be made for heavy-duty trucks in comparison to light vehicles, and thus emissions from freight are expected to bypass those from passenger movement around 2030 in Canada (Wiginton et al., 2019). Furthermore, as needs increase for freight trucking and delivery, barriers such as congestion on Ontario roads, notably within the Greater Toronto Hamilton Area, will increase operating costs for trucking companies (Toronto Region Board of Trade, 2017). Congestion costs Canadian businesses and consumers between $500 and $650 million per year in higher prices for goods (OCC, 2021).

In a survey of 23 upper, lower and single tier municipalities across Ontario, the Pembina Institute found that in larger urban areas, such as the Greater Golden Horseshoe, there is a need for region-wide authorities to take a stronger role to coordinate freight action to bolster data collection, establishing a goods movement network and setting standards (Wiginton et al., 2019). At the municipal level across Ontario, there is a need for improved internal collaboration and to build deeper relationships with local industries (e.g. logistics, warehousing, retail, etc.).

Rail Transportation

Across Canada, there is approximately 41,700 route-kilometres of rail track, owned primarily by CN (52%) and CP (31%) rail companies, as well as 19 intermodal terminals and 27 border crossings with the U.S. (TAC, 2021). There are over 60 rail companies that operate on Canada's rail network, and freight transportation specializes in bulk commodities and containerized traffic over long distances. Imports by rail tend to be automotive and chemical products, while primary exports are similar in addition to forest products and metals. Regionally across Ontario, rail transportation provides critical services to areas in Northeast and Northwest Ontario, such as through Ontario Northland. Ontario's rail network also includes 10 local and regional freight operators, 11 tourist railways, three light rail and subway systems (e.g. Toronto, Ottawa and Kitchener-Waterloo), and the GO transit system, providing regional passenger services in Southwest and Central Ontario (Woudsma and Towns, 2017).

Historically and over time, rail transportation faces several challenges in Ontario that can be exacerbated by climate impacts. Maintenance investment, for example, such as the grade of steel used, the condition of rail beds and the ties, has been limited (Woudsma and Towns, 2017). Rail transportation networks between Canada and the United States and restrictive clearance limits Ontario's ability to deliver significant volume of goods and food, resulting in more demand to move products by freight truck. A lack of direct connectivity to extra-regional intermodal hubs in Eastern Canada, Western Canada and the United States means products must move by truck through the Greater Toronto Area causing congestion, where 20% of trucks moving through highways neither originate nor end in Ontario. Simply put, the transportation network is not balanced for import and export trade with 95% of food and consumer shipments exit Ontario by truck, whereas over 80% of consumer shipments enter Ontario by rail.

Direct and Indirect Impacts

Climate impacts to the Transportation Economy, both direct and indirect, can affect public and political perceptions of risk and lead to damage of infrastructure, disruption to goods movement, shut down of transportation and signal networks, and/or stranded travelers (Woudsma and Towns, 2017). Widespread climate impacts on transportation networks may not be felt uniformly across Ontario, with regions more dependent on roads and highways or with less redundancy for mobility being disproportionately impacted.

Illustrative risk scenarios that were assessed for this Level 1 category can be found in Table 9.24. Table 9.25 provides the risk profiles for each Level 2 category assessed under Transportation Economy, at the end of this section.

Table 9.24: Illustrative Risk Scenarios for Transportation Economy Level 2 Categories

Level 2 Category	Illustrative Risk Scenario	Strength of Evidence
Air Transportation	Interruption or failure of air transportation, or disruption of air transportation support and control services due to an extreme winter precipitation event (e.g. snow, freezing rain) results in financial effects.	**Low**
Deep Sea, Coastal and Great Lakes Transportation	Interruption or failure of transportation vessels and public & private port infrastructure due to a climate risk event results in financial effects.	**Low**
Local Freight Trucking	Interruption or failure of public and private transportation infrastructure due to a climate risk event results in financial effects for local freight trucking and delivery services.	**Low**
Long Distance Freight Trucking	Interruption or failure of public and private transportation infrastructure due to a climate risk event results in financial effects for long-distance freight trucking services.	**Low**
Rail Transportation	Interruption or failure of rail infrastructure, or disruption of rail services due to a climate risk event results in financial effects.	**Low**

Air Transportation

Much like the other industries described above, air transportation can be considered a network where impacts at one location (e.g. an airport) can have a negative ripple effect disrupting air travel and causing delays across Ontario, Canada or North America. Past climate impacts have been associated with extreme weather events (e.g. storms, high winds, fog), extreme cold (e.g. operational impacts on fueling or reducing the ability for chemical treatments to melt ice and snow on airplanes) (Woudsma and Towns, 2017).

Climate change is expected to bring increased variability in extreme weather and rising temperatures, both of which can pose risks to air transportation and the ability of reliable timing and productivity of airlines and transportation companies. Warming temperatures may result in decreased air density providing less lift for aircraft, thereby increasing fuel requirements (costs) and the need for longer runways (Woudsma and Towns, 2017). Impacts to runway materials and safety due to extreme heat may also pose risks from safety and/or delay to aircraft. Rising rain on snow events, or more rain falling in the winter season, may also delay winter operations. Companies within this industry are expected to face risks related to rising prices for fuel, insurance and materials, and more frequent replacement of assets due to decreased serviceable life spans of assets.

Deep Sea, Coastal and Great Lakes

Deep sea, costal and Great Lakes transportation industries can be impacted due to a variety of weather events. Changes in extreme heat and cold, precipitation and drought can lead to longer term rising costs to businesses operating within this industry (e.g. increased for repair or replacement of assets due to shorter lifespans) or more acute impacts as a result of extreme weather conditions on the Great Lakes themselves (e.g. due to high or low water levels). For example, during years of lower water levels, coastal or harbour infrastructure can be exposed and damaged, and shipping routes can be disrupted due to issues of access (Woudsma and Towns, 2017). While significant uncertainty remains in modeling future water levels across the Great Lakes, preliminary results indicate higher variability in water levels – higher highs and lower lows (Seglenieks, 2020). Lower water levels in particular carry a higher potential for far reaching economic impacts, making this a key concern for Ontario's economy (Woudsma and Towns, 2017).

Increased variability poses a variety of risks to this industry more generally, such as infrastructure decay, requirements for additional dredging of navigational channels, flash flooding of inland watercourses due to ice jams, ship handling or navigation challenges, among numerous others (Woudsma and Towns, 2017). A shift in seasonal navigation may also pose operational risks in that construction and maintenance schedules for assets may fall out of alignment with operational demands (e.g. extended or year-round shipping shortening the layup period for operators) (Woudsma and Towns, 2017). Localized seiche impacts, resulting in rapidly changing water levels, can also pose risks to marine transportation in the Great Lakes. For example, in September 2014, seiche event on Lake Michigan changed water levels by more than three metres in under an hour, causing dry marinas beforehand to become flooded suddenly, destroying vessels and infrastructure (Woudsma and Towns, 2017). Additional risks posed to this industry include health and safety impacts to staff and customers, and in changes or increased prices of critical costs (e.g. fuel and insurance of vessels).

Increasing air temperatures and changing climate conditions can also lead to impacts on water quality in the Great Lakes and in watercourses where transportation or transportation-reliant tourism occurs. For example, warmer waters, prolonged stratification, and increased nutrient loading can lead to the creation of harmful algal blooms (GLISA, 2022). These algal blooms pose health and safety risks in accessing, using, and enjoying water as well as can result in lack of access for transportation routes, lead to clogging of infrastructure and docks, and pose risks to any tourism-related activity requiring transportation. From an economic perspective, impacts could include delays, lost revenue and/or the inability to deliver people and goods to their destination.

Local and Long-Distance Freight Trucking and Delivery Services

Local and long-distance freight trucking and delivery services are reliant upon road networks and supporting infrastructure. Climate impacts, such as extreme precipitation, could lead to washouts of road segments, which can lead to stranded travelers, delayed emergency responders, and affect economic flows (Woudsma and Towns, 2017). Extreme heat and increased variability in climate conditions may result in roads requiring earlier or additional maintenance over their life spans. Warming temperatures may pose some opportunities in Ontario, such as longer construction seasons and reduced winter maintenance requirements, but also shorten and threaten the ability to operate winter roads in Northern regions of Ontario. Financial consequences of a shorter winter roads season could include less time for the movement of freight and people in some regions, higher maintenance costs, reduced load capacity and the failure of road embankments (Woudsma and Towns, 2017)

From the perspective of local and long-distance freight companies, degradation and damage to roads and supporting infrastructure may worsen congestion drivers face, may increase delays and costs in shipments, and reduce the ability to pull over safely or stop throughout long-haul routes. Various weather events and conditions (e.g. heat, cold, extreme precipitation, wildfire) could lead to financial impacts to these businesses in the following ways:

- Loss & damage to assets
- Disruption and/or impairment in service quality, productivity, and timing
- Health & safety impacts on staff
- Variability or increases in costs (e.g. fuel, insurance)

Trucks also face unique risks and opportunities as further investment, and adaptation occurs in Ontario's energy systems. For example, Canada's heavy-duty vehicle and engine greenhouse gas emissions regulations or other national programs cannot deliver the reductions to meet Canada's commitments to reduce emissions internationally. To do so requires a major shift from diesel fuels that have long dominated the trucking industry by providing range, pulling power and reliability (Woudsma and Towns, 2017). Likewise, the capacity of Ontario's existing energy systems requires significant investment to enable a shift towards fuel switching or low carbon opportunities (see Section 10.2). As research and actions continue to accelerate development and testing of new zero emissions heavy-duty truck technologies, such as working with utilities and the hydrogen industry (Wiginton et al., 2019), businesses may face changing regulatory requirements, technological change, and rising costs to maintain continuity of services.

Rail Transportation

The rail transportation industry, in many ways, has been on the front lines in terms of experiencing and managing climate impacts under the need for operations and transportation of people and goods across Ontario. Extreme precipitation events have already led to significant impacts on the GO train corridor in July 2013 (Chiotti, 2016). For example, a commuter passenger train was stranded, and resulted in more than 1,000 passengers awaiting hours for rescue. Extreme heat events have already led to steel rail lines buckling in Ontario and Manitoba (Woudsma and Towns, 2017), and rising extreme temperatures pose high risks to operational challenges such as in Southwest, Central and Eastern Ontario where extreme temperatures are projected to be highest.

Rail transportation agencies and operators have been implementing measures to reduce risks throughout transportation routes. For example, Metrolinx, an Ontario agency with a mandate of improving the coordination and integration of all modes of transportation in the Greater Toronto and Hamilton Area (GTHA), has implemented several operational measures such as patrolling rail corridors, inspecting culverts underlying rail beds, speed restrictions or slow orders on hot days and rail adjustments where early problems may appear (Chiotti, 2016).

However, climate change is anticipated to continue to increase risk for rail transportation, such as increased need for maintenance, decrease in serviceable life of track assets, disruptions or service that could lead to reputational challenges, productivity and timing in transportation routes, and health and safety impacts to staff and passengers.

Risk Results

The risk to the Transportation Economy was assessed by Level 2 category and by Region across Ontario. Risk scores were determined for current, 2050s and 2080s under a high emissions scenario (RCP8.5) and moderate emissions scenario (RCP4.5). Table 9.25 illustrates Transportation Economy risks by Level 2 category for each time period, operating under a RCP8.5 scenario (high emissions).

The highest risks to the Transportation Economy are currently associated with marine transportation (deep sea, coastal and great lakes) across every region of Ontario. Risks associated with marine transportation are considered 'high' at current and remain 'high' in all future time periods. These results are in part due to the increasing variability and financial consequences of extreme weather and variability of the Great Lakes.

Risks to rail transportation are classed as 'medium' under current climate conditions but rising to 'high' by mid-century and remaining high out until end of century. This increasing risk profile for rail companies and businesses in this industry reflects the increasing frequency or impacts associated with extreme heat, namely possible heat kinks or impacts to rail corridors resulting in disruptions to transportation schedules and reliability.

Risks to air transportation were evaluated to be 'low' under current and 2050s conditions and rising to 'medium' by end of century. This increase in risk, albeit at a slow rate of increase compared to rail transportation, is largely associated with risks from extreme precipitation and winter conditions associated with increased variability and financial consequences on businesses. Notably, climate risks to air transportation are not expected to increase significantly if GHG emissions are able to be reduced to follow RCP4.5 (see Appendix 7).

Lastly, climate risks to local and long-distance freight trucking were evaluated to be 'low' under current climate conditions but rise to 'medium' in all regions of Ontario, except the Far North, by end of century. These climate risk profiles for businesses are largely based upon extreme precipitation and the impacts associated with shorter duration extreme events causing flooding that may pose issues of access, delays, or inability of freight to travel to destinations. However, for certain transportation infrastructure, such as winter roads in northern Ontario, these risks may in fact be elevated as a result of increasingly variable conditions and rising temperatures. Section 6.7.5 characterizes the risk to roads on the assets themselves. Critically, cascading impacts of other infrastructure systems (e.g. if power outages were to cause fuel shortages and increasing prices) are not quantitatively evaluated as part of this score, and so it is plausible that scores may in fact be rising faster for this industry in the future.

Table 9.25: Risk Scores for Transportation Economy Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Transportation Economy	Air Transportation	Central Region	Low	Low	Medium
Transportation Economy	Air Transportation	Eastern Region	Low	Low	Medium
Transportation Economy	Air Transportation	Far North Region	Low	Low	Low
Transportation Economy	Air Transportation	Northeast Region	Low	Low	Medium
Transportation Economy	Air Transportation	Northwest Region	Low	Low	Medium
Transportation Economy	Air Transportation	Southwest Region	Low	Low	Medium
Transportation Economy	Deep Sea, Coastal and Great Lakes	Central Region	High	High	High
Transportation Economy	Deep Sea, Coastal and Great Lakes	Eastern Region	High	High	High
Transportation Economy	Deep Sea, Coastal and Great Lakes	Far North Region	High	High	High
Transportation Economy	Deep Sea, Coastal and Great Lakes	Northeast Region	High	High	High
Transportation Economy	Deep Sea, Coastal and Great Lakes	Northwest Region	High	High	High
Transportation Economy	Deep Sea, Coastal and Great Lakes	Southwest Region	High	High	High
Transportation Economy	Local Freight Trucking and Delivery Services	Central Region	Low	Low	Medium
Transportation Economy	Local Freight Trucking and Delivery Services	Eastern Region	Low	Low	Medium
Transportation Economy	Local Freight Trucking and Delivery Services	Far North Region	Low	Low	Low

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Transportation Economy	Local Freight Trucking and Delivery Services	Northeast Region	**Low**	**Low**	**Medium**
Transportation Economy	Local Freight Trucking and Delivery Services	Northwest Region	**Low**	**Low**	**Medium**
Transportation Economy	Local Freight Trucking and Delivery Services	Southwest Region	**Low**	**Low**	**Medium**
Transportation Economy	Long Distance Freight Trucking	Central Region	**Low**	**Low**	**Medium**
Transportation Economy	Long Distance Freight Trucking	Eastern Region	**Low**	**Low**	**Medium**
Transportation Economy	Long Distance Freight Trucking	Far North Region	**Low**	**Low**	**Low**
Transportation Economy	Long Distance Freight Trucking	Northeast Region	**Low**	**Low**	**Medium**
Transportation Economy	Long Distance Freight Trucking	Northwest Region	**Low**	**Low**	**Medium**
Transportation Economy	Long Distance Freight Trucking	Southwest Region	**Low**	**Low**	**Medium**
Transportation Economy	Rail	Central Region	**Medium**	**High**	**High**
Transportation Economy	Rail	Eastern Region	**Medium**	**High**	**High**
Transportation Economy	Rail	Northeast Region	**Medium**	**High**	**High**
Transportation Economy	Rail	Northwest Region	**Medium**	**High**	**High**
Transportation Economy	Rail	Southwest Region	**Medium**	**High**	**High**

9.7.11 Utility Services

Overview

In the context of the PCCIA, Utility Services comprise establishments primarily engaged in operating electric and gas utilities. These establishments generate, transmit, control and distribute electric power, distribute natural gas and provide related services through infrastructure such as power lines, pipes, and processing facilities.

Illustrative risk scenarios are presented in Table 9.26. Four Level 2 categories are characterized briefly below, with the associated risk profiles by region and timeframe presented in Table 9.27, at the end of this section. For additional discussion regarding Ontario's energy systems, and characterization of impacts to energy security, refer to Section 10.2.

Table 9.26: Illustrative Risk Scenarios for Utility Services Level 2 Categories

Level 2 Category	Illustrative Risk Scenarios	Strength of Evidence
Electrical Power Generation	Extreme and gradual climate risk events impact different power generation modes (natural gas, nuclear, hydro, solar, wind) in different ways, resulting in financial effects.	**Low**
Electrical Power Transmission, Control and Distribution	Extreme climate risk events impact electrical transmission, control and distribution assets (e.g. poles, wires, switches) and performance, resulting in financial effects.	**Low**
Natural Gas Distribution	Extreme climate risk events impact natural gas distribution assets (e.g. pipelines) and performance, resulting in financial effects.	**Low**
Telecommunications	Extreme climate risk events impact telecommunications assets (e.g. towers) and performance, resulting in financial effects.	**Low**

Electrical Power Generation

In 2020, Ontario generated 154.7 terawatt-hours (TWh) of electricity, which represents the second largest producer of electricity in Canada and has an estimated generating capacity of 38,644 megawatts (MW). (OEB, 2019; 2020; IESO, 2020). Just over 92% of this electricity in the province was produced from zero-carbon sources: 56.8% from nuclear, 24.4% from hydroelectricity, 8.7% from wind and 2.4% from solar. The remainder is primarily from natural gas and biomass (OEB, 2021). Three nuclear power plants provide the bulk of Ontario's baseload generation: Bruce Power on the shores of Lake Huron is the largest, with eight generation units representing one of the largest nuclear power plants operating in the world (CER, 2022). Ontario also has over 200 hydroelectricity generation facilities, and the largest 100% biomass-fueled plant in North America (e.g. the 205 MW Atikokan Generating Station converted from coal in 2014) (CER, 2022). The Ontario Energy Board (OEB) is involved in license approvals for generation companies (OEB, 2022a).

Electrical Power Transmission, Control and Distribution

Electrical power, once generated, requires transmission and distribution to consumers and for end use. The Ontario electricity grid includes high voltage transmission lines delivering electricity from generators to large customers (e.g. major industry) and to local distribution companies who distribute electricity at lower voltages to homes and businesses. The Ontario electricity grid is made up of transmission lines delivering electricity from generators to communities. The Independent Electricity System Operator (IESO) directs the flow of electricity over these lines, while transmission companies (e.g. Hydro One) own, operate, and maintain the lines and towers (IESO, 2022a). Across Ontario, 60 local distribution companies (LDCs) own and operate additional assets (e.g. transformers) for business customers. Some larger industrial consumers connected to the high-voltage grid (transmission lines with equal or greater than 50 kilovolts) purchase wholesale electricity from Ontario's electricity market (IESO, 2022a). Ontario's high-voltage system is also connected with neighbouring jurisdictions to enable importing and exporting from Ontario (e.g. with Manitoba, Quebec, New York, Michigan and Minnesota). The Ontario Energy Board (OEB) is involved in licensing transmission companies and reviewing and setting electricity rates across the province to protect the interests of consumers.

Natural Gas Distribution

As of 2019, Canada was the sixth larger producer of natural gas in the world, representing 4.3% of global supply (CER, 2022). While much discussion has focused on the phase-out of coal power and the existing electricity system being 92% greenhouse gas emissions free in 2020, natural gas is widely used across Ontario to produce electricity, to heat homes and facilities and for other fuels and purposes. Currently almost half (48%) of Ontario's energy use comes from refined petroleum products, 28% from natural gas, 16% from electricity, 4% from biofuels and the remaining 4% from other fossil fuels (OEA, 2021). Natural gas is Ontario's most common heating source, servicing about 3.6 million homes and 160,000 businesses. Natural gas is also a major input for Ontario's petrochemical industry, largely focused within Southwest Ontario and Sarnia and employing about 12,000 people (Ontario Ministry of Energy, 2017). Almost all of Ontario's natural gas comes from outside the province and is delivered by interprovincial pipelines, which are under federal jurisdiction and regulated by the Canada Energy Regulator (CER) (MOE, 2017). In Ontario, the Ontario Energy Board regulates the natural gas sector and approves distribution rates and pricing, as well as providing licenses. Increasing reliance on natural gas-fired electricity runs counter to transitioning to net zero targets and in fact may weaken attractiveness for industries looking to shift to low carbon electricity (Canadian Climate Institute, 2022).

Telecommunications

The telecommunications industry provides critical transmission of information between sites either wirelessly or based on wired infrastructure. Regulated by the Canadian Radio-Television and Telecommunications Commission, this industry is reliant upon telecommunications infrastructure owned by five companies: Bell, Rogers, Shaw, Telus, and Quebecor. The CRTC regulates telecommunications companies operating the wired and wireless networks used by residents in the event of emergencies (e.g. connecting to 911 call centres), and in regulating business licenses based upon policy as it relates to market share, rates, and services.

During the COVID-19 pandemic, the telecommunications sector's contribution to GDP slowed in 2020 but fared significantly better than Ontario's economy as a whole (CRTC, 2022). GDP contribution and jobs supported by the telecommunications industry were estimated to be up to $70.7 billion in 2020, employing around 596,000 people (CWTA, 2022). This economic contribution was driven by the telecommunications industry's sustained and significant capital investment in 2020, with more than $11 billion invested in wireless and wireline connectivity (CRTC, 2022). Despite declining revenues during the COVID-19 pandemic, wireless carriers, as a group, reported slightly higher earnings before interest, taxes, depreciation and amortization (EBITDA) margin, lower churn (subscriber turnover) rates, and increased capital investments on 5G networks. Consumers also used more data than ever before, and subscriptions rose to larger data plans. In 2020, 84.4% of Canadians owned a smartphone, an increase of 4.1 percentage points since 2018 (Statistics Canada, 2022g).

Direct and Indirect Impacts

Electrical Power Generation and Transmission, Control and Distribution

Electrical power generation can be impacted by climate change in a variety of ways and in part depends on the energy source being used for generation and where infrastructure is located. Generation processes more reliant upon natural resources, such as the volume of water required for hydropower and the temperature and availability of water used for cooling in nuclear power, can be considered be at relatively higher risk than those with more internal-driven processes (e.g. natural gas power plants). Similarly, where electrical power generation occurs along shorelines and/or rivers, additional climate variability or relatively higher risk may be present (e.g. due to extreme weather, storm surge and/or erosion).

Increases in water temperature are likely to reduce generation efficiency due to less thermal capacity for generation, especially where water availability is also affected. Hydropower generation may be particularly impacted by dry conditions or drought, should water availability be reduced. Similarly, warmer water resources that are used for cooling purposes (e.g. for nuclear power generation) constrain the cooling function in the generation process. Rising air temperatures may reduce technological or process efficiency (Burillo, 2018) and limit output (CRTC, 2022).

Regardless of how electricity is generated, consumer demand for energy is expected to rise, particularly at peak times in the summer season, which will change the ability to produce and deliver it reliably (US EPA, 2017). Section 10.2 describes cross-sectoral considerations associated with energy security – including generation, transmission, control, and distribution.

Electricity transmission, control, and distribution can be impacted by changes in extreme heat, changing Growing Degree Days, mean and extreme precipitation, wildfire, among other hazards. The following provides several examples of climate impacts on transmission, control, and distribution companies. Rising air temperatures and extreme heat can lead to decreased efficiency of thermal cooling and individual components of assets to become inoperable due to protection devices cutting off power flow if too high for the weather conditions (Burillo, 2018). Higher air temperatures can also result in reduced capacity for above ground power lines to safely carry electricity. If transmission or distribution system capacity is significantly reduced, this can lead to failures, brownouts, or blackouts (Burillo, 2018). Wildfires can lead to asset damage or total loss of infrastructure depending on their size and extent. For example, if wildfires burn under power lines, components can fail due to air ionization. Extreme precipitation and storms can blow trees or other objects into power lines and cause outages. Similarly, extreme precipitation can result in flooding of underground infrastructure (e.g. substations) or erode hardware and underground power lines. Lastly, climate hazards can disrupt supply chains, thereby leading to rising costs of materials, fuel, and important insurance in responding to climate impacts on transmission, control and distribution infrastructure (Burillo, 2018).

These impacts on both generation, transmission, control, and distribution could lead to financial impacts such as decreased serviceable lifespan, reduction in generating station output, shifts in consumer demand daily or seasonally, and increased variability in, or rising costs to, to key industrial inputs (e.g. materials, water, ambient air, fuel, insurance). Health and safety impacts may also become increasingly frequent as a result of climate conditions hazards, such as downed power lines or infrastructure presenting a hazard, or power outages during extreme conditions (e.g. heatwaves) due a lack of cooling for more vulnerable populations such as seniors.

Natural Gas Distribution

Natural gas distribution impacts are dependent upon the state, condition, and location of infrastructure, and particularly whether it is below or above ground. The extent to which distribution may be impacted depends on the condition of individual assets (Antoniou et al., 2020). Climate change is anticipated to influence (possibly worsen) the integrity or reliability of existing pipelines and their associated infrastructure upstream and downstream. For example, extreme precipitation may lead to flooding that can damage facilities or impact construction activities and the ability to upgrade assets, whereas wildfires could lead to gas venting from leaks in compressors or a higher risk of pipelines being ignited by sparks or embers from wildfires (Burillo, 2018).

Broadly, impacts can be characterized as operational loss and damage, higher variability on consumer demand and on consumption that may lead to changes in costs for materials, fuel and insurance. Assets may experience a shortened serviceable lifespan, or have a reduced capacity in distribution (e.g. compressor ratings) and rising costs that could influence service disruptions or annual revenues. The natural gas distribution industry also faces rising transition risks as international, national, and provincial policies shift in accordance with achieving greenhouse gas emissions targets and achieving low carbon energy systems. Shifting regulation, policy and market share, and the uncertainty or rate of change surrounding it, may pose risks to companies and businesses (and it is in part for this reason, some companies are diversifying services and investments).

Telecommunications

Climate impacts to telecommunication companies are varied depending upon their infrastructure footprint and the climate variables that pose risks to these systems. A subset of physical climate impacts is described below. Increasing air temperatures, including extreme heat, is expected to add additional burden for cooling equipment, which may lead to increased operating temperatures of network equipment, malfunction, or failure. Rising temperatures are also expected to reduce the lifespans that telecommunication companies own and operate, or rely upon from other companies, and thus increased costs or replacement of asset components may be needed (Adams and Steeves, 2014).

Changes in precipitation (e.g. rain in the winter season) or extreme precipitation may lead to flooding of low-lying areas or impacts to underground or ground-level assets. Increases in precipitation, coupled with rising air temperatures (or humidity), could also affect the radio spectrum on which wireless communications rely upon. Extreme precipitation events, for example, could disrupt some transmitted signals or require increased transmission power to withstand poorer weather conditions. As a result, this may restrict customers supported within a given region or spectrum band (Adams and Steeves, 2014). Extreme weather events can also disrupt materials supply, damage assets or transmitters, overhead cables or disrupt service delivery and lead to outages. Evidence also suggests that there needs to be additional research focused on the connection between climate risks to telecommunications companies and the information and communications technology (ICT) sector (see Section 6.7.6). Data centres, storage and network inputs, parts and services that are rely upon one another, or that are interdependent (Adams and Steeves, 2014) could be considered an important next research priority to characterize climate change risks and adaptation opportunities.

Risk Results

The risk to Utility Services was assessed by Level 2 category and by region across Ontario. Recall that these risk scores are representative of one typical company or business operating with the industry and based upon possible financial loss measured as a function of annual revenue. Risk scores were determined for current, 2050s and 2080s under a high emissions scenario (RCP8.5) and moderate emissions scenario (RCP4.5). Table 9.27 summarizes Utility Services risks by Level 2 category for each time period, operating under a RCP8.5 scenario.

Across the four Level 2 categories, the relatively higher current risk was determined to be within the electrical transmission, control, and distribution industry. This risk is currently evaluated to be 'medium' and rises to 'high' by mid-century. The relatively higher risk now is associated with impacts due to extreme heat particularly at times where demand is highest and can lead to infrastructure failure and associated financial losses with power outages. However, it is critical to emphasize that unchanging risk scores over time do not indicate that the absolute level of risk (e.g. driven by a rising frequency of extreme weather events) is anticipated to be unchanging out to the end of the century.

Electrical power generation was determined to be at currently 'low' risk but this risk is expected to rise quickly by 2050s and 2080s reflecting rising extreme temperatures. For example, a scenario with electrical power generation that becomes significantly impaired as a result of a single extreme heat risk event, could lead to a significant reduction in business service activity for a short period of time (e.g. days) depending upon the mode of power generation. This could represent a low proportion of annual revenue loss.

Risks associated with natural gas distribution are also anticipated to rise by end of century, though not as quickly as the risks to companies within the electrical power generation industry. This is reflective of 'low' risk currently and in the 2050s but rising to 'medium' risk by the 2080s. Natural gas distribution is similarly characterized and in the case of pipelines, buried infrastructure may be impacted somewhat less frequently than assets above or on-ground. However, it must be emphasized that these results are based upon a single climate hazard event occurring. Damage to pipelines due to other infrastructure (e.g. rupture due to digging, impact from ships where pipes are below water, etc.) and due to cascading climate events (e.g. flooding, followed by freezing and thawing, may undermine the structural ability of soil surrounding buried infrastructure) may be higher. Thus, operational processes, maintenance and inspection efforts by companies in natural gas distribution are critical to ensure safe and continued service delivery.

Climate risks to telecommunication businesses are expected to increase from 'medium' to 'high' by end of century. Increasing heat events can impact assets (e.g. towers) and their capacity and performance, resulting in financial losses to companies that own and operate them. For telecommunications companies, for example, under a scenario with electricity supply disruption and infrastructure performance reduced to 0% (no service) as a result of a single climate event such as extreme precipitation, it could result in a significant reduction in business service activity for a short period of time (e.g. days), but that this is anticipated to be a very low proportion of annual revenue loss.

Table 9.27: Risk Scores for Utility Services Level 2 Categories

How to Read Risk Profiles				
Rating	**Low**	**Medium**	**High**	**Very High**
Score	2	4	8	16

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Utility Services	Electrical Power generation	Central Region	**Low**	**Medium**	**Medium**
Utility Services	Electrical Power generation	Eastern Region	**Low**	**Medium**	**Medium**
Utility Services	Electrical Power generation	Far North Region	**Low**	**Medium**	**Medium**
Utility Services	Electrical Power generation	Northeast Region	**Low**	**Medium**	**Medium**
Utility Services	Electrical Power generation	Northwest Region	**Low**	**Medium**	**Medium**
Utility Services	Electrical Power generation	Southwest Region	**Low**	**Medium**	**Medium**
Utility Services	Electrical Power Transmission, Control and Distribution	Central Region	**Medium**	**High**	**High**
Utility Services	Electrical Power Transmission, Control and Distribution	Eastern Region	**Medium**	**High**	**High**
Utility Services	Electrical Power Transmission, Control and Distribution	Far North Region	**Medium**	**High**	**High**

Level 1 Category	Level 2 Category	Region	Climate Risk Scores		
			Current	2050s (RCP8.5)	2080s (RCP8.5)
Utility Services	Electrical Power Transmission, Control and Distribution	Northeast Region	**Medium**	**High**	**High**
Utility Services	Electrical Power Transmission, Control and Distribution	Northwest Region	**Medium**	**High**	**High**
Utility Services	Electrical Power Transmission, Control and Distribution	Southwest Region	**Medium**	**High**	**High**
Utility Services	Natural Gas Distribution	Central Region	**Low**	**Low**	**Medium**
Utility Services	Natural Gas Distribution	Eastern Region	**Low**	**Low**	**Medium**
Utility Services	Natural Gas Distribution	Northeast Region	**Low**	**Low**	**Medium**
Utility Services	Natural Gas Distribution	Northwest Region	**Low**	**Low**	**Medium**
Utility Services	Natural Gas Distribution	Southwest Region	**Low**	**Low**	**Medium**
Utility Services	Telecommunications	Central Region	**Medium**	**Medium**	**High**
Utility Services	Telecommunications	Eastern Region	**Medium**	**Medium**	**High**
Utility Services	Telecommunications	Far North Region	**Medium**	**Medium**	**Medium**
Utility Services	Telecommunications	Northeast Region	**Medium**	**Medium**	**High**
Utility Services	Telecommunications	Northwest Region	**Medium**	**Medium**	**High**
Utility Services	Telecommunications	Southwest Region	**Medium**	**Medium**	**High**

9.8 Climate Change Opportunities

Evaluating all risk scores across Level 1 and 2 categories for the Business and Economy Area of Focus indicates that no industry has a decreasing risk profile into the future. In other words, climate change is not creating opportunities based upon existing conditions across Ontario's businesses and economic system. This increases the imperative that Ontario's businesses and economy must enable and be prepared to reduce and manage risks in the face of continued climate change. Section 9.2 notes that the economic conditions and the businesses driving Ontario's economy are already within a period of rapid change due to technological advancements, globalization, and other external factors (OCC, 2019). Therefore, as businesses and industries across Ontario evolve and change, opportunities exist to take advantage of resilience-based investments, new technologies and expansion into new markets as global markets change in the face of climate disruptions.

To achieve economic growth, prosperity and a resilient business ecosystem, investment decisions must strive to quantify and acknowledge benefits and costs. Globally, studies have found that the benefits in investing in resilient infrastructure, operations, preparedness, technologies, and other systems outweigh the costs with high benefit-cost ratios (OECD, 2018). Given the interdependencies and cascading impacts of climate change, measuring costs and benefits will be a critical source of evidence to support adaptation decisions. For this reason, the Intergovernmental Panel on Climate Change (IPCC) recommends that decisions consider the monetary value of costs and benefits along with less tangible outcomes.

Businesses also stand a chance to benefit in the medium- to long-term from investments and upcoming infrastructure projects by the Governments of Ontario and Canada (OCC, 2021). These include investments in broadband, transportation infrastructure, digital, and green initiatives. These projects could help stimulate demand and set the stage for job creation, opportunities to innovate, and growth in real GDP that will pivot the province to remain sustainably competitive at the national and international levels (OCC, 2021).

Similarly, Section 10.0 describes the opportunities that exist in adaptation among multiple sectors. For example, significant additional infrastructure investment is needed to meet greenhouse gas emissions targets and ensure a reliable, equitable and affordable energy system for Ontarians, which should be considered an opportunity to enable infrastructure and business resilience while minimizing service disruptions and keeping energy affordable.

In other words, fostering resilient economic development is a climate change opportunity for Ontario and its businesses. In 2019, the Ontario Chamber Commerce also identified several key take-aways related to modern economic development to foster resilience (OCC, 2019):

- Modernize governance of economic development such as that it empowers a wide range of stakeholders outside government, including businesses, post-secondary institutions, and not-for-profit organizations
- Foster regional collaboration and economic reconciliation with Indigenous Peoples, and the use of data to mobilize local assets
- Cultivate ecosystems of talent, trade and infrastructure by fostering an environment conducive to business growth necessary to ensure the long-term success of both traditional and emerging sectors
- Build regional capacity across Ontario for innovation to improve commercialization and technology adoption, strengthening and building regional innovation centres, expanding broadband internet access, and facilitating cluster development

9.9 Adaptive Capacity of Ontario's Business and Economy Area of Focus

9.9.1 Adaptive Capacity Summary

Industries within Ontario have widely varying levels of existing capacity to reduce industry and company-level risk to actual or anticipated climate change impacts. While an empirical stock-take of how Ontario companies are prepared to deal with current and future climate-related extreme was not within the scope of this assessment, there are numerous examples of how businesses of all sizes and across industries are adopting measures that can support their resilience to climate change. There are also examples of Ontario businesses providing 'adaptation goods and services' that can help to address barriers to adaptation, in particular for small to medium enterprises (SMEs).

Adaptation measures and strategies to manage climate risks may be classified as anticipatory and planned, or autonomous and reactive. That is, measures may be designed and implemented to directly address anticipated future change, or they may be in place for other business reasons but with the co-benefit of enhancing resilience and Adaptive Capacity.

Table 9.28 presents an assessment of the current level of Adaptive Capacity for each Level 1 category, with key considerations regarding the level of Adaptive Capacity. Adaptive Capacity has been evaluated for each Level 1 category and consider technology, resource availability, sector complexity and governance. Each of these categories has been evaluated in more detail and is contained in Appendix 10.

Adaptive Capacity, as described in Section 2.4 of this report, is an important component in considering relative climate change priorities. Ideally, an industry would have low climate risk and high Adaptive Capacity. Any Level 1 or 2 category with relatively lower Adaptive Capacity and relatively higher climate risk can be considered a priority. For example, a 'very high' risk posed to manufacturing can be considered a higher priority based on the current Adaptive Capacity of the industry compared to that of a 'very high' risk posed to the finance and insurance Industry. As another example, higher risks to arts, entertainment & recreation Level 2 category that were determined as part of the PCCIA considered alongside this industry's 'medium' Adaptive Capacity imply additional requirements to build resilience for businesses in this industry.

Table 9.28: Level 1 Adaptive Capacity Ratings for the Business and Economy Area of Focus[34]

Level 1 Category	Technology	Resource Availability	Governance	Sector Complexity	Level 1 Category Adaptive Capacity Rating
Accommodation & Food Services	Medium	Medium	Medium	Low	**Medium**
Arts, Entertainment & Recreation	Medium	Medium	Medium	Low	**Medium**
Construction	High	Medium	Medium	Medium	**Medium**
Financial and Insurance	High	High	Medium	Low	**High**
Forestry, Fishing & Hunting Economies	High	Medium	Medium	Medium	**Medium**
Information & Cultural Industries	Medium	Medium	Medium	Low	**Medium**
Manufacturing	Medium	Medium	Medium	Low	**Medium**
Mining, Quarrying & Oil/Gas Extraction	High	High	Medium	Medium	**High**
Retail Trade	Medium	Medium	Medium	Low	**Medium**
Transportation Economy	High	Medium	Medium	Low	**High**
Utility Services	High	High	Medium	Medium	**High**

[34] Note these scores do not consider geographic location within the province. Please see Appendix 11 for regional Adaptive Capacity ratings.

9.9.2 Technology

The level of technological Adaptive Capacity across many Industries is often highly dependent on the size and scale of a business. Larger organizations for example have more ability to conduct market research, evaluate technological solutions to meet their needs, and flexibility in testing potential technology in support of continued operations in the face of increasing climate risks. For the purposes of the PCCIA, technological Adaptive Capacity was evaluated to be 'high' across six industries, and 'medium' across five industries assessed.

Highly Adaptive Industries

Several industries are considered to have a 'high' technological Adaptive Capacity: construction; finance and insurance; forestry, fishing, and hunting economies; mining, quarrying and oil and gas extraction; transportation economy; and utility services. The rationale behind why capacity is considered high differs depending on the industry. For example, industry standard practices in finance and insurance companies indicate a high degree of flexibility, such as actuarial risk management for natural hazards and peril losses, and their ongoing efforts to improve climate risk data and modelling capabilities to assess and disclose risk and offset financial impacts. Utility companies have historically been involved in assessing climate impacts on electricity generation, transmission and distribution via vulnerability and risk assessments and identifying technology solutions to mitigate potential impacts. As another example, construction companies have been actively involved in evaluating and adopting climate-resilient engineering construction techniques and in responding to building code updates for climate-resilient infrastructure.

Moderately Adaptive Industries

Accommodation and food services; arts, entertainment, and recreation; information and cultural industries, manufacturing, and retail trade are all industries where Adaptive Capacity is considered 'medium'. These industries all rely upon real estate and infrastructure for the continued delivery of services. Industry-owned and leased buildings are typically designed to code and engineering standards are based on the historical climate that existed when they were built. In other words, businesses relying upon real estate for continued operations are not necessarily equipped to cope with future climates. It is generally unclear as to the level of generalized adoption of onsite backup energy supply (e.g. generators) or technological solutions to reduce risks to operations or supply chains for materials and commodities. Larger organizations have begun to assess risk and identify risk mitigation measures based on technological solutions, but widespread industry-level investment is not yet sufficient to consider Adaptive Capacity high from a technological perspective.

9.9.3 Resource Availability

Resource availability refers to the human, financial and natural resources available to support in preparing and responding to climate impacts. Resource availability was evaluated across all Leve 1 industries, and only three were found to have a 'high' level of Adaptive Capacity. The remaining industries are all considered to be 'medium'. These are characterized below.

Highly Adaptive Industries

The three industries considered to have the most resources available to them in preparing and responding to climate impacts are finance and insurance; mining, quarrying and oil and gas extraction; and utility services. Organizations in the finance and insurance industry are making significant financial investments to build knowledge on climate science and risk modeling competencies via direct hires, acquisitions, and partnerships among technical firms and academia. Companies in mining, quarrying and oil and gas have historically assessed hazards and risk and have contracted or hired hydrology experts and experienced staff in understanding regulations and in applying for and managing permits to take and discharge water. Knowledge resources also exist in the form of guidance for companies in this industry, and include publications from the Mining Association of Canada. Utility companies manage assets that are long-lived and costly, with budgets approved by regulators based on accepted rate structures. In recent years, rates have risen significantly to enable investments in resources to harden assets and support the knowledge for resilient-informed decision making.

Moderately Adaptive Industries

All other industries assessed as part of the Business and Economy Area of Focus are considered to have 'medium' Adaptive Capacity as it relates to resource availability. In these industries, there is often emergency management resources, or staff involved in traditional business continuity planning. Similarly, arts, entertainment, and recreation industry associations are becoming more engaged and aware of climate change risks. While some progress has been made, smaller organizations and businesses often lack the resources needed to ensure resiliency. There is also insufficient evidence to fully characterize the extent to which resources are available or applied in many industries including manufacturing applications, and companies involved in transportation of goods.

9.9.4 Governance

Governance refers to the institutional support, policies, and networks available to enhance the implementation of adaptation measures. For the purposes of the PCCIA, all industries assessed within the Business and Economy Area of Focus are considered to have 'medium' Adaptive Capacity related to governance. In general, across most industries there are several factors that have led to this evaluation. These factors include:

- Emergency and crisis management structures are often in place in larger sized organizations, providing chain of command and reporting structures in the event of significant impacts or disruptions
- An increasing number of organizations, policies and networks are available with climate risk-focused research efforts to support organizations and advocate for better risk-informed regulations and decision making
- Pilot initiatives and pilot projects are being initiated or are underway among networks and peer-to-peer learning is taking place across numerous industries
- In regulated industries, regulators are beginning to consider climate science as part of guidance and rate structures to support resilient investments

These considerations of governance reveal that no industry is considered to have a high Adaptive Capacity in this category. Significant work remains to be done to provide adequate guidance and robust governance systems to enable resilient operations and investments.

9.9.5 Sector Complexity

Sector complexity refers to the number of players, stakeholders, decision-makers within a particular industry and their ability to make decisions and change course. The higher an industry's complexity, the lower the capacity to adapt. Among the 11 business and economy industries assessed, seven are considered to have 'high' complexity and four industries are considered to have 'medium' complexity.

Industries with Medium Sector Complexity

Four industries are considered to have a relatively moderate sector complexity, or medium Adaptive Capacity. These industries are construction; forestry, fishing and hunting economies; mining, quarrying, oil and gas extraction; and utility services. The construction industry for example tends to be dominated by a small number of large construction and engineering companies, whose main risk exposure is via supply chain disruption and material availability. In the forestry, fishing and hunting economies, there is a wide range of company sizes, but in general complexity is not as high with main climate risks via climate risks posed to terrestrial and aquatic ecosystems upon which their business activity depends. In mining, quarrying, oil and gas extraction, there are a moderate number of companies with differences between sub-sectors. While water conservation and re-use technologies and practices are available, these approaches have limits in ability to mitigate disruption in availability of water for industrial production. Lastly, in utility services, the complexity is considered relatively low based on the handful of electricity generating corporations, Hydro One and local distribution companies.

Industries with High Sector Complexity

All other industries assessed as part of the Business and Economy Area of Focus are considered to have high sector complexity – or 'low' Adaptive Capacity. All these industries are considered to have a significant number of organizations ranging in size. Significant heterogeneity is also present between different regions, size and the extent to which risk may impact services provided. For example, in manufacturing there are a large number of companies involved across numerous sub-sectors in wide-ranging sizes. In this industry, there is heavy reliance on third parties (e.g. electricity supply, leasing of buildings) to implement risk mitigation and resilience measures on behalf of industry companies. Complexity of local and global just-in-time supply chains also exacerbates the complexity and risk of supply chain disruption and impact to materials/inputs availability.

9.10 Climate Adaptation Priorities

Current Adaptation Priorities

As described in Section 9.9, all Level 1 industries as part of Business and Economy have been assessed to have a 'medium' or 'high' Adaptive Capacity. In other words, no industry is considered to have a 'low' Adaptive Capacity based upon technology, resource availability, governance, and sector complexity. When combining these with the regional Adaptive Capacity ratings, industries in Central, Northeast and Northwest regions are found to have the lowest capacity rating for this Area of Focus, with a combined capacity rating of 'medium'.

This Area of Focus has the highest combined Adaptive Capacity ratings, with financial and insurance, mining, quarrying and oil/gas extraction and utility services within the Southwest and Eastern regions, exhibiting a 'high' combined capacity rating. These same industries in Central, Northeast, Northwest and Far North regions are deemed to have 'higher' capacity levels, compared to the industries listed as adaptation priorities

Based on higher levels of Adaptive Capacity reflected throughout this sector, climate adaptation priorities for current and future timeframes can be considered a reflection of those with the highest risk profiles and 'medium' capacity levels. A summary of current adaptation priorities is provided in Table 9.29.

Table 9.29: Current Business and Economy Adaptation Priorities

Current Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[35]
Arts, Entertainment and Recreation	Central	**High**	**Medium**
Fishing, Hunting and Trapping	Central, Northeast, Northwest, Far North	**High**	**Medium**
Forestry and Logging	Central, Northeast, Northwest, Far North	**High**	**Medium**
Deep Sea, Coastal and Great Lakes	Central, Northeast, Northwest, Far North	**High**	**Medium**

[35] See Appendix 12 for combined Adaptive Capacity rating and associated scoring matrix.

Emerging Adaptation Priorities

By mid-century, several additional categories and regions are anticipated to experience 'high' risk, adding to several of those already identified in the current timeframe, all of which continue to persist. A summary of emerging adaptation priorities is provided in Table 9.30.

Table 9.30: Emerging Business and Economy Adaptation Priorities by Mid-Century (RCP8.5)

Emerging Level 2 Priorities	Region	Risk Score	Combined Adaptive Capacity Rating[36]
Arts, Entertainment and Recreation	Northeast, Northwest, Far North	**High**	**Medium**
Rail	Central, Northeast, Northwest	**High**	**Medium**

Advancing Adaptation

The benefits of taking action to address climate risk via planned adaptation interventions are generally appreciated to outweigh the costs, over the medium to long term. The areas for building climate resilience comprise both actions that can be undertaken at the industry and firm-level, as well as actions that can be implemented by governing bodies to establish enabling conditions and/or incentives for adaptation.

The PCCIA Adaptation Best Practices Report (External Resource – 2) categorizes adaptation options for industries within the Business and Economy Area of Focus. Ontario has the solutions and knowledge to act and lessen or avoid many climate risks that industries face. A high-level summary is provided in Table 9.31, with industry-specific adaptation options available in the PCCIA Adaptation Best Practices Report.

[36] See Appendix 12 for combined Adaptive Capacity rating and associated scoring matrix.

Table 9.31: Adaptation Options for Business and Economy Area of Focus

Adaptation Category	Examples of Adaptation Measures
Projects or Programs	- Develop a suite of decision-support tools for climate change adaptation. - Integrate climate change into financial valuation, natural environment impacts, and business continuity planning. - Facilitate development of knowledge sharing networks and encourage participation in UNDRR'S ARISE program. - Support the use of public-private partnerships to reduce climate risk impacts to businesses.
Research and Development	- Review and mobilize case studies across businesses, such as Environment and Climate Change Canada's map of adaptation actions. - Undertake industry-specific climate change risk assessments that factor in interdependencies and supply chain impacts. - Support innovative research at the industry-specific level that achieves low carbon resilience in operations and business activities.
Investment and Incentives	- Develop financial instruments to promote investment in climate resilience. - Develop a grant or loan program to support industry-specific activities that support regional economic employment (e.g. resource-based recreation and tourism industries).
Policy and Regulation	- Develop financial instruments to promote investment in climate resilience. - Develop a grant or loan program to support industry-specific activities that support regional economic employment (e.g. resource-based recreation and tourism industries).

10.0 Cross-Sectoral Considerations

Climate change impacts occur against the backdrop of complex and dynamic social and ecological systems. Most conventional risk assessments consider discrete themes or sectors with some recognition of interconnections. Climate change can cause cascading and compounding effects, depending on the exposure and Adaptive Capacity of systems.

A systems approach to building resilience through adaptation can combat risks at multiple points within a system and achieve more than responses aimed at single themes. A cross-sectoral assessment of climate change impacts and identification of areas where impacts cascade or amplify can help further prioritize resilience needs and target adaptation responses. Figure 10.1 illustrates how capacity building (e.g. equity improvements, policy coherence and improved decision-making etc.) can support effective adaptation to climate risks across the Area of Focus and cross-sectoral themes.

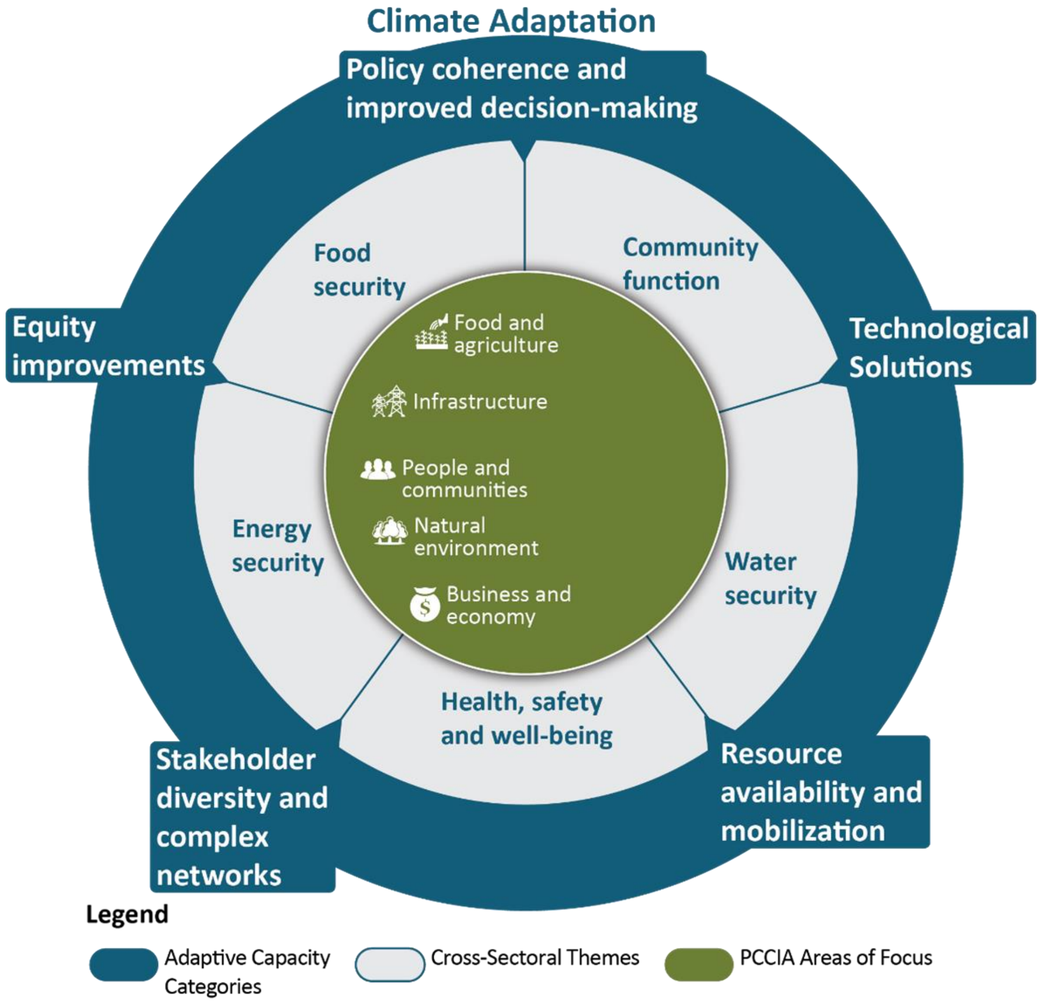
The assessment of climate change impacts within each Areas of Focus has led to the identification of themes that encompass more than one (1) Area of Focus. There are interdependencies among the five Areas of Focus and therefore several pathways along which impacts can traverse. Indirect and cascading impacts identified within each Area of Focus have informed the components of the cross-sectoral analysis. Each theme conveys climate impacts relevant to Ontario. External influences, notably those outside (the control) of Ontario are identified, however, detailed characterization of those external factors has not been undertaken. The five cross-sectoral themes are:

- Food Security
- Energy Security
- Water Security
- Human Health, Safety and Well-being
- Community Function

These themes were identified through review of the climate change literature and were considered against a suite of criteria noted below:

- Typical cross-sectoral information included in climate change impact and risk assessment reports at various scales across Canada, the United States and internationally;
- Themes, priorities, or concepts raised or repeatedly identified as important in PCCIA literature review and PCCIA engagement sessions;
- Topics identified in the PCCIA methodology framework as spanning across multiple Areas of Focus.

Figure 10.1: A conceptual framework outlining the interconnectedness between each Area of Focus and cross-sectoral theme, and the role of capacity building to effectively adapt and reduce climate risk across Ontario.



Although people are not the only possible focus for impacts from climate change, a people-centered approach to cross-sectoral impacts was adopted to demonstrate how impacts ultimately cascade from each Area of Focus into the People and Communities Area of Focus. Taking a people-centric approach labels a single and consistent end point and allows for consistent framing of the cascading impacts across every Area of Focus as they affect people.

A diagram for each of the themes illustrates (from left to right), how climate impacts (light grey boxes) cascade through each Area of Focus (represented in green), to system components or impacts (represented in orange), and subsequently impact key theme dimensions (represented in purple). Interactions illustrated in the diagrams demonstrate direct climate impacts (dark solid line), cascading impacts between Areas of Focus, system components and key dimensions (lighter solid line), and interconnected linkages across Areas of Focus associated with the theme (light dotted line). See Figure 10.2 for a template.

The following definitions provide additional context on each component included in each of the individual cross-sectoral diagrams.

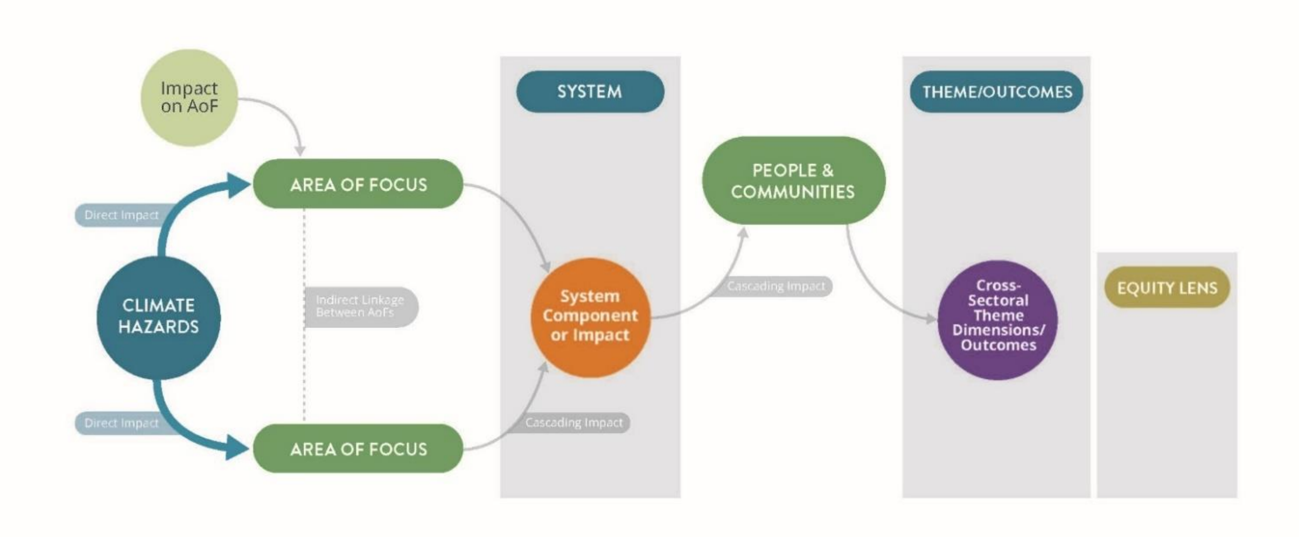
Direct impacts are defined as those resulting from climate variables on the Area(s) of Focus. The interaction between a climate variable and its direct impact has been quantified as part of the PCCIA.

Cascading impacts can be understood as a direct climate impact triggering a series of impacts across several systems and sectors (e.g. domino or contagion effects).

Interconnected linkages are a way to represent the inherent connectedness between all Areas of Focus, where components are intrinsically dependent, or rely upon, one another to provide a function under the context of each cross-sectoral theme. (e.g. linkages between the Infrastructure Area of Focus and Business and Economy Area of Focus under Food Security represent the interconnectedness between critical infrastructure systems and supply chain function).

An **Equity Lens** has been applied to every diagram, which identifies unique factors or populations that may be disproportionately impacted associated with the cross-sectoral theme.

Figure 10.2: Representation of how climate change cascades through Ontario's systems, posing risks to Ontario's People's and Communities



10.1 Food Security

Overview

Food security is achieved when "individuals have access to sufficient, safe, nutritious, and culturally appropriate food that meets their dietary needs" (Government of Ontario, 2017a). It is a multi-dimensional concept that can be influenced by various sectors and is affected by impacts that cascade through food systems.

Food systems underpin food security, and are comprised of activities that span across all Areas of Focus in these areas:

- Food production – encompasses commercial and non-commercial agriculture, livestock fisheries and aquaculture production, as well as the hunting, fishing and harvesting of traditional Indigenous foods
- Food processing – involves the transformation of raw food inputs into retailed food products (e.g. washing, sanitizing and packaging)
- Food distribution –involves the transportation of food products to users (e.g. grocery stores, restaurants etc.)
- Food preparation and consumption – includes the preparation and consumption of food by the consumer

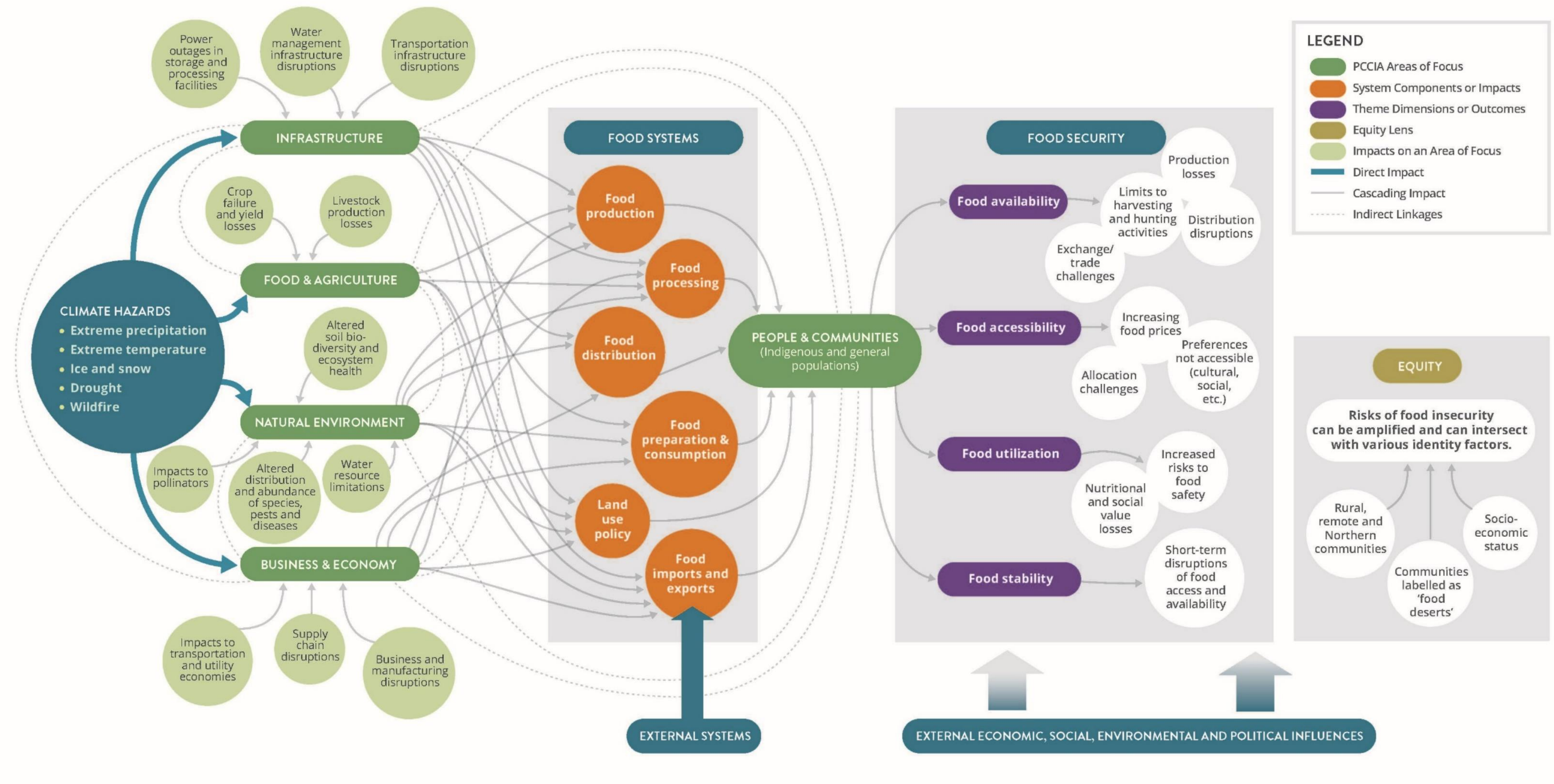
Land use policy and food imports and exports have also been identified as system components. Their influence and role in food security is outlined below.

This section outlines the linkages between climate risks within each Area of Focus, food systems and ultimately food security in Ontario. Climate change is expected to present several risks to provincial food systems, impacting key dimensions of food security such as:

- Food Availability – production, distribution, and exchange of food
- Food Accessibility – affordability, allocation, cultural preference
- Food Utilization – nutritional value, social value, food safety
- Food Stability – continuous and undisrupted availability and access

Figure 10.3 below, illustrates how climate risks cascade through each Area of Focus (represented in green) to food system components (represented in orange), impacting the primary dimensions of food security (represented in purple).

Figure 10.3: Representation of how climate change cascades through Ontario's food systems, posing risks to Ontario's food security



Climate Risks to Ontario's Food Systems and Food Security

Food Production

Food production is a foundational component of Ontario's food system, encompassing all agricultural production activities (field crops, fruit and vegetable and livestock production), as well as fisheries, hunting and harvesting activities. Climate risks to food production in Ontario directly influence food security by impacting food availability (Schnitter and Berry, 2019; Campbell et al., 2014).

As outlined in the Food and Agriculture Area of Focus climate change is expected to increase risks across Ontario's agricultural sector, directly impacting field crop, fruit and vegetable and livestock production. Losses can be compounded by indirect climate impacts to soil health, water availability, pests and disease and livestock feed shortages. Climate risks to food production in Ontario could result in food availability implications should crop and produce yields and/or livestock production decline substantially (Schnitter and Berry, 2019; Mbow et al., 2019).

Infrastructure systems across Ontario play a critical role in food production, from the farm to provincial level. As described in the Infrastructure Area of Focus, utility and transportation systems are vulnerable to impacts of several climate variables, leading to service disruptions for food production. For example, transportation is critical for food production activities, ensuring that inputs (e.g. seed, fuel, fertilizers, and equipment) are delivered to producers in an efficient manner (Food and Agriculture Organization, 2018) Climate-related impacts to infrastructure could result in supply disruptions and shortages for agricultural producers and subsequently increase risks to food availability in Ontario.

As illustrated in the figure above, the natural environment and associated services also play a critical role in food production for the province. The Natural Environment Area of Focus outlines how climate risks are expected to impact access to water quality and quantity, soil and ecosystem health, the role of pollinator species and shifting ranges of native species. These impacts threaten food availability, affect irrigation and field applications, soil productivity, pollination, and biocontrol of pests in agricultural production. Additionally, changes in species distribution and abundance impact food availability for communities that rely on subsistence hunting, fishing, and harvesting activities as primary food sources (Food and Agriculture Organization, 2018).

Food Processing

Food processing is another component of food security and refers to activities that transform raw food inputs into retail food products, including cleaning, sanitizing, packaging, and processing. Climate risks to food processing in Ontario impact multiple elements of food security, including food availability and accessibility.

As outlined in the figure above, climate-driven impacts within several Areas of Focus can impact food processing activities. Limitations to water supply could adversely impact food processors and manufacturers that rely on water use for operations. Energy supply and distribution systems could also be impacted by several different climate variables hazards (extreme weather events and flooding, extreme heat etc.). Prolonged power outages in processing and storage facilities without sufficient backup power could result in significant inventory losses and increase food insecurity in certain regions (Mbow et al., 2019).

Ontario's food processing sector is also dependent on reliable transportation networks to ensure harvested crops and livestock products are efficiently delivered to food manufacturers, warehouses and other facilities (e.g. grain handling). As outlined in the Infrastructure and Business and Economy Areas of Focus, climate change presents a wide range of risks to transportation networks and economies in Ontario. Disruptions and delays of food inputs to processors and manufacturers can result in food availability shortages, and implications for food accessibility through increased food prices in response to supply chain disruptions (Schnitter and Berry, 2019).

Food Distribution

The distribution of food is another critical component of the food system, with direct linkages to availability, accessibility, and stability dimensions of food security. Reliable transportation networks and supporting economies are imperative for food distribution throughout the province and to maintain access to domestic and international export markets. As noted in the Infrastructure Area of Focus, climate change poses risks to the functionality of Ontario's transportation system, resulting in implications for food distribution to markets, retailers, and consumers. Food distribution impacts are of particular concern for remote northern communities (e.g. the Far North), with lower capacity to produce and store food supplies locally. Additionally, prolonged disruptions to public transportation systems in developed regions can impact food accessibility, as many Ontarians rely on public transit to access food distribution sites (e.g. grocery stores).

Climate-related impacts on energy supply and distribution can be impactful for food distribution facilities without sufficient backup power, resulting in significant inventory losses and impacts to food availability (Mbow et al., 2019). For example, the Ontario Food Terminal is in a flood-prone area within the Greater Toronto Area (GTA), with no permanent backup energy source. In the event of a prolonged power outage to the terminal from extreme weather or flooding, there would be significant inventory losses, leading to food availability and stability challenges in several regions across the province (Zeuli, 2018b).

Climate risks to the Business and Economy Area of Focus, could compound impacts to Ontario's food distribution systems due to the economic impacts linked to barriers in accessing domestic and international markets and local business disruptions (C40 Cities, 2018), These impacts would cause additional implications for food accessibility through increased food prices. Ultimately, climate risks to the food distribution sector could impact several dimensions of food security across the province.

Food Preparation and Consumption

Preparation and consumption are at the consumer end of the food system and directly relate to utilization considerations within food security. Availability and accessibility of sufficient, nutritious, safe and culturally appropriate food sources is desirable for all Ontarians (Schnitter and Berry, 2019; Government of Ontario, 2017a).

Climate risks identified and assessed under the Food and Agriculture and the Natural Environment Area of Focus can have cascading implications for food safety and caninherently impact food utilization in Ontario. Climate change influences the growth, survival, abundance, and range of pathogens throughout food systems, including during food production, processing, distribution, preparation, and consumption. This could increase the likelihood of foodborne illnesses in Ontario, resulting in impacts to food utilization and ultimately human health (Harper and Schnitter, 2022).

Evidence suggests that climate change could contribute to declines in nutritional content and density of some agricultural products which would lead to lower levels of nutritional diversity for consumers (Myers et al., 2017; Fanzo et al., 2018). Climate risks to biodiversity as noted in the Natural Environment Area of Focus affect availability of traditional food sources and nutrient access. These impacts would cause implications for food utilization as availability and accessibility of nutrient-rich and culturally appropriate foods declines across different regions of the province (Myers et al., 2017; Fanzo et al., 2018).

Climate-related impacts to the food preparation and consumption components of the system was not assessed under the Food and Agriculture Area of Focus. The indirect economic impacts resulting from climate risks are highlighted throughout the Business and Economy Area of Focus. The impacts outlined above can indirectly impact restaurant and hospitality businesses across the province through increased costs and food safety risks.

Equity

Climate-related risks to food security vary across Ontario and stand to contribute to existing vulnerability and inequities. An equity lens has been applied to this analysis (see Figure 10.3) to demonstrate how climate risks to food security can be amplified for populations with pre-existing vulnerability.

It is estimated that one in six (16.1%) households in Ontario are food insecure (Tarasuk et al., 2022). A variety of social, cultural, and economic determinants can be used to identify pre-existing vulnerability to food insecurity in Ontario. Low-income households, remote regions, and Indigenous Communities have been identified as those being at a disproportionate risk of food insecurity in Ontario. These factors are important to consider when assessing how climate risks on food security could be exacerbated for vulnerable populations (Government of Ontario, 2017a).

As climate change alters food availability (supply) which affects food prices, risks to food security will be amplified for low-income households. Neighbourhoods categorized as 'food deserts' are particularly vulnerable, as these regions face pre-existing challenges with accessing quality and affordable food products (Harper and Schnitter, 2022; Schnitter and Berry, 2019).

Remote regions of the province (e.g. the Far North) have fewer food purchasing choices, limited transportation options (e.g. no public transit options), lower capacity to store food products locally, and generally experience higher retail food prices (Myers et al., 2017). Food availability becomes limited if transportation infrastructure is disrupted (e.g. shortened winter road access) from climate-related events, resulting in food access, availability, utilization, and stability issues, particularly for remote communities in the Far North region.

Many Indigenous Communities rely on the land and water for sustenance and food security. Under a changing climate, these food sources are being threatened as the distribution and abundance of species changes. Indigenous Communities who rely on harvesting traditional foods as their main food source will be greatly impacted, as access to certain plant, fish (e.g. walleye and brook trout) and mammal species (e.g. moose) from their traditional territories may be limited or entirely lost in some areas. These ecological changes compound risks to food security, resulting in declines to diet quality and nutrient access and accompanying impacts to mental health, cultural well-being, and social cohesion (Harper and Schnitter, 2022).

External Influences

Food security stands to be affected by population growth in Ontario. Growth, particularly in urban centres as projected, will place two-fold pressure on agriculture. First, and simply, larger numbers of people will increase demand and place pressure on food supply. Second, some urban centres will expand their footprint to be able to provide housing for population increases thus putting pressure on adjacent agricultural land.

As highlighted in Figure 10.3, land-use policy also has a significant influence on sustaining agricultural productivity and availability across the province. These considerations are necessary for building climate resilience and reducing vulnerability across Ontario's food systems.

Both international and national dimensions, beyond Ontario's borders influence provincial food systems significantly, and therefore play an important role in food security. As experienced during the COVID-19 pandemic, impacts to food and agriculture subsectors across the globe, can have detrimental impacts on Ontario's food system and associated revenue, including impacts to food availability (supply chains), accessibility (cost), and stability (food shortages) (Sood, 2021). In addition, patterns of international trade, market conditions and drivers, supply chain impacts and disruptions, population dynamics, available labour force, as well as climate-related impacts on agriculture production in other domestic (e.g. prairie region) and international regions (e.g. tropical countries), have significant influence on food security in Ontario. These types of external influences should be considered in provincial resilience and response planning (Mosnier et al., 2014; Food and Agricultural Association Organization, 2018).

Summary

To summarize, climate impacts as viewed through the lens of food security dimensions are exemplified through this cross-sectoral analysis for Ontario. Climate risks are evident within all the dimensions of food security and highlight how vulnerable populations and food insecure communities and regions stand to be disproportionately affected by climate change. Adaptation measures that enhance climate resilience and consider the linkages between agriculture and interconnected sectors, such as the natural environment (e.g. protection of pollinator habitats and water conservation measures), business and economy (e.g. increasing resilience of agricultural supply chain) and infrastructure systems (e.g. energy and transportation infrastructure redundancy), will reduce existing vulnerability and strengthen provincial food security (Zeuli, 2018a; C40 Cities, 2018).

10.2 Energy Security

Overview

Energy security includes many elements but can be defined as the uninterrupted availability of energy sources at an affordable price (IEA, 2022). At its simplest, energy security involves long-term considerations of timely investments to supply energy in line with economy development and environmental needs, as well as short term considerations ensuring the energy system can react promptly to sudden changes in the supply-demand balance (IEA, 2022). Factors that influence energy security include appropriate infrastructure, intensity, diversification, market transparency, and links with the environment and political decision-making.

Resilient energy systems underpin short- and long-term energy security and are comprised of activities that traverse through Areas of Focus in the following areas:

- Energy sources and supply – refers to the various energy resources that comprise Ontario's current energy mix, such as nuclear, hydroelectricity, wind, solar, natural gas, biomass, and refined petroleum products, as well as potential future energy supply options such as hydrogen.
- Energy generation – refers to the process of generating power and electricity from sources of primary energy, including various generation facilities and associated infrastructure.
- Energy transmission and distribution – includes technology and infrastructure (of various size), such as powerlines, transmission lines, pipelines, freight, and other forms of energy transport.
- Energy consumption – refers to the activity that is supported by infrastructure to bring energy products to market and the ultimate use of energy in any technology, service, manufacturing, transportation, or any other form relying on energy such as inhabiting a building.

This section outlines the linkages between climate risks within each Area of Focus, energy systems and ultimately energy security in Ontario. Climate change is expected to present several risks to provincial energy systems, impacting dimensions of energy security including:

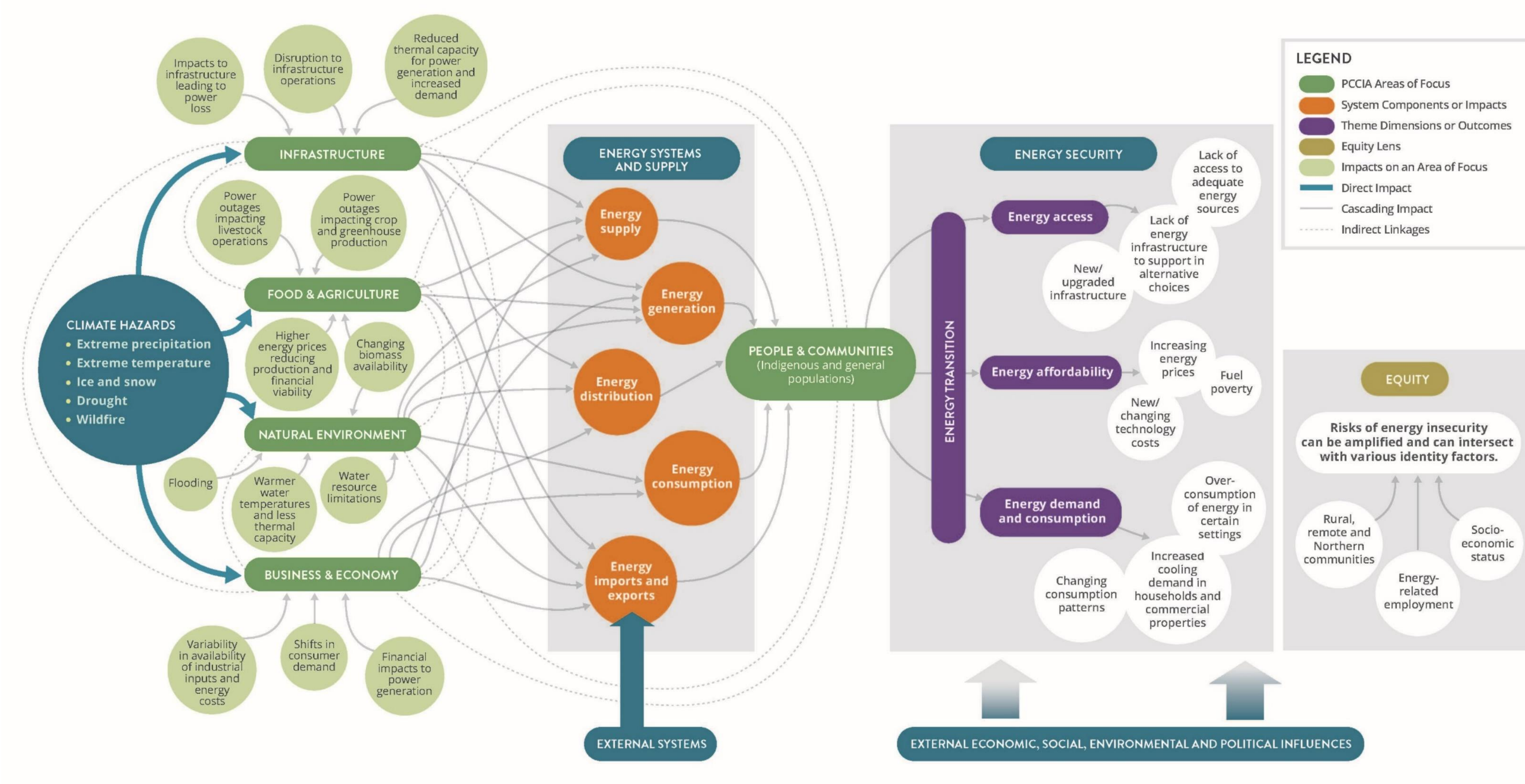
- Energy access – refers to limitations to adequate or sufficient energy sources and/or a lack of sufficient energy infrastructure to support alternative choices in more rural or remote communities.
- Energy affordability – includes energy pricing, and the ability for Ontarians to afford energy in any context in which they may require it, including areas that could be considered to be fuel or energy "poor" relative to other areas across the province.

- Energy demand and consumption – considers consumer behavioural patterns, how and where energy is consumed, changes in energy demand and potential over-consumption of energy.

Importantly, energy security also includes the significant transformation underway in the energy sector. Consumer behaviour and demand is driving a transition from fossil fuel-based resources to renewable energy sources including low carbon fuels and alternative forms of electricity production. The result is a dynamic energy system in a time of rapid change where the various components such as forms (of energy), security, prices and demand/consumption are all affected by climate change.

Figure 10.4 below. illustrates how climate risks cascade through each Area of Focus (represented in green) to energy system components (represented in orange), impacting the primary dimensions of energy security (represented in purple).

Figure 10.4: Representation of how climate change cascades through Ontario's energy systems, posing risks to Ontario's energy security



Climate Risks to Ontario's Energy Systems and Energy Security

Energy Supply

Ontario's energy supply mix is comprised of various forms that are used to provide critical power and heat to homes, fuel transportation of people and goods across the province and power industry to bring various products and services to market. Currently almost half (48%) of Ontario's energy use (primarily transportation) comes from refined petroleum products, 28% from natural gas, 16% from electricity, 4% from biofuels and the remaining 4% from other fossil fuels (OEA, 2021).

Energy needs across Ontario are currently met by a variety of energy sources. For example, Ontario's electricity system comprises only 16% of energy use while the Province's natural gas system, by comparison, provides almost double the energy Ontarians get from electricity, with demand for natural gas heating in the winter season being even higher (OEA, 2021). Stated differently, Ontario has a very clean electricity system; however, its energy system remains a significant source of emissions (Environment and Climate Change Canada, 2022b). In response to shifting policy, consumer demand and investments to expand the electricity system, the energy system will continue to experience transformation which will have implications for energy security.

Climate change can pose risks to the sources and supplies from which energy is generated. This is particularly important as Ontario shifts to low carbon sources and finds opportunities for alternative sources of energy and fuel (e.g. changing biomass availability). One specific example of how climate change can impact energy sources and supplies is through changes to water (generation) resources. Declines in precipitation, either through total annual or variations of seasonal amounts, combined with high summertime evaporation may yield lower surface water volume and thus limit the ability to generate electricity in hydropower generation (University of Cambridge and World Energy Council, 2014). The seasonal (summer) energy security implications of this impact are significant in that it comes at a time when energy demand for cooling peaks. The result is inability to meet peak demand periods which would limit or cancel the ability to cool homes and people. The obvious cascading impact is risks to public health, most notably in adaptation-priority populations that are already predisposed to poor health outcomes. This example of cascading climate change impacts demonstrates both the interconnectedness between energy and other societal systems, and the way that climate change can create multiple impacts through the chain as experienced by people in communities. Resilience in the diversity of forms of energy supply will provide multiple benefits across further layers of the energy system in Ontario.

Energy Generation

Ontario's electricity generating capacity is mainly located in southern parts of the province, but large hydro generating stations are also located in eastern Ontario in the Ottawa River Basin and Northeast Ontario in the Moose River Basin (CER, 2021). Climate change poses risks to the processes, operation, and capacity of power generation in Ontario. Increasing air and water temperatures can lead to less thermal capacity for power generation and decrease the efficiency of combustion turbines (Beecher and Kalmbach, 2012). Similarly, where water bodies or watercourses are adjacent to power generation facilities and used for cooling or receiving, water resources limitations may pose risks to the cooling efficiency of generation processes (University of Cambridge and World Energy Council, 2014). Certain aquatic species with sensitive thermal niches may also be negatively affected by increases in water temperature. In this context, managing the natural water resources and incorporating adaptation and resilience to the extent possible will help secure energy generation operations in the future.

Extreme climate or weather events will also create economic or financial impacts to generation operations in the form of increased costs for businesses, communities and people. Should Ontario's ability to generate sufficient and consistent energy be impacted climate change hazards, energy security implications could include rising costs of access being borne by consumers, intermittent access to energy during peak periods where demand exceeds supply, and possible cascading health and safety risks. These implications would be particularly pronounced in remote communities or among those with a historical lack of infrastructure or energy investment to meet their existing needs, such as Indigenous Communities in northern and remote locations.

Energy Transmission and Distribution

Climate change is also expected to pose risks to energy transmission and distribution across Ontario. The province's existing electricity grid is characterized by both centralized generating stations as well as a large transmission and distribution system that stretches across the province. Natural gas distribution in Ontario also relies on a large network of transmission pipelines and distribution infrastructure (AMO, 2021). In both cases, climate change and extreme weather events can increase system demand or cause damage to distribution infrastructure (e.g. due to falling trees on power lines or flooding-related washouts of soil supporting buried pipelines) ultimately leading to energy system outages. Flooding of distribution infrastructure, stations or components of the distribution networks can lead to damage and power loss with wide-reaching consequences.

Reliability is a key component of energy security and is defined by the continuity of energy supply to meet consumer needs. Reliability of the energy system is monitored and assessed by the Independent Electricity System Operator (IESO) on a quarterly basis and forecast to the future through an 18-month window. In its latest publication, IESO indicates that in general, Ontario's transmission system is expected to continue to reliably supply province-wide demand but combinations of transmission and/or generation outages could create operating challenges (IESO, 2022a). The Ontario Energy Board (OEB) uses a scorecard system to evaluate utilities across the province, reporting annually on 20 measures, including several that are focused on system reliability, asset management and safety (OEB, 2022b). These scorecards offer regional perspectives of shifting performance over the past five years. Both of these examples are unique assessment and reporting mechanisms within which climate change can be incorporated to better understand both short and long term impacts and related policy response. Evolving from assessing system reliability on an 18-month basis, to characterizing and building system resilience over a longer time horizon would serve Ontario's energy distribution well, particularly in the context of accelerating electrification of transportation, buildings, and industrial sectors and subsequent additional demand pressures on electricity the system (Canadian Climate Institute, 2021).

Energy Consumption

Climate change poses significant risks to those using and consuming energy – people, communities, and businesses. Warming air temperatures are expected to further increase peak demand for cooling homes and facilities in summer months. The introduction of new technology, including electric vehicles and supporting infrastructure (e.g. charging stations) can shift the timing of demand for energy and when peak energy requirements may be needed. As investments are made in Ontario's energy system to accommodate these changes and to repair damage to infrastructure due to future climate impacts, there is a risk that consumers may face even higher energy prices compared with today. Those already facing high energy prices, including lower income residents who are more vulnerable, may increasingly face fuel poverty as the impacts of climate change lead to increased costs across energy systems translating into rate hikes. From an economic perspective, risks could lead to shifting availability of industrial inputs and high energy costs depending upon reliance on supply chains within and external to Ontario. Food and Agriculture provides one unique sectoral perspective where the agriculture community may require more energy to support in the deployment of new, adaptive technologies (e.g. robotic equipment, temperature and moisture sensors, aerial imagery, GPS technologies, etc.), but also face intermittent loss of power due to higher demand in the growing season and capacity constraints, which in turn could affect livestock operations and crop and greenhouse production.

Equity

Individuals and communities that endure current challenges with energy security face the compounded effects of climate change along with an energy transition. The disproportionate impacts strike within a context where few options exist for redundancy and resilience and more affordable rates. Emission reduction targets – net zero emissions by 2050 - driven by Federal legislation will provide the impetus for changes to the energy supply mix. The OEA states that this transition will require a major transformation of the province's energy system (OEA, 2021), primarily away from the refined petroleum products that account for almost half of the province's energy use (OEA, 2021).

The Ontario Energy Association identified that any increased demand at times of peak loads will require expansion of the electricity system. Forecasts for the increase in demand are significant and will thus drive expansion and significant changes to the energy mix. In this transition, considerations to climate change resilience are paramount. The financial costs of this transition loom large for those who already struggle with energy prices, thus equitable solutions are critical to ward off further energy-equity segregation within the population.

An equitable energy transition involves international, national, and Ontario-based actions that acknowledge and incorporate the fact that climate change has different impacts on priority populations and that adjusting energy systems should account for these differences and issues. Many uncertainties remain regarding the speed at which low carbon technology is adopted and deployed in the market. Demand for electricity is expected to increase in Ontario and across Canada and costs continue to rise. As of 2018, Ontario was identified as having the fastest growing electricity costs in Canada and among the highest in North America. Between 2008 and 2016, Ontario's residential electricity costs increased by 71 percent, far outpacing the 34 percent average growth in electricity prices across Canada (Aliakbari et al., 2018). These rising costs already placed a significant financial burden on communities, Ontarians, and certain economic sectors, such as Ontario manufacturing, hampering its competitiveness. A study by Aliakbari et al., (2018) stated that Ontario's high electricity prices have already been responsible for approximately 75,000 job losses in the manufacturing sector between 2008 to 2015 (Aliakbari et al., 2018). And while there are challenges associated with meeting growing demand, expansion projects across Ontario in support of rural and remote access and more affordable energy prices have been identified and are underway (Government of Ontario, 2021c).

An equitable transition towards a low carbon energy system requires acknowledging and managing improved reliability, access, and affordability particularly in rural or remote communities, Indigenous Communities, and for Ontarians with lower incomes. As Ontario's energy systems are expanded consideration should be given to how costs affect price and ultimately the potential for disproportionate impacts to vulnerable communities or those that work in energy-related employment.

External Influences

Provincial, national and international changes in regulations, standards, targets, and policy related to energy can lead to changes in how the Ontario Energy Board regulates the energy sector. This also includes approval or denial of energy license requests based on system reliance, capacity, or other criteria and rate pricing. Political and non-political agendas influence the growth of certain commodities or sectors and can affect energy demand in particular regions of the province. As an example, in their latest quarterly Reliability Outlook, the Independent Electricity System Operator (IESO) identifies that significant growth in the greenhouse sector has led to several customer connection requests in the Windsor-Essex region and that a new switching station is being implemented to increase capacity but that outages may be difficult to accommodate in the interim (IESO, 2022b). International imports and reliance on demand and supply of fuel and gasoline also can have significant influence on energy prices, as is being experienced in the Spring of 2022 due to supply chain disruptions, international conflict and increased demand for fuel.

Summary

Climate change risks to Ontario’s energy systems, in tandem with external influences, are expected to continue and become increasingly impactful to energy system reliability, capacity, and pricing. Significant infrastructure investment is needed to not only meet greenhouse gas emissions reduction targets, but to ensure a reliable, equitable and affordable energy system for Ontarians. Investments in these technologies such as energy storage, smart grid technologies, electric vehicles, and distributed energy resources, increased system flexibility can enable energy systems to become more resilient to climate impacts and minimize service disruptions. Other adaptation and resilience opportunities for the Ontario energy system include reducing vulnerability among consumers during climate events by: enhancing energy efficiency, upgrading, burying infrastructure and implementing measures to support recovery.

10.3 Water Security

Overview

Direct and indirect impacts of climate change on water resources pose risks to water use and ultimately compromise water security for human health, livelihoods, and economic development in Ontario. Ensuring access to adequate quantities and acceptable quality of water is key for sustaining human well-being and socio-economic development, ensuring protection against water-borne pollution and water-related disasters. Preserving the functionality of natural ecosystems plays a vital role in maintaining water security.

The impacts of climate change on water resources will manifest within each of the Areas of Focus as disruptions and changes in:

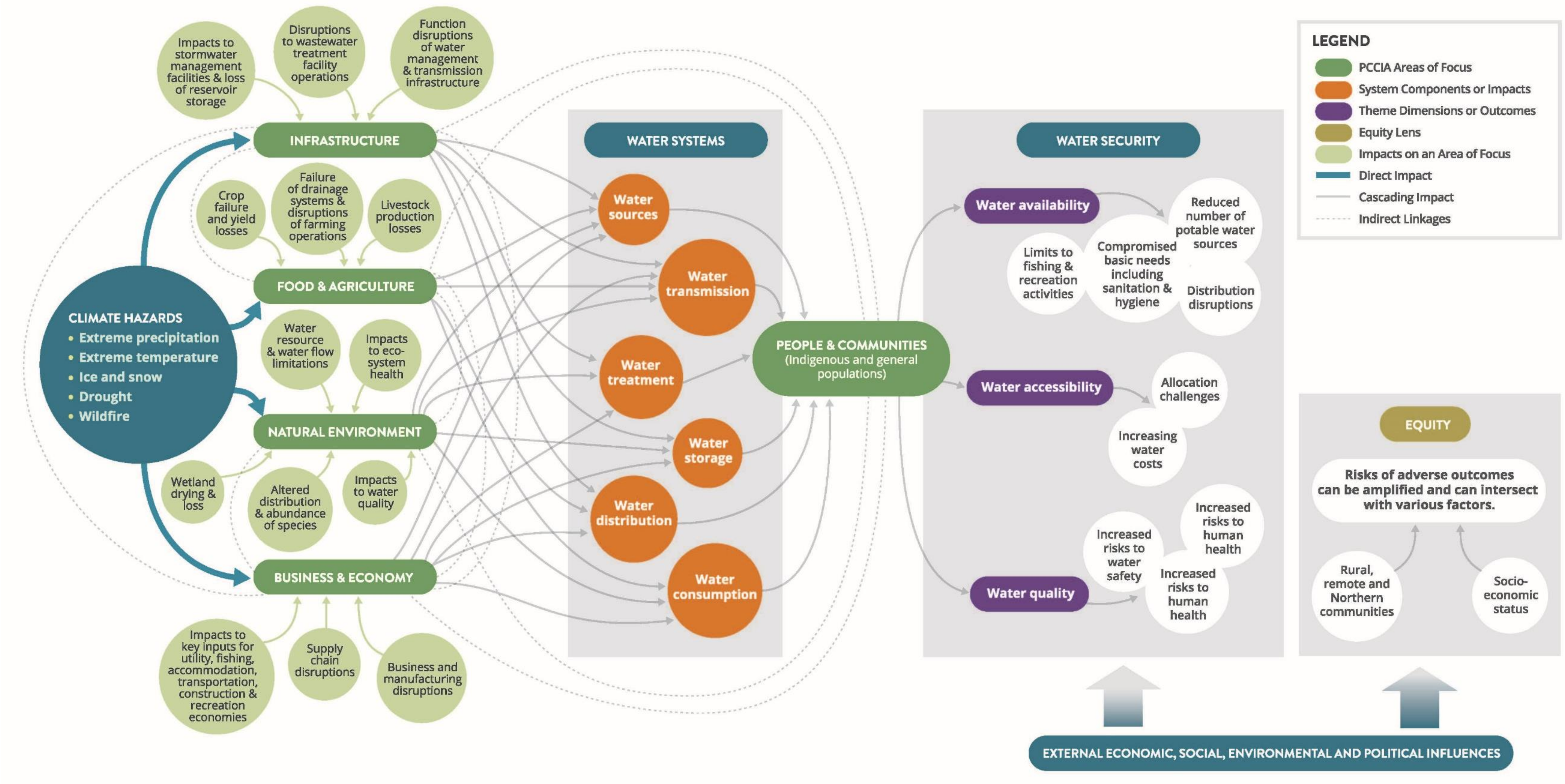
- Water sources – refers to surface aquifers and groundwater that provide water to public drinking water supplies as well as private wells.
- Water transmission – refers to the transport of treated water from storage facilities to distribution networks and sewer/storm water from the location of end-use to a water treatment facility, taking place through water transmission pipelines.
- Water treatment – refers to any process that involves physical, chemical, physicochemical and biological operations to eliminate and/or reduce contamination or non-desirable characteristics of water to make it appropriate for a specific end-use.
- Water storage – refers to holding water in a contained natural or artificial area for a period of time for later use for a variety of purposes.
- Water distribution – refers to a provision of uninterrupted supply of water from a central location to a location of end-use.
- Water consumption – refers to using withdrawn water for a variety of household and industrial purposes/activities without returning it to the source.

This section outlines the linkages between climate impacts within each Area of Focus, water systems and water security in Ontario, focusing on critical community outcomes related to:

- Water availability – described as a safe and reliable freshwater supply important for maintaining human, plant and animal populations and supporting economic development.
- Water access – refers to the ability of community members to obtain water that factors in elements like available water quantity, distance to a water source and time required to reach it.
- Water quality – refers to the chemical, physical and biological characteristics of water based on the standards of its usage.

Figure 10.5 below illustrates how climate risks cascade through each Area of Focus (represented in green), causing impacts to water systems components (represented in orange), associated outcomes (represented in purple), and how equity considerations influence these outcomes.

Figure 10.5: Representation of how climate change cascades through Ontario's water systems, posing risks to Ontario's water security



Climate Risks to Ontario's Water Systems and Water Security

Water Sources

Ontario is home to abundant surface and groundwater resources that are used for multiple purposes. A sufficient number of quality water sources is critical to provide for drinking water supplies, availability of water for fishing and recreational activities as well as agricultural operations, natural environment conservation, construction, manufacturing and more.

Climate change poses risks to water sources affecting which affect supply and quality. Dry conditions and extreme hot temperatures change water balances and cause disruptions to the water flow regulation service, leading to reduced surface and groundwater levels, changes in intra-annual patterns of water availability, loss of available freshwater supplies for human use, wetland drying and loss, changes in distribution and abundance of animal and fish species and altered ecosystem function over a long term (Saarikoski et al., 2015). Limited water availability can affect crop and livestock production, food processing and other sectors of the economy that rely upon a reliable source of water, both potable and non-potable.

Extreme precipitation events can directly affect the components of ecosystems that are most important in water flow regulation such as riparian areas and sensitive wetlands, reducing water flow regulation and causing greater peak flow risks (Kennedy and Wilson, 2009). Additionally, heavy rainfall events increase erosion and wash inorganic sediment and nutrients (e.g. phosphorus) and contaminants from agricultural fields into water bodies, resulting in degraded quality of surface and ground water sources (Lebelo-Almaw et al., 2019).

Collaboration between individual landowners, not-for-profit environmental organizations, conservation authorities, Indigenous Communities and various levels of government plays a fundamental role in supporting natural environment and ensuring continued water security of Ontario's people and communities. Policies, programs and regulations aimed at protecting water supply and quality such as the Environmental Protection Act (1990), the Ontario Water Resources Act (1990), provincial land use planning statutes including the Planning Act (1990), Ontario's Clean Water Act (2006), Lake Simcoe Protection Plan (2009), the Water Opportunities and Water Conservation Act (2010), and Ontario's Great Lake Strategy (2017) provide support for the protection of hydrologic features and areas and ultimately – water security in the province.

Water Transmission

Water transmission is a key component of the water system, and includes the delivery of clean water to businesses and communities and safe transport of sewer and stormwater to treatment facilities through water transmission pipelines. Disruptions to water transmission have direct implications for water security, especially water availability and quality.

Climate-driven impacts within several Areas of Focus can affect water transmission that relies on a large network of transmission pipelines and distribution infrastructure. Flooding, droughts, storms and extreme heat events can damage or destroy water transmission infrastructure resulting in significant disruptions of service, high repair costs and dangerous conditions for the affected communities, including drinking water contamination and sewage backups (Andrey, 2014). The risks are particularly significant for older infrastructure whose ability to withstand extreme weather events and provide adequate levels of service is reduced.

In Ontario, clean water transmission has historically been, and continues to be, the responsibility of municipalities. Provincial legislation, including the Safe Drinking Water Act (2002), the Public Utilities Act (1990), the Ontario Water Resources Act (1990), the Municipal Act (2001) gives municipalities the power and responsibility to finance, build, own, and operate water works. Additionally, regulations and policies aimed at protecting wetlands and other green infrastructure in order to improve local stormwater management provide opportunities to increase the resilience of water systems to climate change and enhance water security in Ontario's communities.

Water Treatment

Water treatment is an important component of the water system, referring to any process that involves physical, chemical, and biological operations to eliminate contamination and reduce non-desirable characteristics of water to make it appropriate for a specific end-use. Proper treatment of water both before and after use/consumption is critical for water quality and contributes to overall water security.

Climate impacts within several Areas of Focus can cause challenges and disruptions to water and wastewater treatment activities. Extreme precipitation events and flooding may affect wastewater treatment plants that depend on unsaturated soil to store tanks and result in subsurface discharge, clogging, and cracking in tanks (Saarikoski et al., 2015). Contamination of drinking water sources by chemicals and waste in surface runoff is another impact related to extreme precipitation events, presenting challenges to the water treatment process and causing risks to water safety and human health. Droughts may cause disruptions in the wastewater treatment process resulting in unpredictable effluent concentrations which may exceed water quality limits, impacting the assimilative capacity of the receiving water body (Saarikoski et al., 2015). This will impact water accessibility and increase water costs to the consumer.

Vulnerable communities with older essential infrastructure (sewers, water treatment facilities) are particularly vulnerable to such risks. Different types of treatment systems, such as sewage treatment plants and natural treatment sewage lagoons used in some Northern communities may be affected by the changing climate and extreme weather events in different ways. This has financial and infrastructure implications in retrofitting or replacing wastewater treatment facilities as well as human health and environmental implications if treatment systems are not performing adequately.

Water Storage

Water storage is a component of the water system that refers to holding water in a contained natural or artificial area for a period of time for later use for a variety of purposes.

Climate impacts within several Areas of Focus can cause challenges and disruptions to water storage and lead to adverse outcomes in communities, natural environment, businesses and agricultural operations. Extreme precipitation could lead to flooding that can cause loss of reservoir storage and physical damages to dams and pump stations that will require replacement or maintenance and could lead to downtime or reduced capacity in the system (Feltmate & Moudrak, 2021). Additionally, extreme precipitation and large snowmelt may overwhelm existing stormwater management facilities, increase loads to pumping infrastructure or could cause electrical failure in pumping stations resulting in flooding, risks to human safety, property damage, and need for additional funds for repairs and maintenance of stormwater management facilities and other infrastructure. Less rainfall and longer dry periods mean groundwater recharge may be reduced and ponds, water-storage tanks and reservoirs may not fill enough to support agriculture, communities and businesses that are dependent on them, causing issues with water availability and accessibility (McCartney & Smakhtin, 2010). Impacts to water quality and ecosystem health caused by both dry and extreme rainfall conditions may be further exacerbated by climate change. Increased wildfire activity may result in elevated sediment load in water bodies causing loss of some hydro reservoir storage or additional cleaning requirements.

Water storage provides a mechanism for dealing with water resources variability related to climate extremes by resolving the temporal disconnect between water supplies and demands from wet to dry periods (Scanlon & Smakhtin, 2016). Proper planning and management of water storage systems, with focus on their flexibility and unique characteristics, could increase water security and overall Adaptive Capacity of a community.

Water Distribution

Water distribution refers to the provision of an uninterrupted supply of water from a central location to a location of end-use and is closely linked to water supply and state of transmission infrastructure. Disruptions in water distribution have direct implications for water security, especially water availability and accessibility.

Climate impacts within several Areas of Focus can cause challenges and disruptions to water distribution. Climate events such as storms and flooding can damage infrastructure and result in functional disruptions of underground water transmission and distribution systems. In some cases, consequences of these impacts include noxious substances being released into municipal drinking water supplies which threaten human health and compromise basic needs. Drought and flow limitations in surface waterways and groundwater cause reductions in water supply, and ultimately result in allocation challenges, distribution disruptions and increasing water costs.

Rehabilitation of old infrastructure, policies and regulations aimed at improving water management and encouraging responsible stewardship (e.g. Safe Drinking Water Act) are some of the ongoing efforts to increase resilience of water management facilities, transmission and distribution infrastructure at the local level.

Water Consumption

Water consumption is a component of the water system that refers to using withdrawn water for a variety of household and industrial purposes and activities without returning it to the source. Water consumption directly relates to water availability, accessibility and quality considerations within water security. Availability and accessibility of sufficient, clean, and safe drinking water are essential for all Ontarians, while Ontario industries and businesses are similarly in need of ample and timely water inputs.

Impacts of climate change within several Areas of Focus pose significant risks to those using and consuming water – people, communities, wildlife, livestock, industries, businesses and more. Extreme precipitation and flooding events may result in declining water quality from excessive run-off as nutrient and sediment could affect drinking water supplies and overall ecosystem health. Communities would need to find new water sources and could face compromised basic needs such as sanitation and hygiene as well as increased risks to human health. Drought, Moisture Deficits and extreme heat conditions may impact water supply and management, resulting in increased demand and requiring allocation restrictions. Industries such as construction, manufacturing and agriculture could experience water use limitations (e.g. for crop irrigation and livestock watering), causing disruptions to operations, impacts to productivity and revenue losses. This could be exacerbated based on the timing and magnitude of water use restrictions and drought conditions (Disch, J. et al., 2012).

Equity

Climate-related risks to water security vary across Ontario and often contribute to existing vulnerability and inequities. An equity lens has been applied to this analysis (see Figure 10.5) to demonstrate how climate risks to water security can be amplified for populations with pre-existing vulnerability.

As climate change alters water sources and reliable supply of clean drinking water, water safety risks and allocation challenges are amplified. Rural, remote, Indigenous and Northern communities are at greatest risk of water insecurity in Ontario.

Eighteen percent (18%) of Ontario's population live in areas that are not covered by the Clean Water Act (2006) and, therefore, do not have source water protection plans to prevent the contamination of their sources of drinking water. This number includes people living in communities that draw drinking water from domestic wells and over 40 municipal drinking water systems (such as the Village of Cobden in the Township of Whitewater region) that are not within a source water protection area and whose water quality is not assessed for drinking water threats with no policies in place to reduce the risks (Rees andMcClenaghan, 2022). Additionally, at present only a few First Nations have opted into the Clean Water Act and a limited number of Indigenous Communities are protected by the source water protection system.

Those living in large mixed-use watersheds (e.g. the Grand River watershed) are most likely to be impacted by competing interests between communities, agriculture and industry. That said, the Provincial Policy Statement (Government of Ontario, 2020f) requires coordination between local municipalities, conservation authorities and other sectors in planning, development, conservation, and the management of resources, balancing the interests of multiple stakeholders in a single watershed.

Investing in upgrades to water transmission infrastructure and construction of water and sewage services in rural, remote and Northern communities along with extending the protective coverage of the Clean Water Act to include all municipal drinking systems, Indigenous Communities and private wells would contribute to reducing inequities related to water safety and human health, minimize distribution disruptions and save costs in the long-term.

Summary

Climate change is expected to present challenges to Ontario's water systems through impacts on water resources, drinking water, stormwater, and wastewater infrastructure. High complexity of the water sector and interconnectedness of its elements stress the need for collaboration, improved decision-making processes and policy coherence. Opportunities for a shared vision and coordination of climate adaptation actions within the water sector include a holistic One Water Approach, a management framework that could integrate drinking water, wastewater, and stormwater into one entity, accounting for all water resources, at a river basin level, enhancing climate resilience, reducing existing vulnerabilities and strengthening Ontario's water security.

10.4 Human Health, Safety and Well-Being

Overview

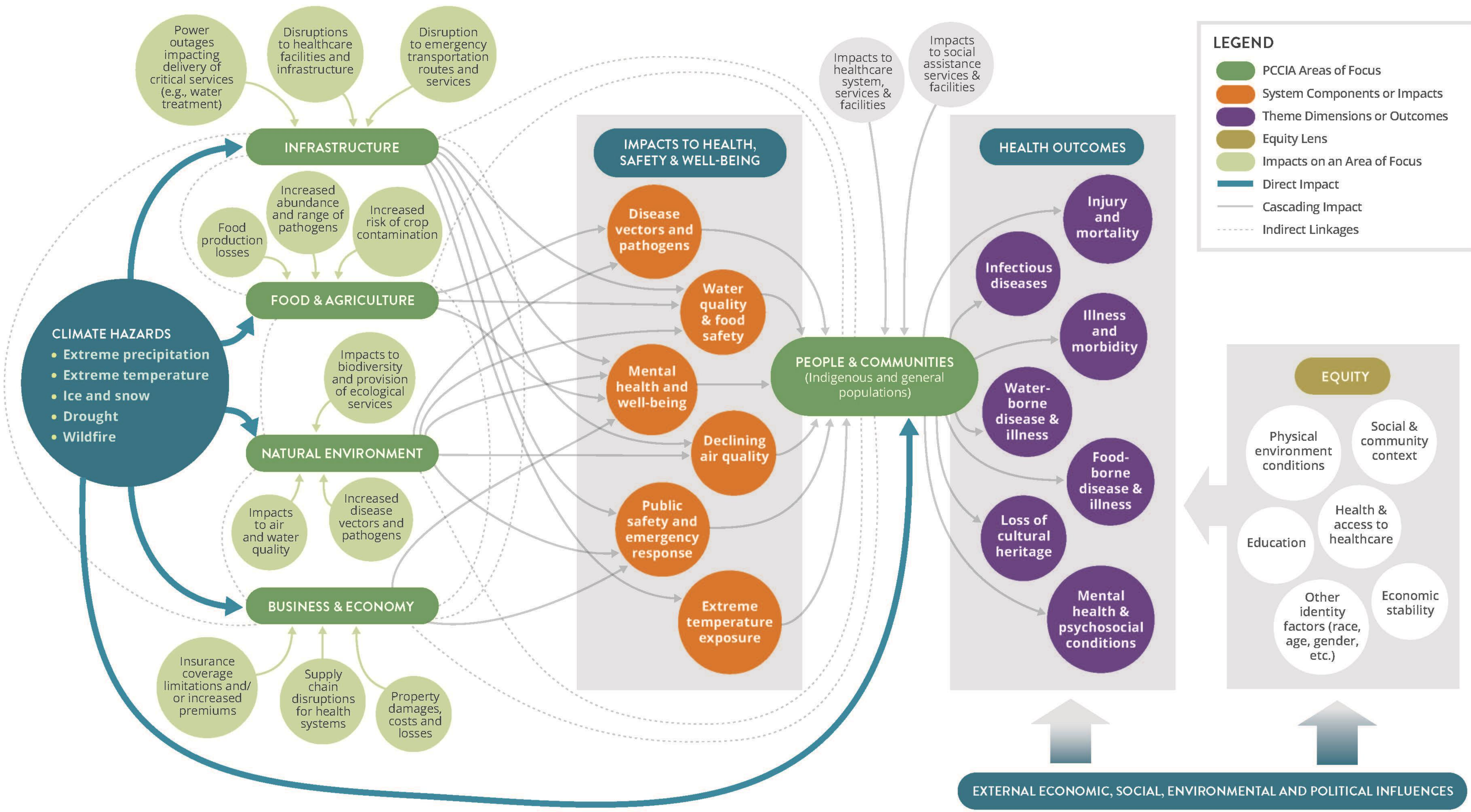
Public health, safety and well-being is a critical cross-sectoral theme considering the importance of a healthy human population in the face of climate change. Climate risks to health, safety and well-being are complex and mediated by a range of determinants of health and other situational, behavioural, and organizational factors, including health and safety-related infrastructure. The management of climate risks and projected impacts to health, safety and well-being requires close partnerships with officials within and outside the health sector.

Climate change can impact the health, safety, and well-being of Ontarians both directly, through different climate and weather events hazards (e.g. extreme heat), and indirectly through a range of environmental, built, and economic pathways. This section outlines how climate risks can cascade across each Area of Focus of this PCCIA, resulting in health, safety and well-being impacts and outcomes for Ontarians. The following impacts are summarized under the following categories and associated health outcomes:

- Disease vectors and pathogens relates to infectious and vector-borne disease health outcomes.
- Water quality and food safety relates to food and water borne disease and illness health outcomes.
- Mental health and well-being relate to mental health, psychosocial illness and loss of cultural heritage health outcomes.
- Declining air quality relates to respiratory morbidity and illness health outcomes.
- Public safety and emergency response relate to injury and mortality outcomes associated with natural hazards.
- Extreme temperature exposure relates to morbidity and mortality health outcomes associated with extreme heat and cold.

Figure 10.6 illustrates how climate risks cascade through each Area of Focus (represented in green), causing impacts to public health, safety, and well-being (represented in orange), associated outcomes (represented in purple), and how determinants of health equity influence these outcomes.

Figure 10.6: Representation of how climate change causes impacts to human health, safety, and well-being and associated community outcomes. Risks to health, safety and well-being can be influenced and amplified by determinants of health and equity.



Climate Risks to Human Health, Safety and Well-being across Ontario

Disease Vectors and Pathogens

Warming temperatures and changing precipitation patterns are increasing the likelihood of diseases carried by insect vectors in Ontario. As noted in the Food and Agriculture and Natural Environment Areas of Focus, disease vectors can impact not only human health, but also can adversely impact crop production and ecosystem health. When considering risks specific to human health, Lyme disease and West Nile virus are two diseases that are increasing in frequency and range across the province, due to an expansion of their vectors and more favourable conditions for transmission (Ogden et al., 2022). Ontario Public Health Units (PHUs) across the province have been increasing surveillance of insect-borne diseases, monitoring changes, and studying associated vectors to advance knowledge and inform responses (Buse et al., 2022; Levison et al., 2017; Grey Bruce Health Unit, 2017).

Warming temperatures and shifting moisture conditions are also projected to impact the prevalence of diseases transmitted to humans by wildlife. For example, within the Natural Environment Area of Focus, it is noted that climate change is likely to increase the range and abundance of white-tailed deer in Ontario. However, deer are expected to experience higher pathogen loads and more disease outbreaks. This could result in cascading risks to human health and safety, especially for hunters and Indigenous Communities who rely on harvesting traditional foods as main food sources (Masood et al., 2017). Migratory birds, moose, coyotes, and foxes are other animals that have been observed with higher pathogen and parasite loads and disease outbreaks among populations, increasing risks to human health and safety under a changing climate.

Water Quality and Food Safety

Climate change in Ontario is also expected to pose risks to water quality and food safety in the province. As noted within the Natural Environment and People and Communities Areas of Focus, climate risks can affect the quality of drinking water, resulting in significant health, well-being and safety of Ontarians.

Extreme precipitation and rapid spring snowmelts carry bacteria and chemicals into surrounding watersheds and increase the risks associated with water-borne diseases. These impacts are intensified by surrounding development, industry, agricultural production, and land-use changes. Regulating ecosystem services, covered in the Natural Environment Area of Focus, provide natural filtering of contaminants, underlining the importance of protecting wetlands and ecosystems, especially within source water protection zones (Takaro et al., 2022).

The Natural Environment Area of Focus identifies risks associated with warming temperatures and outbreaks of toxic algae and cyanobacteria (referred to as “harmful algal blooms”).

Cyanotoxins within algal blooms can have significant human health impacts associated with exposure through drinking water systems and recreational water use (e.g. swimming at beaches).

As highlighted in the Infrastructure Area of Focus, extreme precipitation and flooding can also cause disruptions to drinking water, wastewater, and stormwater infrastructure. For example, in the event of a wastewater facility failure, there is a heightened risk of water contamination and sewage overflows. The impacts to water quality cascade throughout different built and natural systems, resulting in an increased likelihood of water-borne disease and illness. Remote areas and households that rely on non-municipal groundwater sources and infrastructure (e.g. private wells) are at a higher risk of contaminated drinking water following extreme precipitation and flooding events, however larger municipal systems can still be impacted (Takaro et al., 2022).

Access to safe drinking water is an ongoing issue for many Indigenous Communities across Ontario, leaving communities to rely on private water systems, treatment methods and sources. Impacts to water quality driven by climate change will be disproportionately felt in these communities with limited or inadequate drinking water infrastructure systems (Schnitter et al., 2022).

Climate risks presented under the Food and Agriculture and Natural Environment Areas of Focus introduce implications for food safety in Ontario, covered in the Food Security Cross-Sectoral section). Climate change influences the growth, survival, abundance, and range of pathogens throughout stages of the food system (production, processing, distribution, preparation, and consumption). Associated food safety impacts are likely to increase risks related to food-borne disease and illness in Ontario and ultimately to human health and safety (Harper and Schnitter, 2022).

Mental Health and Well-being

Over recent years, it has become clear that climate-related disasters can often lead to negative mental health outcomes (Decent and Feltmate, 2018). For example, the economic impacts and financial losses of flooding, wildfire, and other climate-related disasters, as highlighted in Business and Economy Area of Focus, can lead to increased levels of post-traumatic stress disorder (PTSD), general distress, depression, and anxiety. Additionally, personal losses, displacement, environmental degradation, and food and water insecurity after a disaster, can compound mental health impacts in affected communities and lead to increased stress, anxiety, and depression (Decent and Feltmate, 2018; Hayes et al., 2022).

As noted throughout the Food and Agriculture Area of Focus, crop failures due to drought and other climate-related conditions can have cascading effects on the mental health of farmers and others in agricultural communities (Hayes et al., 2022). Changing climate conditions leading to ecosystem degradation and biodiversity loss, can also lead to mental health problems such as stress, anxiety and depression, especially for individuals and communities with limited access to healthy ecosystems and quality natural spaces (e.g. provincial parks and protected areas) (Hayes et al., 2022; Reining et al., 2021).

Finally, the threat of climate change itself can impact mental health and well-being among Ontarians as fear and worry surrounding future climate conditions and impacts can result in increased anxiety and depression rates (Galway et al., 2019; Hayes et al., 2022).

Declining Air Quality

Within the People and Communities Area of Focus, declining air quality is identified as a key health risk associated with increasing extreme heat, wildfire, and drought conditions. More frequent extreme heat events can increase smog and ground-level ozone, with urban areas being particularly vulnerable. In addition, wildfire smoke contains fine particulate matter that can cause the exacerbation of asthma and respiratory conditions. Drought conditions can also contribute to increased dust across the natural environment, affecting cardiovascular and respiratory health function (Egyed et al., 2022).

In addition to outdoor air quality, climate change can also impact indoor air quality, leading to adverse health impacts (highlighted within the Infrastructure Area of Focus). Smoke from wildland fire is estimated health impacts of $5B to $21B annually in Canada ($190 million in the GTA alone). With the expected increase in wildland fire, this will be a significant impact on health (Matz et al., 2020). Changing climate conditions have been found to increase airborne allergens and lengthen pollen season, infiltrating into buildings. Additionally, impacts of flooding can result in mold growth, also affecting indoor air quality and causing implications to respiratory and overall health (Egyed et al., 2022).

Public Safety and Emergency Response

Climate-related events and disasters can amplify risks to public health and safety, especially when healthcare facilities and emergency response services are also affected. For example, extreme weather events (e.g. flooding, storms, wildfire etc.) can increase the likelihood of motor vehicle accidents and injuries, increasing the demand of emergency services. As noted in the Infrastructure Area of Focus, climate risks can lead to power outages and damage to critical infrastructure (e.g. washouts of emergency transportation routes, prolonged power outage in hospitals etc.), resulting in a disruption of critical services (e.g. delays in emergency response, evacuation of hospital patients etc.) (Clark, 2009).

It is during these extreme events and disasters that emergency services and health care disruptions can have major effects on the health and safety of Ontarians. In the circumstance that health facilities and services remain operational during a climate-related disaster, they can be pushed beyond capacity thresholds because of related injuries, illnesses, and patient transfers from the event/disaster. Indirect impacts could lead to cascading risks for several health outcomes simultaneously.

Extreme Temperature Exposure

Extreme heat events are projected to continue to increase with climate change, leading to increased risks related to heat-related illness and mortality, affecting the health and safety of Ontarians and communities (Zhang et al., 2019; Berry et al., 2022).

As highlighted within People and Communities Area of Focus, extreme heat directly impacts the health of Ontarians, with several factors increasing vulnerability of individuals and communities to heat stress. It has been observed that extreme heat events can increase mortality rates, cause heat-related illnesses, increase hospitalization rates, and exacerbate mental health illnesses and disorders (Gosselin et al., 2022). Certain populations may be a greater risk due to existing health conditions and social inequities associated with health care access, pre-existing health status, poverty, and housing considerations (e.g. access to air conditioning units) (Schnitter et al., 2022).

Health impacts associated with extreme heat are exacerbated by the urban heat island effect, where higher temperatures are observed in areas with greater coverage of dark surfaces (e.g. concrete roadways and buildings) and less natural area and tree cover (demonstrated in Figure 66 through direct impact from the Infrastructure Area of Focus). In absence of proactive adaptation measures, dense urban regions of the province are at greater risk from extreme heat, with health outcomes (e.g. illnesses and increased mortalities) being intensified, compared to surrounding rural areas (Buse et al., 2022; Levison et al., 2017).

While extreme cold-related health issues and mortalities will likely decline under a warming climate, it is expected that health impacts associated with extreme heat will outweigh this decline in Ontario (Berry et al., 2022).

When responding to the cumulative health and safety impacts associated with extreme heat, it is important to consider how cross-sectoral coordination is required to enable effective adaptation (e.g. incorporating green space into regional planning, designating and providing equitable access to public cooling centres etc.).

Equity

The primary determinants of health and health equity considerations play a crucial role when assessing how climate change will impact the health, safety and well-being of Ontarians. Determinants of health include conditions and characteristics that influence an individual's health and well-being. Examples of determinants of health include, social and community contexts, education, working and living conditions, access to healthcare services, employment, and economic stability and ither identify factors (age, race, gender etc.) (Schnitter et al., 2022).

Health inequity considerations tend to overlap with the determinants of poor health, including low socioeconomic status, poor living conditions (e.g. housing), and limited access to healthcare services. These determinants can be drivers of vulnerability to climate-related health, safety, and well-being outcomes, influencing individual and community exposure and sensitivity to climate risks, as well as associated capacity to adapt or cope. These factors and conditions can also present barriers for adaptation, amplifying vulnerability to climate-related impacts on human health, safety and well-being.

As the understanding of health vulnerability under a changing climate evolves, the intersections of inequities across Ontario are crucial to integrate into adaptation and response planning.

Summary

To summarize, climate risks as viewed through the lens of human health and safety are exemplified through this cross-sectoral analysis. Climate risks will impact many of the primary determinants of health, highlighting how certain populations and regions across Ontario stand to be disproportionately affected by climate change.

It is clear that health-related adaptation in Ontario requires several players both inside and outside of the health sector (e.g. water resource management, infrastructure, emergency management), as well as several levels of government (e.g. Indigenous, regional municipal etc.). Regional PHU assessments of climate change vulnerability and health equity have provided a foundation for collaborative and widespread adaptation action in Ontario (Grey Bruce Health Unit, 2017; Levison et al., 2017; Buse et al., 2022). Moving forward actions to address existing inequities and population vulnerability should be prioritized for interventions to minimize the health, safety and well-being outcomes that climate change poses to Ontarians and their communities.

10.5 Community Function

Overview

From a systems perspective, a community is comprised of different parts that represent specialized functions, activities, or interests, each operating within specific boundaries to meet community needs. For the community to function well, each part has to effectively carry out its role, and disruptions caused by climate change can significantly undermine this.

Climate change can impact community function both directly, through different climate and weather events (e.g. extreme precipitation or wildfire), and indirectly through a range of environmental, built, and economic pathways. This section outlines how climate risks can cascade across each Area of Focus, resulting in multiple impacts and outcomes for Ontarians. Key elements of community function that can be impacted by the changing climate are:

- Social support and inclusion – refer to help accessible to an individual through social ties to other individuals, groups, and the larger community and the process of improving the terms on which individuals and groups take part in society.
- Economic stability – refers to the absence of excessive fluctuations in economy meaning that people have the resources essential to a healthy life.
- Access and infrastructure redundancy – refers to available backup alternatives when other components are disrupted (e.g. due to flooding, landslides etc.).
- Emergency response management – refers to the management of resources and responsibilities and organization of measures and actions for dealing with the consequences of emergencies (e.g. flooding, power failure etc.) to ensure safety and security of communities and minimize damage to infrastructure and disruptions to essential services.
- Ecological stewardship – refers to responsible use and protection of the natural environment through conservation and sustainable practices.
- Land use planning and development – refers to the process of regulating the use of land to promote desirable social and environmental outcomes and efficient use of resources.

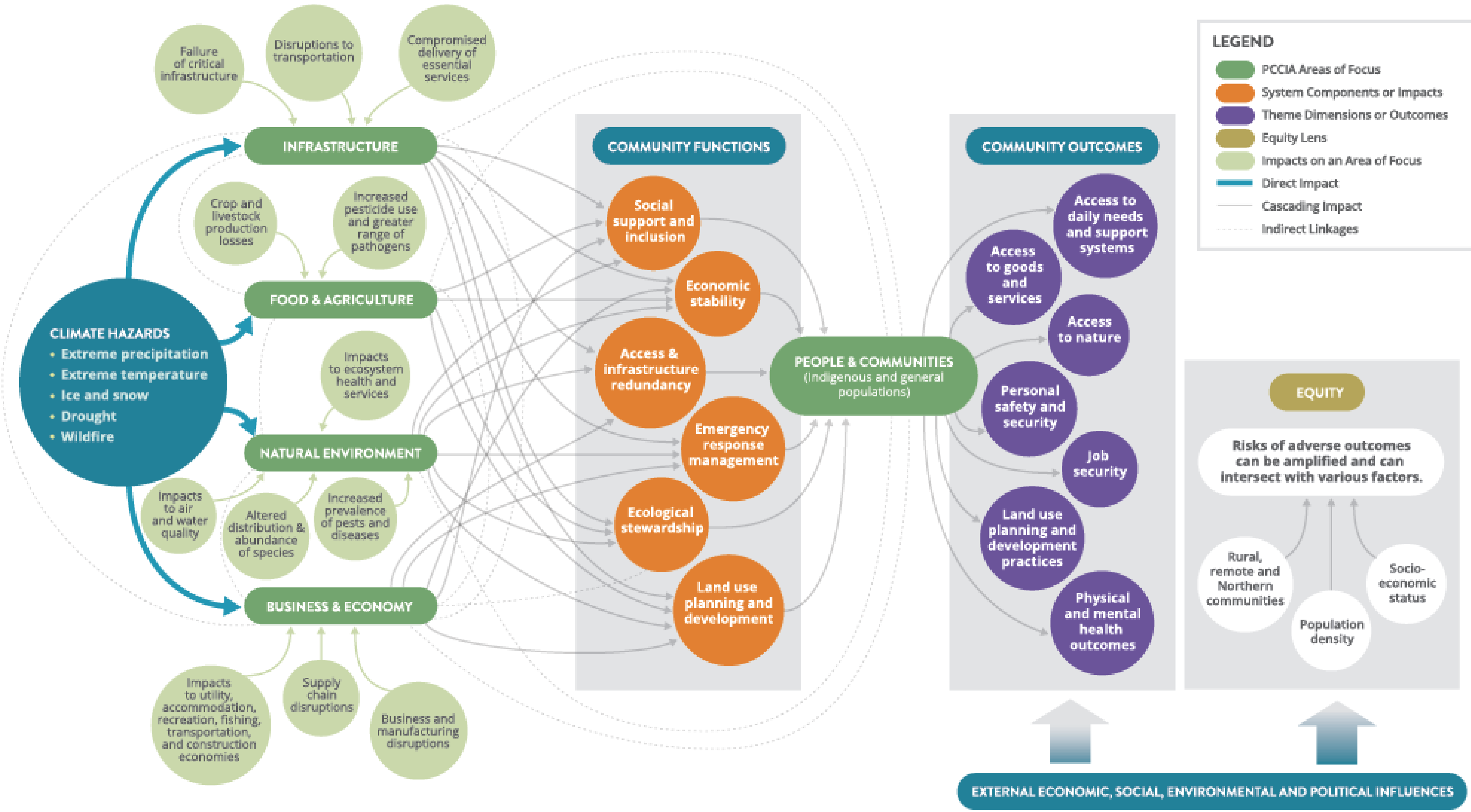
Critical community-specific outcomes include changes in:

- Access to daily needs and support systems – refers to the ability of individuals to maintain social ties to others and the larger community and ensure that their daily needs are met.
- Access to goods and services – refers to the ability of individuals to acquire tangible items and tasks performed for the benefit of the recipients.
- Access to nature – refers to the ability to regularly use green spaces and amenities for recreation and other purposes.

- Personal safety and security – refer to the general recognition and avoidance of possible harmful situations or persons in an individual's surroundings.
- Job security – refers to the probability of an individual to keep their job and is an important component in measuring the quality of life and well-being.
- Land use planning and development practices – refer to sets of policies and procedures regulating the use of land, and specifically changes in these policies and procedures aimed at minimizing development risks to a municipality from natural hazards due to the changing climate.
- Physical and mental health outcomes – refer to measurable changes in the health status of an individual.

Figure 10.7 illustrates how climate risks cascade through each Area of Focus (represented in green), causing impacts to various community functions (represented in orange), associated outcomes (represented in purple), and how equity considerations influence these outcomes.

Figure 10.7: Representation of how climate change causes impacts to community functions and associated community outcomes



Climate Risks to Community Function across Ontario

Social Support and Inclusion

Social support and inclusion are important elements of the community function that include assistance that is accessible to an individual within the larger community through ties to other individuals and groups. It also includes the process of improving the terms on which individuals and groups take part in society and societal functions.

Climate change can impact social support and inclusion in communities across Ontario through direct impacts on infrastructure, natural environment and economy. Extreme ice or snowstorm events can cause property damage and communications system failures, resulting in increased lack of access to support and daily needs, particularly exacerbated for people with disabilities, elderly populations, and people in more remote communities (Morss et al., 2011). Extreme weather events increase potential for localized and widespread power outages leading to service disruptions, greater demand for space in shelters and emergency community centers, and limited ability of residents to reach essential services for social assistance, or for service workers to reach them (Smoyer-Tomic et al., 2003). High temperatures result in altered distribution and abundance of species of importance for Indigenous Communities, impacting food security, daily activities and use of social spaces (Neufeld and Richmond, 2017). Increased number or pathogens, pests and diseases, and changes to air and water quality linked to the changing climate are likely to contribute to poor physical health outcomes, while climate anxiety and stress are strongly linked to mental health (Cianconi et al., 2020).

Understanding the complexity of community outcomes and diverse stakeholders is key to improved decision-making and ensuring that social services can continue to operate, maintaining community function and resilience.

Economic Stability

Economic stability is a key component of community function that refers to the absence of excessive fluctuations in economy meaning that people have the resources essential to a healthy life.

Changes in extreme heat, Growing Degree Days, mean and extreme precipitation, and wildfire may lead to financial impacts in multiple industries and sectors including telecommunication, electrical power generation, transmission and distribution, commercial transportation services, retail trade, manufacturing, agriculture as well as entertainment and recreation activities.

Rainfall decreases and drought could result in shortage of water for construction and manufacturing use, leading to production delays (CMIC, 2017). Extreme rainfall could delay outdoor construction and cause loss to unprotected, on-site stored materials (CMIC, 2017). Additionally, extreme precipitation and flooding may result in water infiltration to accommodation, retail, manufacturing, financial and other buildings, leading to disruption of service. Extreme temperature events, particularly when combined with high humidity, may affect the storage and shelf life of material inputs as well as semi-manufactured and finished products (Moudrak and Feltmate, 2019). Changes to temperature and precipitation regimes, including extreme weather events, may lead to damage of farm infrastructure, agricultural production losses and supply chain disruptions, while increases in extreme precipitation may lead to poor driving conditions, resulting in accidents, disruptions to transportation and compromised delivery of goods and essential services (Woudsma and Towns, 2017).

Industries could face impacts including asset and infrastructure loss and damage, decrease in asset serviceable lifespan, supply chain and logistics delays, changes in consumer demand for seasonal goods and services, health and safety impacts to staff, and changes in availability of key industrial inputs and costs (e.g. materials, fuel, insurance). The extent of impact will depend on the duration, persistence, extent, and intensity of the climate risk event and may cascade to community outcomes such as job security and access to goods and services.

Economic prosperity and stability will be influenced by how businesses adapt to the changing climate. They may gain an advantage by investing in the resilience of their supply base, managing supply chain risks and acting to minimize negative impacts as much as possible to reduce the chances of paying higher costs later on to fix past oversights. Taking critical actions for planning, infrastructure and business management is needed to ensure availability of resources to support various sized communities in Ontario.

Access and Infrastructure Redundancy

Within community function components, access and infrastructure redundancy refer to available backup alternatives when other infrastructure components are disrupted (e.g. due to flooding, landslides etc.). Key community and public infrastructure include buildings, transportation, telecommunication, stormwater and waste management systems, impacts to which would affect multiple public services provided to the general public within communities. Importantly, green infrastructure within settlement areas is viewed as a key component and backup measure for critical community infrastructure.

Continuous access to services in communities across Ontario can be compromised by severe weather events and conditions such as extreme temperature and precipitation, ice and snowstorms, wildfires, and heat waves. Extreme precipitation and flooding could cause damage to roads, property and infrastructure as well as power outages and shutdowns of facilities providing essential goods and services such as grocery stores and medical clinics. Additionally, damaged or flooded roads could block access for emergency vehicles and transport to healthcare and contribute to the disruption of supply chains for medicines, food and more (Tsang and Scott, 2020). Vulnerable populations including people with compromised health status, inadequate or no housing as well as those living along coasts and waterways or in rural/remote communities are likely to be the most affected.

Incorporating redundancy and flexibility into community systems is important in order to ensure nimble responses to challenges and impacts caused by severe weather and climate events. For example, ensuring availability of backup generators in case of more frequent and prolonged power outages would ensure backup power exists for medical facilities, community centers and other locations used for emergency relief (Paterson et al., 2012). Such targeted redundancy would enable systems that are safe to fail in the event of a weather-related emergency.

Emergency Response Management

Emergency response management refers to the management of resources and responsibilities and organization of measures and actions for dealing with the consequences of emergencies (e.g. flooding, power failure etc.) to ensure safety and security of communities and minimize damage to infrastructure and disruptions to essential services.

Large-scale climate events such as flooding, wildfire, extreme precipitation, and wind events lead to power outages, damages to critical infrastructure (e.g. emergency transportation routes, stormwater and sewer systems etc.) and disruption of critical services (e.g. healthcare etc.). Importantly, they affect organized response actions including evacuation measures, search and rescue missions, provision of basic needs and emergency services, and recovery or substitution of critical infrastructure (Government of Ontario, 2022g). Emergencies triggered by weather-related impacts on infrastructure and natural environment amplify risks to personal safety and security, access to daily needs and support systems as well as physical and mental health outcomes.

Ontario municipalities are required to develop and implement emergency management programs tailored to local needs and priority risks and are supported by the province in delivering emergency services when their response capability is insufficient to deal with larger-scale disasters (Government of Ontario, 2022g). To accommodate increased demand for emergency services and support community resilience, it is important to consider long-term planning tools and enhanced guidance for adaptive considerations in regulatory framework, such as asset management plans as well as maintaining sufficient reserves and appropriate insurance coverage to manage the costs of disasters.

Ecological Stewardship

Ecological stewardship refers to responsible use and protection of the natural environment through conservation and sustainable practices. It includes diverse actions such as creating protected areas, replanting trees, reducing pollution, restoring degraded areas, or purchasing more sustainable products, and supports nature-based solutions, green infrastructure, and renewable energy initiatives (Bennett et al., 2018).

Climate impacts on the natural environment and agriculture (e.g. degradation of air and water quality, increased range of pathogens, pests and diseases, altered distribution and abundance of species and changes in ecosystem health and services etc.) affect overall environmental sustainability and, at the personal and community level, result in poor physical and mental health outcomes, limited access to nature and decreased quality of life. Additionally, failures of critical infrastructure (e.g. waste management plants) could have significant cascading impacts on surrounding ecosystems and, ultimately, communities that rely on them.

Supporting efforts to develop ecological stewardship activities like community gardening, removal of invasive species and conservation of soil, water and green spaces can be an effective approach to improving community resiliency and integrating environmental, community and individual outcomes (Krasny and Tidball, 2012). In Ontario, ecological (or sometimes called environmental) stewardship programming is a key element identified in the commitments of Canada-Ontario Lake Erie Action Plan (Environment and Climate Change Canada and Government of Ontario, 2018), Ontario's Agricultural Soil Heath and Conservation Strategy (Ontario Ministry of Agriculture, Food and Rural Affairs, 2016c), Made-in-Ontario Environment Plan (Government of Ontario, 2020a), and other initiatives. Actions supported by these initiatives include adoption of management practices to improve soil health and water quality, wetland restoration and management, implementation of low-impact development practices, and more. These actions help inform evidence and data collection, increase awareness and understanding of key risks and opportunities to the environment, and enhance planning and decision-making tools to manage risks related to environmental sustainability at the ecosystem and community levels.

Land Use Planning and Development

Land use planning and development refers to the process of regulating the use of land to promote desirable social and environmental outcomes and efficient use of resources. Planning, capacity building and implementation are important elements of addressing adaptation and resilience issues in a holistic manner (Bajracharya et al., 2011).

Changing climate and extreme weather events affect the natural environment and various sectors of Ontario's economy, causing impacts on critical infrastructure, agricultural lands and production, ecosystem health and services, recreation, fishing and other economies as well as cultural heritage resources and assets. Coupled with socio-economic changes (e.g. population growth) these impacts result in the need to adjust land use planning and development approaches to achieve cross-sectoral resilience improvements. Importantly, the impacts of climate change and the consequences of land use planning and management decisions will be borne unequally by different communities and individuals, with those who are already vulnerable impacted most acutely. Issues of equity and environmental justice require special attention and considerations when seeking solutions to impacts of climate change (Canadian Institute of Planners, 2010).

Ontario communities and municipal governments have traditionally used land use planning tools such as official plans, zoning, development permits, public awareness campaigns, management of public lands and buildings and others – to minimize risks to communities from floods, wildfires, landslides and other natural hazards and facilitate local adaptation to climate change (Richardson and Otero, 2012). Specifically, planning and development tools can reduce climate risks by limiting development in hazard-prone zones (e.g. on floodplains), ensuring that built infrastructure can withstand changing levels of environmental stress and retain, as applicable, key attributes, integrity, and heritage values, helping preserve natural environments and prime agricultural lands, and educating communities about climate risks while fostering dialogue about adaptation (Richardson and Otero, 2012).

The Provincial Policy Statement (Government of Ontario, 2020f), issued under section three of the Planning Act, provides policy direction on matters of provincial interest related to land use planning and development, including the mitigation of greenhouse gas emissions and adaptation to a changing climate. The statement recognizes that Ontario's long-term prosperity, environmental health and social well-being depend on protecting water, agricultural, natural and cultural heritage and resources for long-term benefits of all Ontarians. The statement includes a range of policies that require municipalities to prepare for the impacts of a changing climate, support climate resiliency and mitigate risks to public health or safety, or property damage from natural hazards, including the risks that may be associated with the impacts of a changing climate. It requires municipalities to incorporate climate change considerations in their local planning policies and in land use planning decision-making.

Equity

Climate-related impacts vary across Ontario and often contribute to existing vulnerability and inequities within and between communities, with rural, remote, Northern and Indigenous Communities being at greatest risk. An equity lens has been applied to this analysis (see Figure 10.7) to demonstrate how climate risks to various elements of community function can be amplified for populations with pre-existing vulnerability.

Climate change is expected to disproportionately affect certain groups of people, depending on where they live and their ability to cope with different climate-related issues. Exposure sensitivity to extreme weather conditions such as heat, cold and heavy rain is high among people living in community housing, low-income, inner city, and high homelessness areas where impacts to critical infrastructure, air and water quality have a pronounced effect on communities (Smoyer-Tomic et al., 2003). Inequitable provision and access to community and essential services is expected to increase in extreme weather conditions, with people relying on healthcare and home care supports, unable to access these due to increased demand and service disruptions. Disruptions to transportation and supply chains are expected to have dramatic effects on rural, remote, northern, and Indigenous Communities, who rely on materials and goods from weather-impacted transportation routes to support construction, manufacturing, retail, recreation and accommodation economies (Council of Canadian Academies, 2019). Significant impacts of stormwater and wastewater treatment infrastructure failure would affect communities, particularly those with combined sewage and rainwater sewer systems (Trudeau, 2018).

Importantly, communities and individuals that are vulnerable in the current climate will only be more vulnerable in the future. It is therefore necessary to make sure that intersections of inequities across Ontario are integrated into adaptation and response planning. Increased networks between different levels of government and community groups coupled with knowledge sharing and better understanding of lived experiences and resource needs of diverse stakeholders will improve decision making and ensure better outcomes for people and communities across the province (World Bank, 2022).

Summary

In summary, climate risks will impact the resiliency of Ontario's communities through impacts on various components of the Natural Environment, Business and Economy, Food and Agriculture and Infrastructure. A better understanding of risks and impacts and use of approaches that take into account future climate change considerations will provide opportunities for making policy decisions to improve infrastructure redundancy, emergency response management, foster social support and inclusion, economic stability and ecological stewardship. Collaboration and knowledge sharing are required to achieve resilience of community function while adequately considering equity issues in adaptation planning.

11.0 A Path Forward and Considerations for Future Assessments

The depth and breadth of information developed from Ontario's PCCIA is significant. Qualitative and quantitative risk characterizations offer insights into the extent to which various sectors and systems across the province may be at risk, as well as how they are at risk and what variables are driving impacts.

Information produced through the PCCIA is actionable directly through adaptation and resilience best practices as well as through supplemental assessment can be completed at different scales. The PCCIA Technical Report, Adaptation Best Practices Report, and other products offer critical information to advance adaptation planning and action for a variety of different decision-makers. Practitioners and others engaged through the PCCIA process are stewards of the work and recognize how adaptation efforts can be mainstreamed as people, communities and sectors find ways to mitigate risks and build climate resilience.

All participants identified aspects of the study that provide valuable topics and lessons for future iterations of an Ontario-wide climate change impact assessment. In some cases, regional and Area of Focus specific risks were congruent with those noted in published literature on climate change adaptation. The common and uniting theme that stretches across all the PCCIA work, was one of urgency that highlights the resilience gap in Ontario and the need for increased levels of adaptation as climate risks continue to be felt across the province. Conducting the assessment has led to the following seven themes for consideration in subsequent provincial scale climate change impact assessments.

Engage Further

Engagement throughout the PCCIA focused on updates on progress, and education and validation of information. Even with the addition of more interactions with external participants due to the pandemic, a more sustained and deeper engagement with external participants would have offered more details on the process and opportunities for local and regional knowledge to supplement literature and professional judgement. There is a need to engage Indigenous organizations and communities more meaningfully to consider and incorporate Indigenous ways of knowing into the assessment. The way in which engagement with Indigenous organizations was conducted (and necessarily), left room for a dis-connect with adaptation planning and implementation that is happening at the community level. In the same way, engaging with external participants through umbrella or member organizations and associations meant that some of the adaptation work being done at finer scale may have been missed or underrepresented. This is an inherent challenge in climate change assessment at this scale. Nonetheless, engagement for this PCCIA has undoubtedly improved awareness of the issue and risks, and stimulated efforts to build climate resilience in many participating organizations and their members.

The Balance of Depth and Breadth

Across all Areas of Focus and Geographic Regions, opportunities exist to undertake additional research, evaluation and produce more locally driven actionable information. Regional averages and regional representative conditions were characterized in the PCCIA, but each region of Ontario is unique with local context including current resilience action, capacity and local supports and constraints. For example, 1) farming within PCCIA regions occurs at different of scales, 2) different commodities are sensitive to different climate variables, 3) use of different technologies varies from region to region, 4) some regions, sub-themes or commodities are subject to different policy constraints and other external factors like water availability. Ecosystems within urban and semi-urban watersheds differ significantly than those in rural or more naturalized areas, and the impacts and strategies to adapt differ accordingly. The complex systems within which society operates creates a web of interdependencies within which climate change impacts cascade. For example, business function and continuity rely on well maintained and resilient infrastructure, and the health and safety of people depend on a resilient food system. The PCCIA sought to find a balance of assessment depth and breadth and while assessment depth into Level 2 categories achieved significant spatial resolution, the necessary roll up of information meant that some of the spatial nuances may be hidden and perceived to have been missed. Subsequent province-wide assessments will endure this challenge, but results have been positioned to assist with finer scale, deeper assessments.

Climate Change Data

Climate and climate change data are crucial to a climate change impact and risk assessment. The data establishes the baseline to help understand how climate has changed, but best science and modeling help paint the picture of future climate change upon which we build risk scenarios and understand consequences. The desire to have ‘perfect’ data that is at a fine spatial scale with limited uncertainty can distract from the overall goal of assessments and constrain adaptation. The dearth of data that is available to support assessments leaves assessors wondering which data (and methods) to adopt and which is most suitable for the context. The suite of climate variables chosen for the PCCIA are not inclusive of all possible hazards, but they are extensive, and indices for each give yield to known impacts. External participants pointed to certain hazards that were relevant to their area of expertise and the suite was expanded. Climate information could be expanded to include additional hazards, such as future sub-daily extreme precipitation, freeze-thaw cycles, among others. These hazards would expand the range of climate interactions and impacts and likely be most helpful for finer scaled assessments in regions or sectors.

The climate change modelling field is one of the fastest developing science interests ever and there will always be new sources of information available. For example, at the time of this PCCIA study, a recently released IPCC AR6 suite of models was available but in early release. Going forward climate models are improving both their spatial and temporal scales along with deeper understanding of the physics of the atmosphere which earlier were more simply considered. This includes the development of improved convective schemes, permafrost components, cloud development, and full carbon cycles. With improved resolutions, scaling of results will be more straightforward, but it still must be considered that even with improvements, uncertainty will always be present. Indeed, even current climate conditions contain uncertainties related to siting of observation, instrument error and range, and the sparsity of observations in the north. Additionally, in future assessments, observed impacts and historical climate could include more detailed remote sensing data as more data is collected and gaps are filled.

Advance Implementation

Through the engagement process, external, and some internal PCCIA participants strongly indicated the need to move from research and assessment/planning to action. Beginning with the "end in mind" is one way to approach implementation stemming from the PCCIA. Highest risks, climate change opportunities, and priorities are all identified in the PCCIA Technical Report. There are numerous ways to interpret results in order to mainstream climate resilience into policies and programs and to motivate or catalyze action. There are many domestic and international examples of frameworks that can help the transition from climate change assessment and planning to implementation, including some developed in Ontario and applied by regional and municipal governments. Establishing a consistent Ontario approach, including guidance, methods, best practice for adapting to climate change across Ministries and for external stakeholders and organizations would accelerate adaptation implementation and foster a network for peer-to-peer learning.

Coordination and Strategic Investment

Evaluation of adaptation measures and planning for implementation includes assignments and necessary human resources and financing details. Areas of high risks and opportunities as identified in this Technical Report and in other PCCIA products, should help prioritize adaptation investment. Ideally, adaptation actions that are considered for implementation are reviewed using multiple criteria and in a collaborative manner with those who have implementing mandates. Investment in adaptation is not the sole responsibility of the provincial government, but rather a series of partnerships to pool resources to support climate resilience. Investing in adaptation and resilience pays dividends over the long term which has been proven in Canada and around the world. It is recommended that investments take a precautionary (risk-informed) and equity-based approach such that people and systems that are more disproportionally impacted by climate impacts are prioritized alongside managing and reducing higher climate risks. Convening provincial ministries to discuss PCCIA outcomes and priorities and a strategic approach to resilience investment would foster a shared climate resilience vision and catalyze meaningful adaptation outcomes. Strategic investment in resilience is particularly important for plans for new infrastructure in Ontario.

Bolster Monitoring

Monitoring stations and data networks collect crucial information necessary to understand trends for numerous climate, environmental and sector-specific areas. Continued coordination of monitoring roles and sharing of data expands our knowledge of system response to climate change and other socio-economic factors. In addition to monitoring of climate variables and impacts, striving for a system to monitor adaptation is important. Establishing and tracking progress on climate adaptation is complex but there is a growing body of literature on indicators that measure progress on adaptation implementation as well as outcomes from adaptation (risk levels). Similarly, a system to monitor and evaluate adaptation is the important context in which adaptation indicators are mobilized. As adaptation expands and accelerates in Ontario, it would be valuable to identify performance indicators that are time-bound, actionable, and transparent and share the results externally across Ontario. These indicators can be aligned with priorities for implementation and with sectors, systems, and communities where adaptation efforts may be targeted.

Learn and Adapt

Climate adaptation is an iterative process, and there are no one-size-fit-all solutions. It requires ongoing learning, collaboration, and iterations of assessment to foster successful adaptation. A commitment from the province to undertake the next iteration of PCCIA would account for new priorities, changes within society and communities and gain insight into new adaptation technology. A formal provincial adaptation plan would coordinate action among various levels of implementation, prioritize investment in high-risk areas and enable an understanding of changing climate risks. Accounting for inequity and utilizing traditional knowledge would further strengthen the assessment of climate impacts to inform equitable adaptation that not only mitigates risk, but also improves economic productivity, social cohesion and health and well-being across Ontario communities. Regional considerations are imperative as part of learning across Ontario, and opportunities also exist to distinguish between adaptation discrepancies and differences that exist between Ontario’s north and the more urban and rural regions further south. And perhaps most important, is the consideration of climate change adaptation in the context of critical measures to reduce carbon emissions.

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