CHAPTER 3

Ontario

REGIONAL PERSPECTIVES REPORT

Government of Canada Gouvernement du Canada

Canada

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Key Messages

Ontario's infrastructure is vulnerable to climate change (*see* section 3.2)

As a result of interdependencies between multiple infrastructure types, climate change and especially extreme climate events can have cascading economic and social impacts. Flooding in the highly populated southern subregion, and impacts on winter roads in the northern subregion of the province demonstrate the range of risks. Targeted approaches to better understand the threats, and reduce infrastructure vulnerability are being used across the province.

Nature-based approaches help address climate change impacts on biodiversity and ecosystem services (*see* section 3.3)

Climate warming has driven and will continue to drive changes to species and create new opportunities for invasive species. Impacts on biodiversity are magnified through the cumulative effects of climate change, habitat loss, urbanization, pollution and other threats. Actions to mainstream nature-based solutions, including the establishment of protected areas, such as Indigenous Protected and Conserved Areas, can help maintain ecosystem services and reduce climate change risks, as well as mitigate climate change.

Adaptive management is key for addressing impacts in the Great Lakes Basin (*see* section 3.4)

The combined effects of climate change, land-use changes and other stressors are negatively impacting the Great Lakes Basin. Despite mechanisms to address complex governance challenges, adaptation efforts across the Basin remain relatively fragmented. Many communities have embraced adaptive management practices to address impacts in light of uncertainties in future changes.

Adaptation improves forest health, carbon storage and biodiversity (*see* section 3.5)

Climate change impacts the composition, disturbance regimes, and timing of life cycle events in Ontario's forests and forested landscapes. Changes in drought, pests, and fire and wind regimes are of particular concern given the resulting cumulative impacts.

Climate change brings threats and opportunities to Ontario agriculture and food systems (*see* section 3.6)

Longer growing seasons and warmer average temperatures will benefit the agriculture sector in some parts of Ontario. However, projected reductions in summer rainfall along with more severe heatwaves, higher frequency of precipitation extremes, and increased risks from pests and diseases threaten farm operations, as well as supporting activities, such as food processing and distribution. Increased capacity and adaptation across the sector would permit the seizing of opportunities and management of risks posed by climate change.

Existing human health inequities will be worsened by climate change (*see* section 3.7)

Many non-climate factors, including income, housing quality and employment, play key roles in determining the vulnerability of communities and individuals to the health risks of climate change. Marginalized and low socio-economic populations will experience disproportionate health impacts and will have increasing difficulty in coping and adapting. Regional and local assessments of climate change vulnerability that include consideration of health equity provide a foundation for stronger and more widespread adaptation action.

Progress on adaptation remains limited in Ontario (*see* section 3.8)

Levels of climate change adaptation planning and implementation vary considerably across Ontario, with the primary focus still placed on the assessment of risk and vulnerability. Although there are examples of implementation, there is little evidence of adaptation being mainstreamed into decision making broadly. Systems for monitoring and evaluating adaptation action and effectiveness remain inadequate in most jurisdictions.

3.1 Introduction

Canada's climate is warming at a rate about twice that of the global average (Bush and Lemmen, 2019). Ontario's mean annual temperature 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 (*see* Figure 3.1).

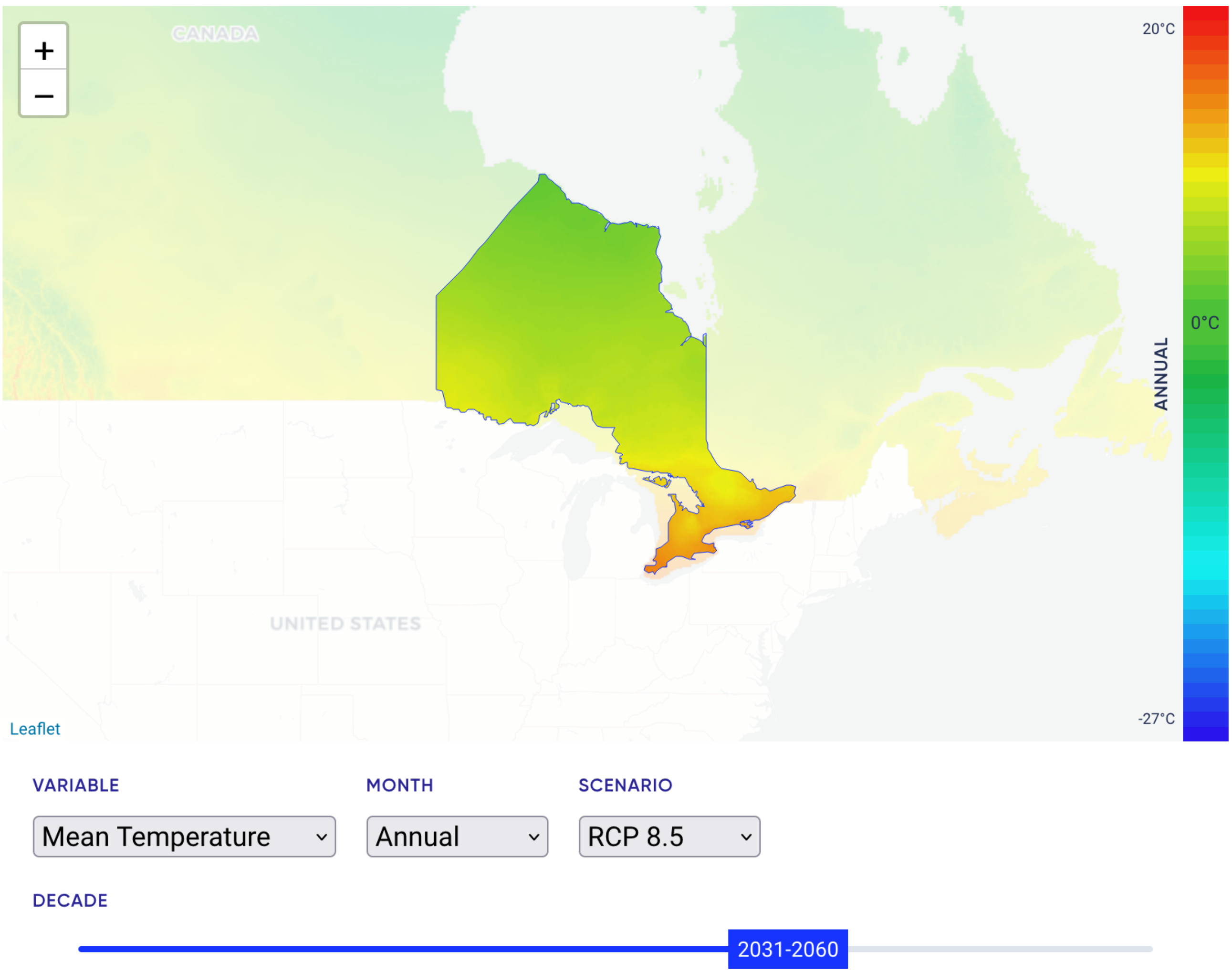


Figure 3.1: Interactive regional map of Ontario that draws from climatedata.ca and visualizes various climate variables from 1980 to 2100 using a high-emissions RCP 8.5 scenario. Source: climatedata.ca.

Gradual changes in mean climate conditions combined with changes in the frequency and magnitude of extreme weather events drive impacts that are having, and will continue to have, predominantly negative effects (Cohen et al., 2019; Zhang et al., 2019). The impacts associated with a changing climate have become more apparent in daily life, increasing risks to social, economic and ecological systems (Government of Ontario, 2015a; 2011a). While Ontario's capacity to undertake adaptation actions to address these risks is relatively high in terms of institutional, technical, human and financial resources, this capacity has not yet been widely mobilized. This is despite clear recognition of the imperative of proactively managing the risks associated with climate change through effective adaptation (Environmental Commissioner of Ontario, 2018a).

3.1.1 Geography

Ontario's diverse landscapes, topography and natural resources help shape social, economic and cultural characteristics across the province (*see* Figure 3.2). The climate ranges from sub-Arctic in much of the north to hot-summer humid continental in the southern tip of the province near Windsor. Climate change impacts and adaptation capacity will differ across landscapes in Ontario and within the context of regional social, economic, cultural and environmental diversity.

Figure 3.2: Map of Ontario's subregions. Source: Chiotti and Lavender, 2008.

This report characterizes Ontario as having three subregions. The South subregion extends from Point Pelee Island in the south to the Quebec border in east. It contains half of Canada's most densely populated metropolitan centres, including the Greater Golden Horseshoe Area (which includes the Greater Toronto and Hamilton Area (GTHA) and the Kitchener-Waterloo Region), and the cities of Ottawa and London. Most of Ontario's projected population growth will continue to be in urban areas, particularly within the Greater Toronto Area and primarily through migration (Ontario Ministry of Finance, 2021a). The region includes the Canadian portions of Lake Huron, Lake Erie and Lake Ontario, which are critical for regional shipping, industry, tourism and agriculture (Woudsma and Towns, 2017).

The Central subregion includes the cities of Sudbury, Thunder Bay, Timmins, Sault Ste. Marie and North Bay, and has a much lower population density compared to southern areas of the province. The communities within this subregion remain largely dependent on natural resource industries, as well as on smaller, emerging sectors such as financial and business services, research and innovation, construction and tourism (Conteh, 2017). The region contains over two-thirds of the province's highway lines, which along with the rail network, provide important economic and social linkages between communities (Woudsma and Towns, 2017).

The North subregion, whose boundaries are consistent with those of the Far North as defined in the *Far North Act* (Government of Ontario, 2010), is sparsely populated. Despite covering 42% of the area of Ontario, this subregion contains only 0.17% of the province's population (Ontario Ministry of Indigenous Relations and Reconciliation, 2017). It is primarily populated by small First Nation communities that rely on subsistence practices and winter road access in order to acquire necessary resources (Ontario Ministry of Indigenous Relations and Reconciliation, 2017). Extending to the coasts of Hudson Bay and James Bay, the subregion includes areas with continuous and discontinuous permafrost and peatlands that sequester large amounts of carbon dioxide (McLaughlin and Webster, 2014). If disturbed, peatlands can release stored carbon into the atmosphere, reversing the carbon sequestration process and enhancing global warming. There are relatively few social, economic or ecosystem similarities between the North subregion and the Central and South subregions of the province.

3.1.2 Social and demographic profile

Ontario has a population of 14.7 million people and its population was the fastest growing amongst Canadian provinces as of July 2020, growing by 1.3% over the preceding year (Ontario Ministry of Finance, 2021b). The rate of population growth varies across the province, with populations in urban centres of the South subregion growing faster than those in the Central and North subregions, which are remaining stable or declining in some areas. These trends are expected to continue to mid-century under a medium-growth scenario, with the provincial population projected to grow by 35.8% (5.3 million people) over the next 25 years, largely resulting from increased net migration (Ontario Ministry of Finance, 2021c). Climate change will amplify existing social and economic stressors in high population urban centres (Wuebbles et al., 2019).

More than 374,000 people in Ontario are registered Indigenous Peoples, including First Nations, Métis and Inuit; of this number, about 116,000 people speak Indigenous languages (Statistics Canada, 2017). The Indigenous population is distributed across the province, with about one-third living in large population centres, such as Thunder Bay, Sudbury, Sault Ste. Marie, Ottawa and Toronto (INAC, 2018; Statistics Canada, 2017). Over one-quarter of Ontario First Nations Peoples live in remote communities of the North subregion that are only accessible by air or winter roads, two modes of travel that are highly dependent on weather and climate conditions (Ontario Ministry of Indigenous Relations and Reconciliation, 2017).

3.1.3 Economic profile

The diversity of economic activity across the province's subregions contributes greatly to the strength of Ontario's overall economy (Ontario Chamber of Commerce, 2020). Goods-producing and service sectors are primary contributors to the provincial economy, with the large metropolitan areas of the South subregion experiencing the highest employment growth rate (Government of Ontario, 2021a). Efforts to diversify resource-dependent economies and to build overall resilience include expanding the service and manufacturing sectors and enhancing ecosystem resilience (Government of Ontario, 2011b). For parts of the North subregion, particularly in the chromium-rich "Ring of Fire" area, newly discovered diamond and metallic deposits present unprecedented opportunities for economic development, with associated concerns about impacts on cultural practices and ecosystems (Chong, 2014).

3.1.4 Chapter approach

Building on the findings of previous assessments, this chapter identifies climate change impacts and risks specific to Ontario, evaluates adaptation progress across the province, and reports on knowledge gaps and emerging issues. The chapter assesses the knowledge base pertaining to both impacts and adaptation in Ontario, which has grown substantially since completion of the 2008 national assessment report (Chiotti and Lavender, 2008). Ongoing research continues to strengthen the evidence base and, while literature on risks and impacts still dominates, research focused on adaptation and resilience has increased considerably over the past decade (Brinker et al., 2018; Zeuli et al., 2018; AECOM, 2015; Chu, 2015; Lemieux et al., 2013).

Academic and other literature sources have been supplemented by input received through engagement sessions held with key stakeholders and practitioners across the province. The Key Messages reflect the social, economic and ecological diversity of Ontario, as well as the breadth of climate change impacts.

3.2 Ontario's infrastructure is vulnerable to climate change

As a result of interdependencies between multiple infrastructure types, climate change and especially extreme climate events can have cascading economic and social impacts. Flooding in the highly populated southern subregion, and impacts on winter roads in the northern subregion of the province demonstrate the range of risks. Targeted approaches to better understand the threats, and reduce infrastructure vulnerability are being used across the province.

Economies and society depend on well-functioning and resilient infrastructure for the continued delivery of critical services. Recent examples of infrastructure failures in Ontario, especially related to extreme rainfall and flooding, highlight both economic and social impacts. In the northern parts of the province, transportation infrastructure, in particular winter roads, are at risk. Local and regional governments in Ontario are starting to address the associated risks through risk assessments, asset management and design practices, emergency response planning, and strategic planning, including low impact development, that explicitly consider future climate conditions. Addressing the interdependencies that exist between different types of infrastructure, such as water, transportation, energy and telecommunications, is increasingly recognized as important to successful adaptation.

3.2.1 Introduction

Ontario's communities vary in size, population, geography and social fabric (*see* Sections 3.1.1 and 3.1.2). The infrastructure supporting these populations and economies varies in age and performance and will require significant investments in the coming decades (Canadian Infrastructure Report Card, 2019). These investments, encompassing maintenance, repair, reconstruction and new construction, present opportunities for climate change adaptation. Accounting for climate change risks in infrastructure renewal and upgrades yields broad and long-term social, environmental, and economic benefits (Adaptation to Climate Change Team, 2021; Canadian Climate Institute, 2021).

Widespread damage from extreme events in Ontario (*see* Section 3.2.2), including to human health and safety, has highlighted the vulnerabilities of infrastructure to climate change. This section focuses on flooding in southern Ontario and the impacts of climate change on winter roads in the north. It then discusses how adaptation is advancing across the province, through the application of infrastructure risk assessments and incorporation of climate change into infrastructure asset management. It concludes with a discussion on the importance of considering independencies between different types of infrastructure when planning for adaptation.

3.2.2 Flooding

Climate impacts with the highest documented costs and frequency in Ontario include flooding related to extreme rainfall, rainfall on frozen ground, rapid snow melt and ice jams (Moudrak and Feltmate, 2019;

Farghaly et al., 2015; Boyle et al., 2013). Extreme rainfall intensity is increasing in Ontario (Coulibaly et al., 2016; Soulis et al., 2016; Mekis et al., 2015; Shephard et al., 2014; Cheng et al., 2012; Paixao et al., 2011), as it is in adjacent regions in the United States (Easterling et al., 2017; Walsh et al., 2014). Non-climatic stressors, such as urban growth and land-use changes, also serve to increase the risks associated with flood events in Ontario (Henstra et al., 2020; Oleson et al., 2015).

Flood-related damage to infrastructure has been a primary driver of the increases in both insured and uninsured losses across Ontario and in many other parts of Canada (Moudrak and Feltmate, 2019; Feltmate et al., 2017; Moghal and Peddle, 2016; IBC, 2015). Flooding events in cities have interrupted business activity and caused hardship and anxiety among residents (Manning and Clayton, 2018; Decent and Feltmate, 2018; Moudrak and Feltmate, 2017). The rising costs associated with flooding in Canada are estimated to be accompanied by significant productivity losses (Insurance Bureau of Canada and Federation of Canadian Municipalities, 2020; Davies, 2016). While reporting on insured losses paints a picture of high costs from urban flood events (*see* Table 3.1; Robinson and Sandink, 2021), additional uninsured damages increase the magnitude of total losses and are often unknown. However, estimates by the Insurance Bureau of Canada suggest that for every dollar of insured loss, there are three to four dollars of uninsured losses, which are borne by homeowners, business owners and governments (Moudrak et al., 2018).

Table 3.1: Examples of Ontario cities that have experienced extreme weather events in the past decade leading to significant insured losses

CITY	EVENT DATE	INSURED LOSS
Toronto	July 8, 2013	$1.024 billion
Windsor/Tecumseh/Essex	August 28 and 29, 2017	$177 million
Windsor/Tecumseh	September 28, 2016	$165 million
Hamilton, Ottawa	July 2012	$104 million
Greater Toronto Area	August 2014	$84 million

Source: Adapted from Robinson and Sandink, 2021.

Given the vulnerability of Ontario's infrastructure to extreme precipitation and flooding, adaptation approaches frequently involve the use of updated rainfall Intensity-Duration-Frequency (IDF) curves that determine the probability of a given rainfall event occurring (Simonovic et al., 2017; IBI Group, 2016; Soulis et al., 2015; Shephard et al., 2014). Methods to adjust IDF curves to account for climate change vary (Schardong et al., 2020; Soulis et al., 2016) and can yield significantly different results. User-friendly Web interfaces (Ontario

Ministry of Transportation, 2016; Schardong et al., 2020) and other technical guidance (Canadian Standards Association, 2019) are available for engineers and others to access updated IDF data, helping to facilitate the consideration of changing climate conditions in infrastructure-related decisions (Switzman et al., 2017; Sehgal, 2016; Soulis and Sarhadi, 2016; Solaiman and Simonovic, 2011).

To address extreme rainfall and flood risk, municipalities have traditionally employed end-of-pipe solutions to deal with stormwater. However, in recent years there has been an increase in the use of permeable surfaces and natural infrastructure to help control larger amounts of water (quantity) and to filter the water that recharges sub-surface aquifers (quality) (*see* Ecosystem Services chapter of the National Issues Report; Eckart et al., 2017; Environmental Commissioner of Ontario, 2017, 2016). Hamilton, Toronto, Thunder Bay, London, Newmarket and many other Ontario municipalities and conservation authorities have been actively promoting climate change adaptation through low-impact development (LID), master planning and watershed adaptation strategies (Henstra et al., 2020). Successful LID pilots include the use of permeable pavement, bioswales, rain gardens, green roofs, infiltration trenches and other forms of stormwater management that can be particularly valuable in limiting the impacts of smaller event storms (*see* Cities and Towns chapter of the National Issues Report). Natural areas like ponds, wetlands and vegetated areas are increasingly being viewed as tools for flood prevention and have numerous environmental and social benefits (e.g., for biodiversity and water quality), the value of which is highlighted in robust total economic value assessments (Moudrak et al., 2018).

Forty-four Ontario municipalities have combined sewer overflow (CSO) systems that release untreated or partially treated sewage into receiving lakes and rivers, and that are at higher risk of surcharging during flooding due to inadequate design standards at the time of construction, increased impervious surfaces and urban growth (Environmental Commissioner of Ontario, 2018b). As municipalities seek to replace outdated CSO systems and improve stormwater infrastructure, consideration of projected increases in the frequency and magnitude of flooding events will significantly reduce the risk of sewer backup and damage in homes, and the accompanying human health risks (Kovacs et al., 2014).

3.2.3 Transportation in Northern Ontario

Compared to more southerly and more densely populated areas of Ontario, infrastructure in the North subregion of Ontario services smaller, more dispersed and less populated communities, which are mostly Indigenous. Transportation infrastructure, which includes winter roads and air strips, is particularly crucial for the movement of goods and services into isolated communities. Warmer winters and temperature variability make winter road construction and maintenance difficult affecting road stability and safety, and ultimately impacting the supply of fuel, food and other staples (Hori et al., 2018a; 2018b).

Winter roads in northern Ontario provide overland connection to provincial highways and railway systems (*see* Figure 3.3). Winter roads reduce transportation costs of goods, compared to other alternatives, provide more affordable access to services (such as health care), support the self-sufficiency and well-being of people who travel for cultural and community events, and enhance access to remote communities and mineral resources. The roads are partly ice roads, in that portions of them cross rivers and lakes, while other sections traverse land. One metre of good quality ice can support loads of 50,000 kg (NWT, 2015). Over recent years, the operating seasons have been shortening due to early thaw in the spring and warm spells in mid-season, as well as more frequent service disruptions due to variable weather events. These have resulted in softening of the road surface, deteriorating driving conditions requiring slower speeds and smaller loads, increased operations and maintenance costs, and increased risks to health and safety (Barrette, 2018; IBI Group, 2016).

Figure 3.3: Methods and routes for accessing communities in Northern Ontario, including access by air, boat, rail and numerous road types. Winter roads are shown using red broken lines. Source: Ontario Ministry of Northern Development, Mines, Natural Resources and Forestry, 2019

While conditions for more northerly locations may remain suitable for ice road construction in Northern Ontario through the middle of this century, even under high emission scenarios, seasonal warming and variability in weather conditions will affect more southerly locations and may preclude a viable ice road season (Hori et al., 2018b). Warm spells, such as those reported by winter road operators (Barrette, 2018; Kimesskenemenow Corporation, Ontario National Assessment Engagement Sessions, 2018–2019), and the trend toward fewer days of extreme cold (e.g., average number of days of -25 °C or lower decreased from 79 days in the mid-1950s to 57 days in the mid-2010s; IBI, 2015) pose significant challenges for construction and maintenance.

A range of solutions is available to help manage risks to winter/ice roads in the Far North, including the following: 1) using ice-penetrating radar for determining adequate ice thickness; 2) establishing permanent creek and small river crossings at key locations; 3) realigning some sections of road to be on land that is less susceptible to flooding during thaws or winter rain; 4) realigning some sections of road to be in corridors that are suitable for later upgrading to all-season roads; and 5) consistently using the best possible construction and maintenance protocols (Barrette, 2018). Moving from roads to airships or hovercraft for transporting heavy loads continues to be discussed as an option (IBI Group, 2016). In addition to technical solutions, communities have considered other alternatives, including the possibility of having all-weather roads and increasing self-sufficiency with respect to consumables (Reid, 2015). Adaptation responses are ultimately at the discretion of the community and dictated by regional circumstances and capacity.

3.2.4 Climate change risk assessments

Climate change risk assessments are key tools for understanding infrastructure vulnerability and options to enhance resilience. Since 2007, more than 20 engineering-focused climate change risk assessments have been conducted in Ontario as part of a national effort to train engineers on how to consider climate change in infrastructure decisions (*see* Table 3.2). Most of these assessments were completed using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol, which is a systematic, risk-based approach to reviewing how different weather and climate drivers affect infrastructure performance and life expectancy (Engineers Canada, 2016). The protocol has also been adapted for application in First Nations communities (First Nations Infrastructure Resilience Toolkit (FN-IRT); Félio and Lickers, 2019) and is planned to be released in summer 2022. The resulting assessments reveal the thresholds at which different infrastructure systems will be compromised when exposed to extreme weather and climate variability, and validate the interdependencies between infrastructure systems. They also identify and prioritize locations and populations that are most vulnerable in terms of climate change impacts on infrastructure and related service disruptions (Zeuli et al., 2018). Furthermore, they help raise awareness about climate risks among senior managers (AECOM, 2015) and, more broadly (Chiotti et al., 2017), signal the need for collaboration and coordination regarding adaptation responses, and serve as a catalyst for the creation and implementation of adaptation measures (Chartered Professional Accountants of Canada, 2015a; 2015b). Risk assessments are usually the first step in developing a comprehensive climate change adaptation strategy (*see* Case Story 3.1).

Table 3.2: PIEVC infrastructure vulnerability assessments completed in Ontario

INFRASTRUCTURE TYPE	LOCATION OF ASSESSMENT	REFERENCE
Energy	Toronto	AECOM (2012)
	Toronto	AECOM (2015)
	Ottawa	Stantec (2019)
	Province-wide	Toronto Region Conservation Authority (2015)
Transportation	Greater Sudbury	R.V. Anderson Associates Limited (2008)
	Toronto	GENIVAR Inc. (2011a)
	Toronto	AECOM, TRCA, and RSI (2016)
Water and Wastewater	Toronto	GENIVAR Inc. (2010)
	Prescott	GENIVAR Inc. (2011b)
	Welland	AMEC (2012)
	Leamington/Kingsville/Essex	GENIVAR Inc. (2013)
	GTA/Mississauga	Greater Toronto Airport Authority (2014)
	Akwesasne First Nation	Stantec (2017)
	Ottawa	R.V. Anderson Associates Limited (2017)
	Windsor	Landmark Engineers Inc. (2019)
	Moose Factory / Moose Cree First Nation	Stantec (2018a)
Food Services	GTA	Zeuli et al. (2018)
Buildings	Ottawa	HOK Canada (2008)
	Southwest Ontario	Golder Associates (2012)
	Oneida Nation of the Thames	Stantec (2018b)
	Kasabonika Lake First Nation	Stantec (2020)
Natural Infrastructure	GTA	Risk Sciences International (2018)
Ports	Toronto	AECOM (2019)

Case Story 3.1: The Metrolinx adaptation strategy

Metrolinx is a crown corporation responsible for the multimodal transportation system in the Greater Toronto and Hamilton Area (GTHA). A leader in adaptation in the transportation sector, the corporation designed the 2018 Metrolinx adaptation strategy built upon a vulnerability assessment undertaken by an interdisciplinary team using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) protocol (AECOM et al., 2016) and a Planning for Resilience report (Chiotti et al., 2017). The strategy outlines seven key adaptation measures for improving resiliency of rail transportation to weather extremes and changes in climate (Metrolinx, 2018). These measures include the following:

1. Improving infrastructure, such as enhancing and monitoring embankments, incorporating of low impact development (LID), and increasing culvert size and stormwater capacity to reduce risks of flooding and washouts;
2. Using a higher preferred rail laying temperature of 37.8 °C as the revised construction standard to preheat tracks, reducing the risk of track warping and buckling ("sun kinks") during heat waves;
3. Improving monitoring, such as weather forecasting, ballast integrity sensors (to detect washout in the free-draining aggregate that supports the railway track), and real-time stream levels and flood conditions at track level, to reduce vulnerability to extreme precipitation events;
4. Developing a corporate-wide Winter Plan to prepare for severe snowfall, freezing rain and extreme winter temperatures to allow for operations to be sustained;
5. Enhancing emergency response and operating procedures during and after extreme weather events;
6. Updating operational protocols for trains in case of high water conditions caused by extreme precipitation events and flooding; and
7. Upgrading standards for back-up power generation at stations and facilities to ensure power supply during prolonged blackouts caused by extreme weather events.

The Metrolinx adaptation strategy was one of the first of its kind for rail infrastructure. The plan development process included elements of asset management, design practices, emergency response planning and preparedness, and regional and strategic planning, along with engagement and education activities. The process and resulting plan can be considered as good practice for other Ontario and Canadian metropolitan settings.

3.2.5 Asset management

Municipalities and other infrastructure owners and managers have begun to incorporate adaptation into their asset management practices (*see* Cities and Towns chapter of the National Issues Report; Kenny et al., 2019; Kenny et al., 2018; Metrolinx, 2018; Federation of Canadian Municipalities, 2017; Félio, 2017; Ontario Chamber of Commerce, 2017; Ernst and Young, 2016; Félio, 2016). New statutory and regulatory requirements have been an important driver of this activity. Of particular importance is the *2015 Jobs and Prosperity Act*, with regulation 588/17 requiring municipalities to develop and implement an asset management plan and supporting policies for municipal infrastructure (Ontario e-Laws, 2018). The regulation also requires municipalities to "consider actions that may be required to address vulnerabilities that may be caused by climate change..." (Ontario e-Laws, 2018). Another key driver has been the Federation of Canadian Municipalities Municipal Asset Management Program, which since 2016 has funded 157 projects in Ontario focused on improving asset management practices (Federation of Canadian Municipalities, 2020). Integrating climate change into the planning, maintenance, renewal and rehabilitation cycle of infrastructure assets ensures their longevity and helps to safeguard service levels for communities (*see* Figure 3.4; Canadian Infrastructure Report Card, 2019; 2016).

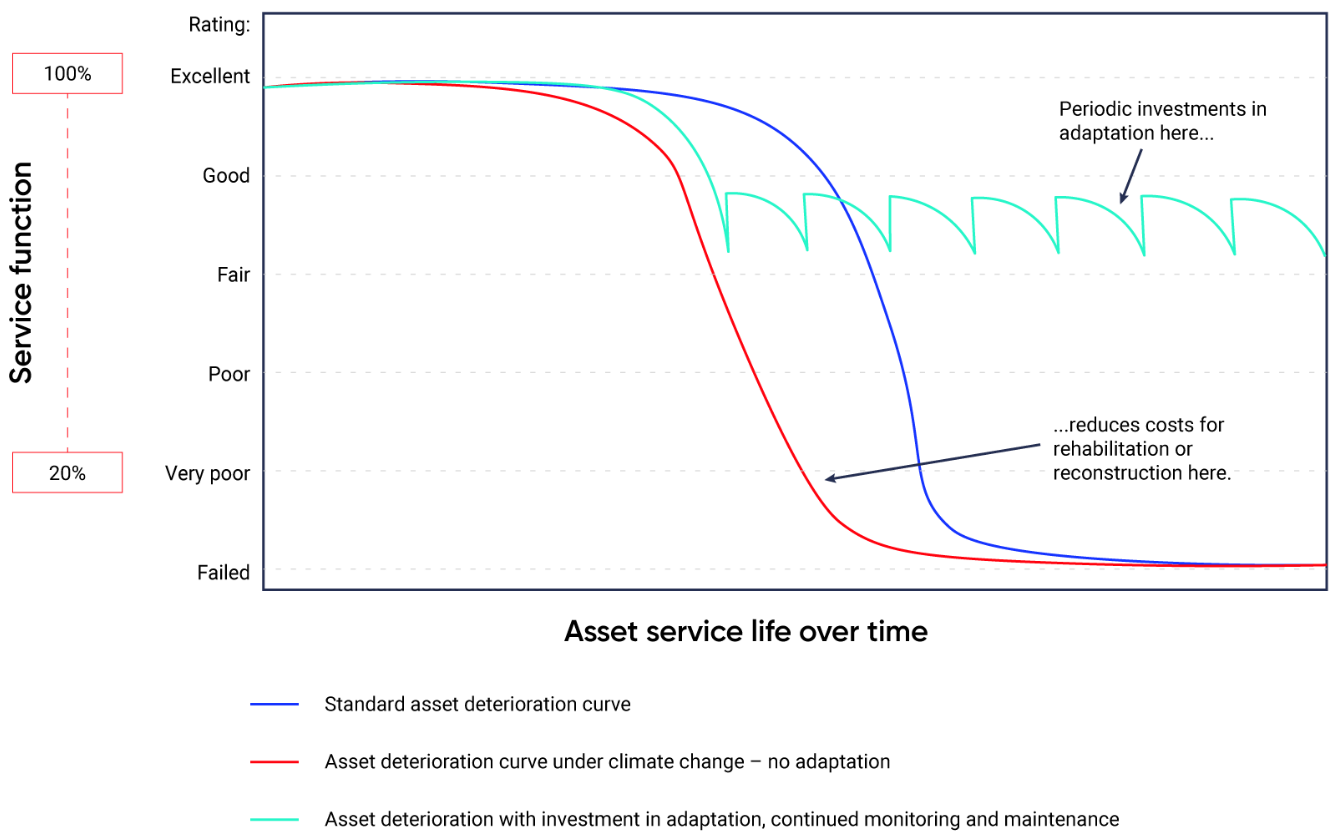


Figure 3.4: Example of asset deterioration curve for roads showing how reoccurring, planned investments in adaptation and the preservation of assets during the initial degradation phase (e.g., from "excellent" to "good") are significantly more cost-effective than reactive management through rehabilitation or reconstruction for conditions ranging from "fair" to "very poor". Source: Canadian Infrastructure Report Card, 2019; 2016.

Under the *Environmental Assessment Act*, the Ontario Ministry of Environment, Conservation and Parks (MECP) has issued guidance on how best to consider climate change in the environmental assessment process. Additionally, the Ontario Provincial Policy Statement 2014 states that "planning authorities should promote green infrastructure" (Ontario Ministry of Municipal Affairs and Housing, 2020) that delivers additional benefits in the areas of human health and reduction of greenhouse gas emissions.

3.2.6 Interdependencies

Ontario's water and wastewater, transportation, energy and telecommunications infrastructure, buildings and other forms of infrastructure are highly interconnected. In many cases, interdependencies exist, which means that the safe and consistent operation of one asset contributes to a similarly safe and consistent operation of another. Disruptions, caused by climate events or other factors, can lead to multiple and compounded infrastructure failures, affecting the delivery of critical services and routine business operations (*see* Sector Impacts and Adaptation chapter of the National Issues Report). Infrastructure interdependencies are not just physical, but also pertain to ownership, responsibility and liability. Businesses are often shared users and owners of infrastructure, and while they can take steps independently to be more climate resilient (through, for example development of business continuity plans, acquiring suitable insurance, etc.), they still remain dependent on the climate resiliency of neighbouring services. Decision making in such situations requires tools and planning processes that incorporate complex interdependencies (Bondank and Chester, 2020; Farhad et al., 2019; Zeuli et al., 2018; AECOM 2017).

The City of Toronto led a high-level risk assessment to identify interdependencies and adaptation responses that span multiple sectors (hydroelectricity, transportation, water and wastewater, food and agriculture, etc.) (AECOM, 2017). One example highlighted how a natural gas provider and district energy supplier are dependent on Toronto Hydro for electricity, and Toronto Hydro in turn relies on infrastructure like the City's road network and stormwater system, with the result that flooding associated with extreme rainfall could cascade through all electricity assets and lead to failure (*see* Figure 3.5; AECOM, 2017).

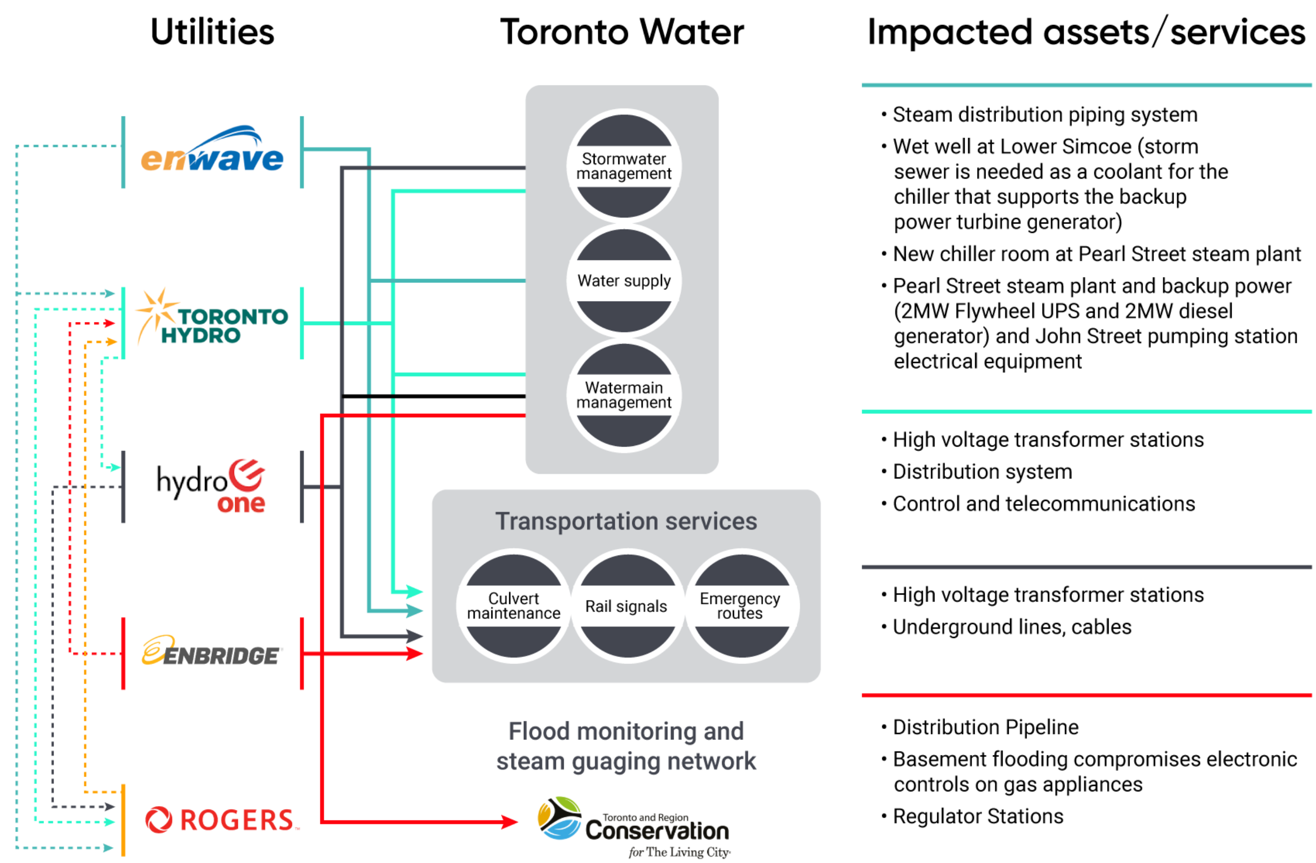


Figure 3.5: Interdependencies in utilities within the Greater Toronto Area. Source: AECOM, 2017.

The Toronto risk assessment exemplifies the collaboration required to mobilize adaptation. It sheds light on the cascading impacts of climate change, as well as efficiencies in planning that can make adaptation more cost-effective. The assessment also highlighted the need for information sharing protocols, detailed engineering-level investigations, enhanced funding and more proactive infrastructure planning and policy development (AECOM, 2017).

3.3 Nature-based approaches help address climate change impacts on biodiversity and ecosystem services

Climate warming has driven and will continue to drive changes to species and create new opportunities for invasive species. Impacts on biodiversity are magnified through the cumulative effects of climate change, habitat loss, urbanization, pollution and other threats. Actions to mainstream nature-based solutions, including the establishment of protected areas, such as Indigenous Protected and Conserved Areas, can help maintain ecosystem services and reduce climate change risks, as well as mitigate climate change.

Ontario includes a wide range of ecosystems, from forests, wetlands and grasslands in the south, to tundra, expansive wetlands, peatlands and coastal marshes in the Far North. These ecosystems provide important services to Ontarians, including provisioning services such as food and water, and regulating services such as flood and disease control. Changes in climate are placing added pressure on ecosystems, through changes to the composition, structure and function of ecosystems, changes to the geographic ranges of species, disruptions to the timing of life stage events and, in some cases, altering genetic diversity. In the absence of effective protection and restoration measures, heavily populated parts of the province and areas labelled for economic development could see additional declines in biodiversity and ecosystem services. Rapid and scaled-up interventions that target ecological resilience and foster natural adaptation will help manage climate change risks and protect ecosystem services on which communities rely.

3.3.1 Introduction

Biodiversity is defined as "the variability among living organisms from all sources including inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems" (United Nations Convention on Biological Diversity, 1992). Biodiversity includes the goods and services that ecosystems provide, including those on which humans depend for our survival, health, safety and/or prosperity (Ontario Biodiversity Council, 2015, 2011). Weather and climate combined with physical site conditions largely determine which species can survive and which cannot (Nituch and Bowman, 2013). Given the climate's relative stability over the past several millennia, entire ecosystems and their associated species have evolved to cope with prevailing climate and soil conditions (Brinker et al., 2018).

The Ontario Biodiversity Strategy recognizes climate change as one of the greatest threats facing biodiversity (Ontario Biodiversity Council, 2011, 2015). Existing stresses on terrestrial and aquatic ecosystems can be exacerbated by climate impacts, such as changes in the frequency and magnitude of extreme weather, the extent and duration of freshwater ice cover, vegetative phenology, breeding activity and insect emergence, with cascading effects on food webs. A number of other provincial strategies and programs address biodiversity and ecosystem impacts, including the Ontario Ministry of Natural Resources and Forestry (MNRF) Climate Change Adaptation Strategy (Ontario Ministry of Natural Resources and Forestry, 2017b), the Wetland

Conservation Strategy (Ontario Ministry of Natural Resources and Forestry, 2017c); and the 50 Million Tree Program (Forests Ontario, 2016).

3.3.2 Impacts and vulnerabilities

3.3.2.1 Terrestrial ecosystems

Natural selection pressures under climate change and other human-created stresses are changing the structure and composition of many of Ontario's ecosystems, as well as the socio-economic services and functions that they provide (Brinker et al., 2018; Ontario Ministry of Natural Resources and Forestry, 2017b). Ontario species already demonstrating shifts in distribution include the common opossum, white-tailed deer, southern flying squirrel and Nodding Ladies' Tresses orchid (Kennedy-Slaney et al., 2018; Nituch and Bowman, 2013). Peatlands in the northern subregion store immense amounts of carbon, providing a regulating ecosystem service (*see* Ecosystem Services chapter of the National Issues Report). Warming winter temperatures causing permafrost thaw, enhanced microbial action and peat decay in the soils will lead to further loss of carbon to the atmosphere (Turetsky et al., 2020; Natali et al., 2019; McLaughlin et al., 2018). Drier conditions in peatlands also increase fire risk with long-lasting smouldering and subsequent carbon release (McLaughlin et al., 2018; Turetsky et al., 2014).

Warming will be greatest in parts of the North subregion (*see* Figure 3.1), where potential northward migration of terrestrial species is limited by Hudson Bay and James Bay. Ecosystems located further south, most notably in the mixedwood plains ecozone (southwestern Ontario, and parts of central and northeastern Ontario) will experience less warming, but impacts will be exacerbated by habitat fragmentation from increasing land-use pressures and pollution in the human-dominated landscapes of southern Ontario (Brinker et al., 2018; McLaughlin et al., 2018; Ontario Ministry of Natural Resources and Forestry, 2017b; 2017c; McLaughlin and Webster, 2014;Varrin et al., 2007). Species with generalist habitat requirements (e.g., raccoons, coyote and deer) and greater dispersal abilities are capable of colonizing new areas, diversifying food sources and thriving within broader thermal thresholds, and will manage to adapt to changing conditions. This also includes invasive terrestrial and aquatic species that will be able to thrive and expand their ranges, contributing to a changed and possibly simplified ecosystem structure (McDermid et al., 2015a; Government of Ontario, 2012). Species with poor dispersal capabilities, or with specialized and narrow habitat requirements, will be the most vulnerable to changing conditions (Ontario Ministry of Natural Resources and Forestry, 2017b; Nituch and Bowman, 2013; Government of Ontario, 2012). Other species, such as types of fish, insects and plants, will decline in population as temperature or moisture conditions approach or exceed their tolerance limits (Brinker et al., 2018).

Climate change will influence changes in species interactions, including competition and predation, and impacts from diseases, pests and invasive species. Problems occur when climate change has different effects on predator and prey species, producing a mismatch in timing between life cycle events that limit food availability, ultimately affecting successful breeding for many species (*see* Ecosystem Services chapter of the National Issues Report; Guzzo and Blanchfield, 2016; Nantel et al., 2014; Joyce and Rehfeldt, 2013; Klaus and Lougheed, 2013). In the North and Central subregions, the distribution of deer, moose and caribou is expected to change substantially over the current century, in part because of changes in temperature and precipitation. White-tailed deer distribution is limited at its northern boundary by the severity of winter climate. Studies suggest that warmer winter temperatures and less deep snow will remove this limitation and contribute to expanding the northern distribution of white-tailed deer in Ontario by 2100 (Kennedy-Slaney et al., 2018). Even small changes in the abundance of common species can have cascading effects on ecosystem composition and structure, and on the services that those ecosystems provide (Brinker et al., 2018; McDermid et al., 2015b; Government of Ontario, 2012).

The cumulative impacts of climate change, habitat loss and fragmentation, and other drivers will continue into the future, resulting in declining viability of some species in Ontario (Ontario Ministry of Natural Resources and Forestry, 2017b). Where landscape connectivity is limited, vulnerable populations have an increased risk of becoming locally or regionally extinct (Nituch and Bowman, 2013). For example, the Great Lakes and the Saint Lawrence River are significant barriers for wildlife; with increasing habitat fragmentation from urban and agricultural development, connectivity for many terrestrial species will decline. Even generalist native species, such as the bobcat, are experiencing disrupted gene flow where landscape connectivity is low (Marrotte et al., 2020). The extent to which species can navigate routes through the Great Lakes region will be important for the future biodiversity of areas north of the Great Lakes. Species living in warmer habitats to the south of the Ontario-U.S. border will continue to follow shifting temperature zones into Ontario, ultimately leading to the emergence of novel ecosystems (Nituch and Bowman, 2013). Impacts on biodiversity may include reorganization of species, replacement of dominant or keystone species, and pass-through effects on higher trophic levels (Nituch and Bowman, 2013).

3.3.2.2 Aquatic ecosystems and watersheds

Aquatic species have adapted to temperatures that optimize their physiological processes (Brinker et al., 2018; Alofs et al., 2014). Changes in precipitation patterns alter the amount of available habitat for many species, and increasing water temperatures modify the thermal regimes of lakes, rivers and wetlands (Minns et al., 2014; Chu, 2015). Increasing water temperatures can have cascading effects that alter the growth, reproduction and survival of aquatic organisms. As temperatures continue to warm, fish species will migrate northward to follow their favoured climate, resulting in increased growth, survival and abundance for warm-water species such as smallmouth and largemouth bass, but decreases in cold-water species such as lake trout (Edwards et al., 2016; Guzzo and Blanchfield, 2016; Sharma et al., 2009). The warming trend in Ontario has already facilitated the range expansion and establishment of warm-water fish species in northern regions of Ontario (Alofs et al., 2014), and has caused shifts in the abundances of different species within assemblages (Staudinger et al., 2021).

Changes in Ontario's climate are affecting the timing of important life stage events, such as spawning or lake-riverine migrations, and selecting for certain evolutionary traits (Myers et al., 2017; Lynch et al., 2016). Such phenological shifts have been recorded among several fish species, including smallmouth bass in Algonquin Park, whose spawning is advancing significantly earlier in the spring (Ridgway et al., 2017). These changes alter the competition and predator-prey relationships among wildlife and increase the likelihood of invasive species establishment (Brinker et al., 2018; Chu et al., 2018b; Sharma et al., 2009).

Extreme high and low water levels in lakes affect the amount of suitable habitats for native plant and animal species, particularly in wetland environments. Coastal wetlands in southern Ontario are particularly vulnerable to climate change, which adversely impacts wildlife habitat availability, bird migration patterns and overall ecosystem health (Chu et al., 2018b; Ontario Ministry of Natural Resources and Forestry, 2017c; Chu, 2015; McDermid et al., 2015b).

Aquatic species have an inherent capacity to adapt to a certain amount of ecological change because of their genetic and behavioural plasticity (Kelly et al., 2014; Stitt et al., 2014); however, the pace of ecological change associated with climate change is extending beyond the tolerance range of many species (Moritz and Agudo, 2013; Quintero and Wiens, 2013). Improved understanding of the natural variation in aquatic ecosystems and their capacity to rebound from perturbations (e.g., Gutowsky et al., 2019; van Zuiden et al., 2016; Stitt et al., 2014; Gronewold et al., 2013 and Sharma et al., 2007) helps to inform and prioritize effective adaptation measures.

3.3.3 Resiliency and adaptation

More than 14% of the 15,800 plant and animal species in Ontario that have been assessed by scientists are considered vulnerable, rare or rapidly declining, and their future survival is uncertain (Canadian Endangered Species Conservation Council, 2016). Opportunities to enhance the resilience of species to a changing climate vary depending upon available habitat, species vulnerability and available management tools (*see* Box 3.1). Integrating species vulnerability assessments into habitat and species management, restoration and species recovery planning can help to enhance resilience, as can judiciously applied assisted migration (*see* Section 3.5.3) in forest and other habitat restoration activities (Brinker et al., 2018; Douglas et al., 2014; Lemieux et al., 2014; Chu and Fischer, 2012; Gleeson et al., 2011; Ste-Marie et al., 2011).

Box 3.1: Assessing species vulnerability

The NatureServe Climate Change Vulnerability Index (Young and Hammerson, 2015) was used to assess the relative vulnerability to climate change of 280 species in Ontario's Great Lakes Basin (Brinker et al., 2018; Young and Hammerson, 2015). The Index assesses species exposure to climate change, as well as sensitivity and adaptive capacity, in order to derive a vulnerability score (*see* Figure 3.6). The categories of the indexed scores range from "Insufficient evidence" and "Less vulnerable" to "Extremely vulnerable", and they are accompanied by statistically based confidence ratings (*see* Figure 3.7).

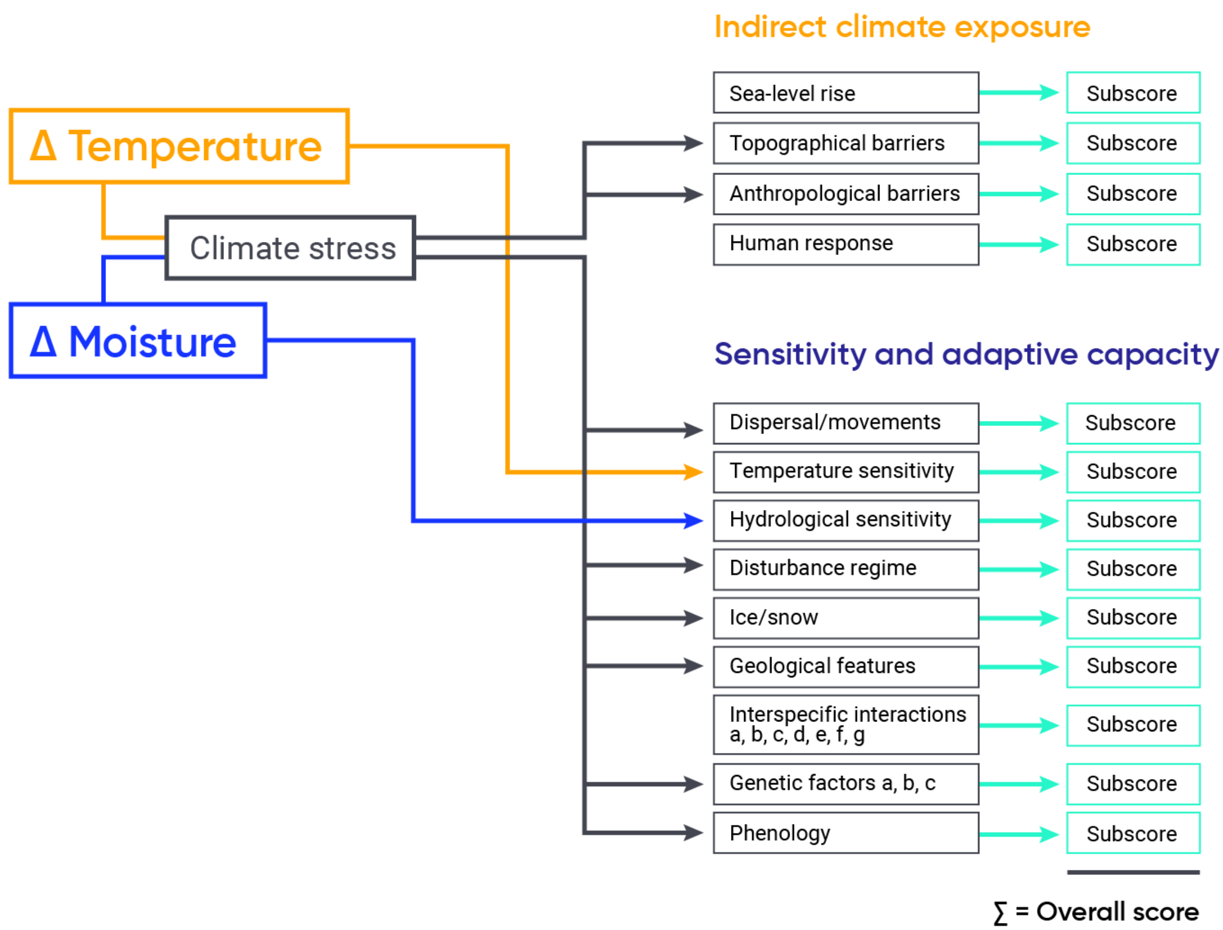


Figure 3.6: Determining factors of the Climate Change Vulnerability Index. Source: Young and Hammerson, 2015.

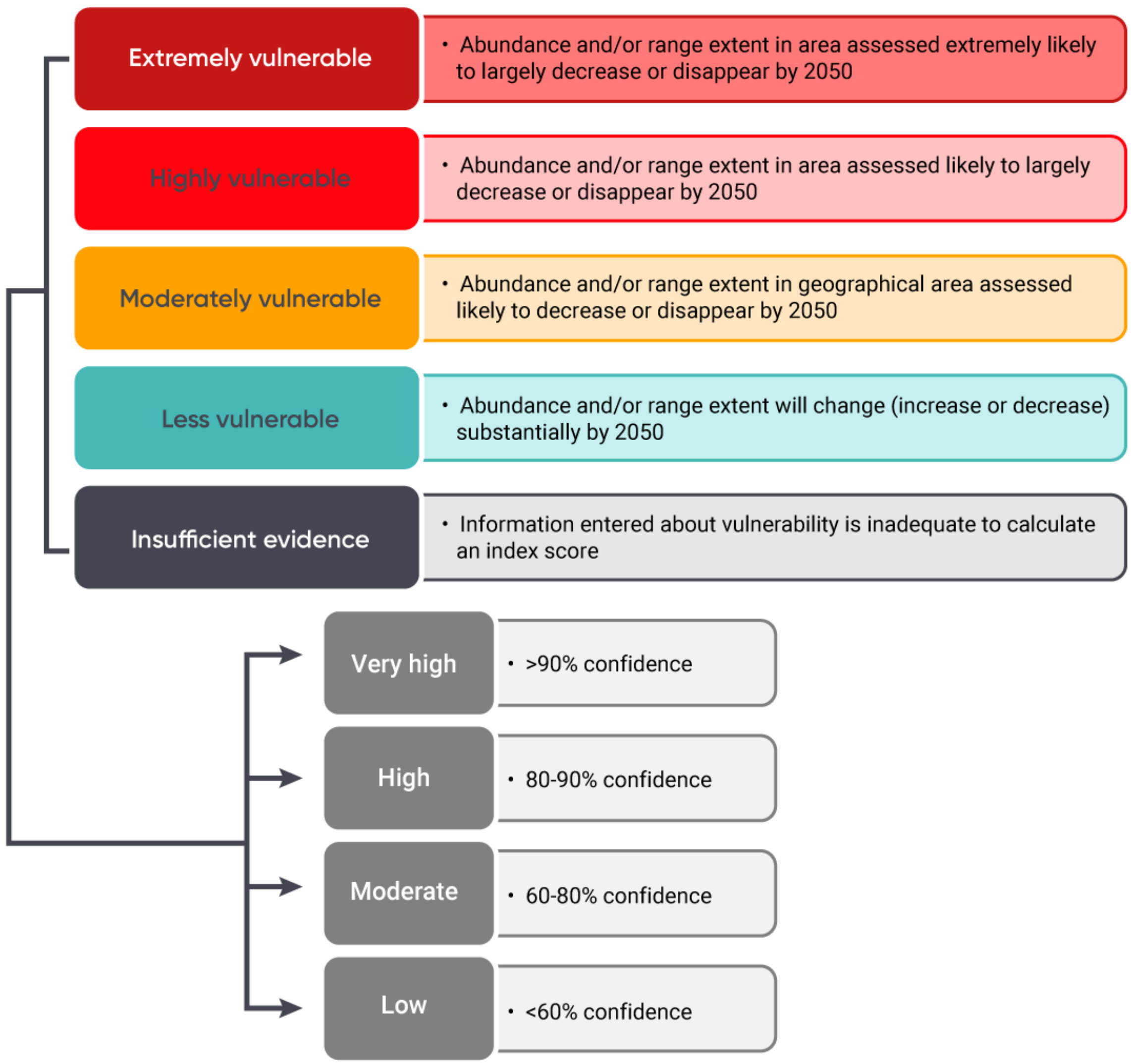


Figure 3.7: Climate change vulnerability indexed scores and confidence levels. Sources: Brinker et al., 2018; Young and Hammerson, 2015

Results showed that 175 of the 280 species assessed are vulnerable to climate change, of which 11 are extremely vulnerable, 49 highly vulnerable and 115 are moderately vulnerable. Molluscs, fish, amphibians and lichens were most vulnerable. Vascular plants and mammals varied widely in assessed vulnerability, while birds, insects and spiders, and reptiles were found to be the least vulnerable. The common risk factor for all groups was the species' past exposure to precipitation variations across their habitat range, and ultimately their ability to adapt to future hydrological changes within their niche. Other important factors include species' temperature tolerance, the ability of seeds to migrate, barriers to movement and habitat specificity (Brinker et al., 2018).

A number of guidance documents are available to assist ecosystem managers and practitioners to include climate change in planning and management practices (e.g., Environment Canada, 2013; Gleeson et al., 2011). Key approaches for enhancing ecosystem resilience include the following: protecting intact ecosystems; increasing connectivity through the protection and implementation of ecological corridors (*see* Box 3.2) and regional/urban biodiversity strategies; and strategically using native species suited to new locations and predicted climatic conditions in habitat restoration efforts. Actions that can boost the resiliency of aquatic ecosystems and organisms are as follows (Myers et al., 2017; Chu, 2015; Gleeson et al., 2011):

1. Restricting withdrawals of surface and groundwater from vulnerable lakes, rivers and wetlands;
2. Providing nest boxes or rehabilitating nesting habitats for vulnerable wetland birds;
3. Maintaining natural water levels in lakes and wetlands, and flow rates in rivers;
4. Restoring or enhancing riparian vegetation along stream shorelines;
5. Identifying and protecting refugia; and
6. Limiting human development and industrial activities.

Box 3.2: Assisting wildlife migration

Measures that keep wildlife safe from roads, such as fencing and dedicated wildlife tunnels and bridges, are critical infrastructure components that help achieve habitat connectivity objectives in Ontario (*see* Figure 3.8). Ontario continues to develop policies that direct municipalities to identify, conserve and link natural features for the movement of native plants and animals across the landscape to ensure the long-term protection of biodiversity in an era of rapid climate change.

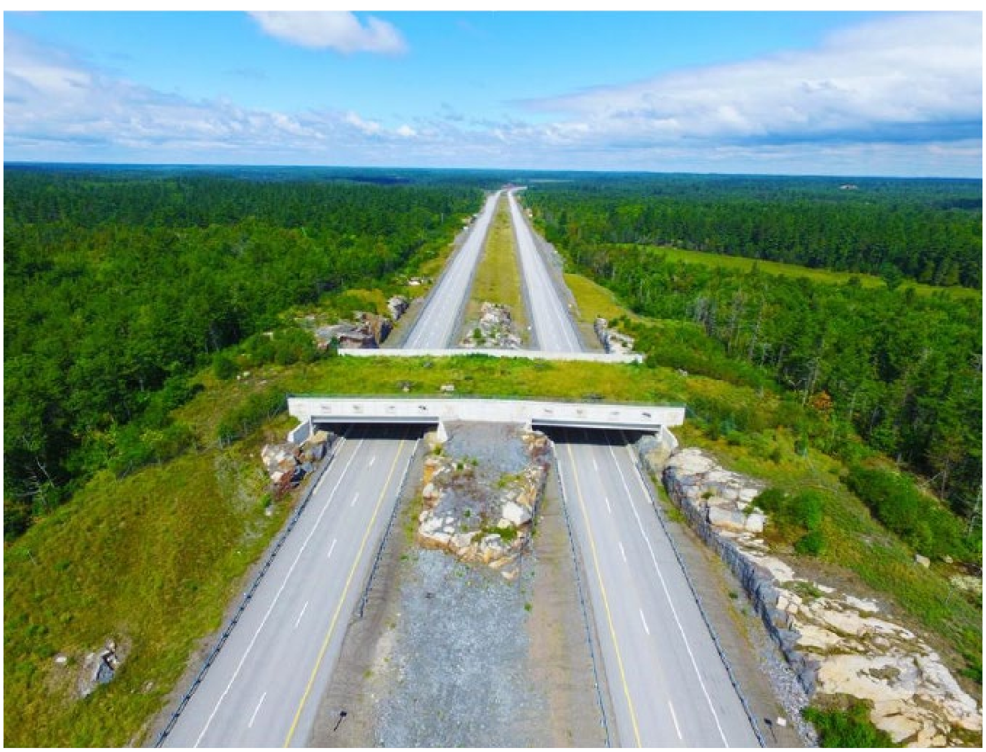


Figure 3.8: First photo shows a wildlife overpass on Highway 69. Second photo shows a diversion fence in Bruce Peninsula National Park. The fence helps to direct wildlife towards an eco-passage, while the grating shown in the third photo maximizes the amount of natural sunlight inside, creating an attractive passage for species-at-risk. Source: First photo courtesy of Timercraft Consultation Inc. Latter photos courtesy of Christopher Lemieux.

3.3.3.1 Parks and protected areas

Ontario features a network of approximately 700 parks and other types of protected areas that include National and Provincial Parks, Conservation Reserves, Nature Conservancy of Canada (NCC) Sites and at least 40 other designations (Environment and Climate Change Canada, 2021; Ontario Ministry of Natural Resources and Forestry, 2012; Gray et al., 2009). These comprise about 10.7% of the province's total terrestrial area and provide important habitat for biodiversity, as well as space for recreation, research, monitoring and education.

Ecosystem resilience to climate change can be supported through performance targets for conservation, such as those within the 2020 Biodiversity Goals and Targets for Canada (biodivcanada, 2020). The Strategy sets targets for conservation of terrestrial and inland waters, as well as coastal and marine areas. In Ontario, the Ontario Biodiversity Strategy also sets targets in areas that include engaging people, reducing threats, enhancing resilience and improving knowledge (Ontario Biodiversity Council, 2021; 2015; 2011). The federal government's reaffirmation of its commitment to protect 30% of land and ocean by 2030, and to ensure that action and investment for nature and climate change are central to COVID-19 recovery planning (Office of the Prime Minister, 2019), have implications for Ontario's conservation efforts.

A significant body of knowledge focuses on the impacts of climate change on species distribution and ecosystem structure and function (e.g., Chu et al., 2018a; Parker, 2017; Dove-Thompson et al., 2011; McKenney et al., 2010), and the implications for protected areas management (Barr et al., 2020; Gutowsky and Chu, 2019; Parker, 2018; 2017; Lemieux et al., 2014; Canadian Parks Council, 2013; Lemieux et al., 2011). The literature highlights that managing for climate change impacts on biodiversity and ecosystem function will require an adaptive, flexible, forward-looking and collective approach (Gross et al., 2016; Lemieux et al., 2010). This includes developing and sustaining relationships and communication networks among various levels of government, scientists and other partners, and increasing participation from Indigenous communities in all aspects of conservation planning and management (Lemieux et al., 2011).

Protected areas have fixed boundaries that cannot easily change as the ecosystems and species that they were established to conserve migrate in response to the changing climate. Therefore, enhancing connectivity between existing natural and protected areas is a key adaptation goal (Lemieux et al., 2011). Connectivity can be enhanced through the protection or restoration of "greenway" and "blueway" networks, such as natural corridors, riparian areas (zones between aquatic and dry-land habitat), rivers and lakes, or other habitats that connect natural areas (Andrew et al., 2014). Connectivity mapping for terrestrial ecosystems has been completed across Ontario and applied to multiple species to evaluate genetic connectivity for informing landscape planning and efforts to build ecosystem resilience (Marrotte et al., 2017). Such networks enable range shifts for certain species, as well as the exchange of genetic material, and enhanced resilience to cope with significant disturbance (e.g., large forest fires and pest outbreaks) and disruption by human activity (*see* Case Story 3.2).

Case Story 3.2: The Norfolk Sand Plain Natural Area

The Norfolk Sand Plain Natural Area in southwestern Ontario (*see* Figure 3.9) is home to more than 45 provincially, nationally or globally rare plants and animals—one of the highest densities of rare and endangered wildlife in Canada (Nature Conservancy of Canada, 2019). Long Point Provincial Park is a Provincially Significant Wetland,, an internationally recognized wetland under the Ramsar Convention, a UNESCO Biosphere Reserve and a nationally significant Important Bird Area.

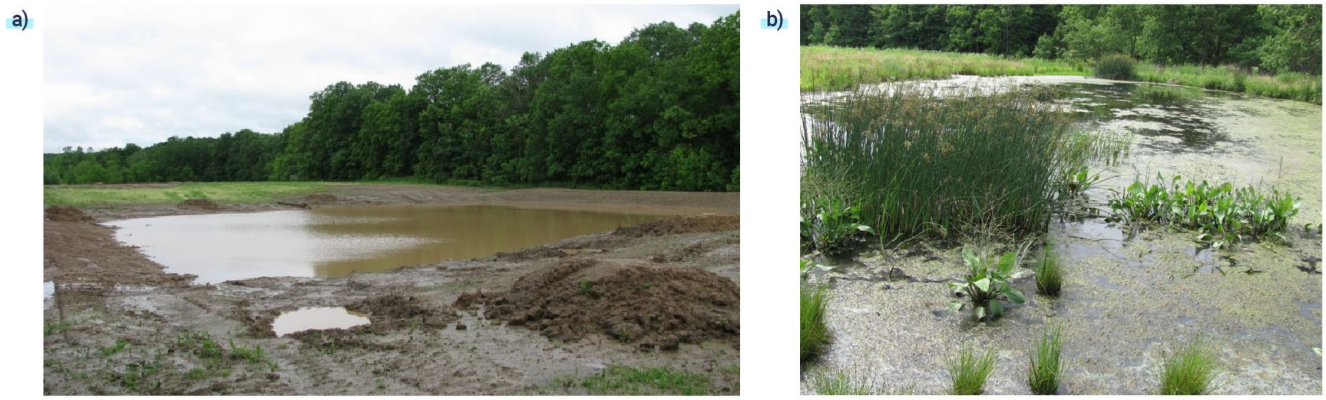


Figure 3.9: Pre (left) and post (right) photos of the Nature Conservancy of Canada Williams Wetland restoration project within the Norfolk Sand Plain Area. Source: Nature Conservancy of Canada, 2019.

The Nature Conservancy of Canada has been restoring agricultural fields in the area since 2006, improving connectivity between existing core areas. Wetland restoration has created additional habitat for species-at-risk, including the Blanding's turtle (*Emydoidea blandingii*). The wetlands also act as a staging area for migratory shorebirds and waterfowl. In addition to enhancing the climate resilience of the Norfolk Sand Plain Natural Area, the restored wetlands play a valuable role in protecting ecological services in the area. These include maintaining and improving water quality by filtering nutrients and sediment from overland flow, recharging groundwater, holding flood waters and reducing erosion. The natural area has become critical for conserving species and habitats unique to Canada's Carolinian Life Zone and for achieving conservation at a landscape level (Nature Conservancy of Canada, 2019).

In the Far North of Ontario, the provincial government and local First Nations are engaged in a process to jointly prepare community-based land-use plans that will designate areas for protection as well as areas for sustainable use (Government of Ontario, 2010). Many large areas of high regional and continental conservation value in North America lack formal protection, with the Hudson Bay Lowlands and Northern Forests of Ontario included in a list of biomes with the lowest rates of protection for high-value climate refugia and corridors (Stralberg et al., 2020).

Nature-based approaches that encourage the protection, sustainable management and restoration of natural or modified ecosystems and simultaneously provide human well-being and biodiversity benefits significantly improve the chances of successfully responding and adapting to climate change (Smith, 2020). Protection of Canada's most carbon-dense/high-biodiversity ecosystems has also been identified as the most effective nature-based approach for obtaining short-term results on immediate (by 2030) reduction in annual greenhouse gas emissions through the maintenance of carbon sinks for carbon storage (Smith, 2020). In addition to targeted protection, other approaches that would result in large benefits for biodiversity, as well as co-benefits for carbon storage include the following: growing 30% of managed forests that are currently over 60 years old to ecological maturity and protecting them; additional tree planting; and increasing the length of time between harvests.

Applying nature-based approaches will require collaboration between the Province, conservation authorities, municipalities, Indigenous communities and the broader public. The establishment of Indigenous Protected and Conserved Areas (IPCAs) in Ontario represent an opportunity for Indigenous governments to have a primary role in protecting and conserving ecosystems through Indigenous laws, rights, governance and knowledge systems, and such areas can support and encourage further research and capacity building (The Indigenous Circle of Experts, 2018). A Memorandum of Understanding has been reached between the Mushkegowuk Council and the Government of Canada to assess the feasibility of creating a National Marine Conservation Area (NMCA) in western James Bay and southwestern Hudson Bay (Parks Canada, 2021).

The combined understanding of climate change impacts and adaptation solutions that emerge from consideration of local knowledge, Indigenous Knowledge and Western science can serve to reduce climate risks to safety, property and infrastructure, while at the same time promoting the resilience of Ontario's ecosystems and communities. Establishing information networks to facilitate ongoing knowledge exchange within the conservation community is one of the most important practices that organizations can employ in an era of rapid climate change (Gross et al., 2016). Within Ontario, the overall organizational capacity to conserve biodiversity and foster the partnerships necessary to implement adaptation options is considered low (Barr et al. 2020; Office of the Auditor General of Ontario, 2020; Lemieux and Scott, 2011; Lemieux et al., 2010).

3.4 Adaptive management is key for addressing impacts in the Great Lakes Basin

The combined effects of climate change, land-use changes and other stressors are negatively impacting the Great Lakes Basin. Despite mechanisms to address complex governance challenges, adaptation efforts across the Basin remain relatively fragmented. Many communities have embraced adaptive management practices to address impacts in light of uncertainties in future changes.

The Great Lakes Basin is a region of high environmental, social and economic importance to Ontario. Climate change has resulted in a range of physical, chemical and ecological impacts on the lakes themselves, which are amplified by the impacts of urbanization, agricultural practices and other human activities. Seasonal lake ice cover and water levels both show high year-to-year variability, necessitating adaptation actions that address a range of future conditions. The international setting of the Basin necessitates the involvement of the Canadian and American national governments, as well as that of provincial, state and local governments in order to develop regional responses to climate change. While a number of functional governance mechanisms are in place, implementation of adaptation actions remains fragmented. Leadership is emerging from several municipalities employing adaptive management practices that involve continuous monitoring, evaluation and improvement of management plans. Strong and coordinated adaptation efforts across the Basin can help to protect communities, and to sustain the resources and services that the area provides.

3.4.1 Introduction

The Great Lakes Basin play a critical role in shaping Ontario's environmental, social, cultural and economic landscape. As a region, including both Canada and the U.S., the Great Lakes–Saint Lawrence Basin covers more than 765,000 square kilometres, contains 21% of the world's fresh surface water, and is home to more than 8.5 million Canadians (22% of the population) (Council of the Great Lakes Region, 2017). Surrounding communities rely on the freshwater resource for drinking water, recreation and tourism, manufacturing, fishing, agriculture and shipping industries.

Climate change is considered one of the greatest threats facing the Great Lakes Basin, exacerbating risks associated with land-use changes and other human activities, resulting in changes to the physical, chemical and ecological characteristics of the lakes, and presenting social and economic risks to surrounding communities (Brinker et al., 2018; Government of Ontario, 2016a; McDermid et al., 2015b). The widespread impacts of climate change have been well documented, as discussed in Section 3.4.2 (Great Lakes Integrated Sciences and Assessments (GLISA) and Environment and Climate Change Canada (ECCC), 2018; International Joint Commission Great Lakes Water Quality Board, 2017; McDermid et al., 2015b) and are projected to worsen over the coming decades (Bonsal et al., 2019; Derksen et al., 2019; Angel et al., 2018; GLISA and ECCC, 2018; McDermid et al., 2015b). The risks associated with climate change are presented in Annexes to both the Great Lakes Water Quality Agreement (Government of Canada and Government of the United States, 2012) and the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health (Government of Canada and Government of Ontario, 2014). Solutions lie in coordinated and collaborative adaptation planning and management across the Basin.

3.4.2 Impacts and vulnerabilities

3.4.2.1 Environmental Impacts

The Great Lakes directly influence and regulate the regional weather by moderating seasonal temperatures and generating local precipitation through lake effects (Mortsch, 2016; McDermid et al., 2015b; Gula and Peltier, 2012). In recent years, the impacts of changing climate have been manifested through changes in ice cover and water temperatures, (Zuzek, 2020; Bonsal et al., 2019; Derksen et al., 2019; Byun and Hamlet, 2018; Di Liberto, 2018). Changes in ice cover and water levels have been assessed as part of this assessment (see the Changes in Snow, Ice, and Permafrost Across Canada chapter and the Changes in Freshwater Availability Across Canada chapter of Canada's Changing Climate Report).

Warming air temperatures contributed to a 71% decline in annual average ice cover across the Great Lakes in the period from 1973 to 2010, with the greatest declines occurring in Lake Ontario, Lake Superior and Lake Michigan (Derksen et al., 2019; Mason et al., 2016; Wang et al., 2012). Heavy ice cover occurring in 2014, 2015 and 2018 obscured any apparent trend, such that the record is marked by high inter-annual variability, but no long-term trend (*see* Figure 3.10; Derksen et al., 2019). Projections of future ice cover for Lake Ontario and Lake Erie indicate near ice-free conditions by the middle to the end of the 21st century under the RCP 8.5

scenario (Zuzek, 2020; Hewer and Gough, 2019). Seasonal ice cover is an important factor influencing wave formation, shoreline erosion, evaporation and lake levels (Zuzek, 2020; Zuzek, 2019; Lenters et al., 2013).

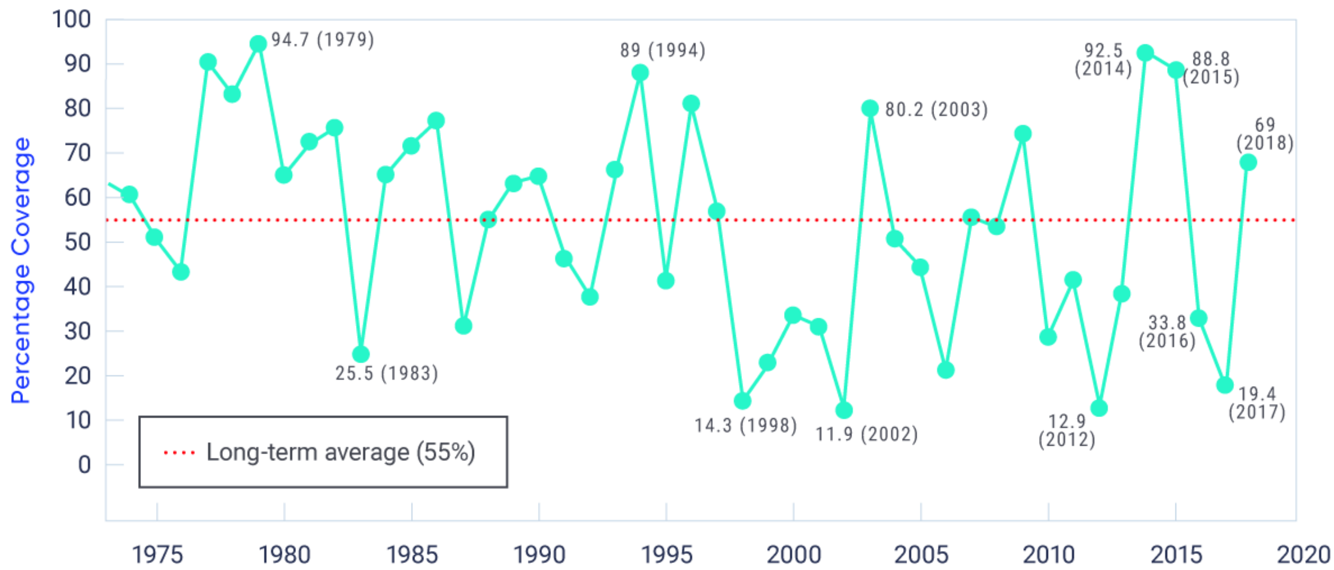


Figure 3.10: Observed Great Lakes annual maximum ice cover (%) from 1973 to 2018. The red dashed line indicates the long-term average. Source: NOAA - Great Lakes Environmental Research Laboratory, 2019.

Water levels of the Great Lakes have fluctuated over the past century, driven by natural variability, human interventions (e.g., detention diversions) and climate change. Both record low and record high levels have been experienced over the past few years. From 1998 to 2013, lower than average water levels were experienced across the lakes, with notable lows in Lake Michigan and Lake Huron during the winter of 2012/2013. These lows were followed by a rapid increase in water levels starting in 2014, largely attributed to decreased evaporation rates and increased regional precipitation (Derksen et al., 2019; Gronewold et al., 2016). In July 2019, each lake was observed to be near or above record-high water levels, with Lake Superior, Lake Erie and Lake Ontario hitting record-high values (*see* Table 3.3). The high water levels accelerated shoreline erosion and caused flooding events throughout the summer of 2019 (Seglenieks and Caldwell, 2019). It is expected that year-to-year and multi-year variability in lake levels will remain large, with potential for an increase in ranges (Bonsal et al., 2019; McDermid et al., 2015b; Gronewold et al., 2013; MacKay and Seglenieks, 2013). Extreme and unpredictable water levels are associated with significant economic costs (e.g., Shlozberg et al., 2014), such that management for both extreme high and low water levels along Ontario's shorelines will be required moving forward.

Table 3.3: Great Lakes water levels in July 2019 compared to the long-term (1918–2019) monthly average

JULY 2019 MONTHLY MEAN WATER LEVEL

Lake	Compared to Monthly Average (1918–2019)	Compared to 2018
Superior	35 cm above	21 cm above
Michigan-Huron	79 cm above	39 cm above
Erie	80 cm above	31 cm above
Ontario	79 cm above	74 cm above

Source: Adapted from Seglenieks and Caldwell, 2019.

Annual surface water temperatures of the Great Lakes have increased by between 0.02 °C and 0.06 °C per year since 1980 (United States Environmental Protection Agency and Environment and Climate Change Canada, 2021). The trend has been gradual but steady, with recent increases being driven by warming during the spring and summer months (NOAA, 2021; United States Environmental Protection Agency and Environment and Climate Change Canada, 2021). Surface water temperature is influenced by many factors, including regional air temperatures, solar radiation and ice cover conditions from the previous winter (United States Environmental Protection Agency and Environment and Climate Change Canada, 2021; Zhong et al., 2016). While water temperature projections are more complex compared to air temperature projections, models indicate that surface water temperatures across the Great Lakes will continue to warm under a changing climate (Wuebbles et al., 2019; Xiao et al., 2018; McDermid et al., 2015b).

The lengthened ice-free season and increasing surface water temperatures have led to earlier springtime and later fall lake stratification, which extends the period between turnover (Angel et al., 2018; Wuebbles et al., 2019; McDermid et al., 2015b). The physical process of turnover allows for dissolved oxygen and nutrients to be circulated and vertically mixed. As the duration between overturning events lengthens, there is less vertical mixing of dissolved oxygen and nutrients, which impacts water quality and biological function (Anderson et al., 2021; Xiao et al., 2018; McDermid et al., 2015b). During the warm winters of 2012 and 2017, surface water temperatures in parts of Lake Ontario did not fall below 4 °C (the maximum density of water), such that the overturn process was not initiated, resulting in inadequate oxygen and nutrient mixing (Wuebbles et al., 2019; Angel et al., 2018; McDermid et al., 2015b). Longer periods between stratification can be detrimental for cold-water species, as the latter are pushed closer to the surface to obtain adequate oxygen, but then challenged by unsuitable thermal conditions (Collingsworth et al., 2017; Lynch et al., 2016; Dove-Thompson et al. 2011; Minns et al. 2011).

Warming surface water temperatures, coupled with increased nutrient and sediment runoff from land-use changes (urban development, loss or conversion of wetlands, etc.), provide optimal conditions for algae growth, increasing the likelihood and magnitude of algal bloom events (Wuebbles et al., 2019; McDermid et al., 2015b; d'Orgeville et al., 2014). Cyanotoxins within algal blooms can have significant human health impacts. Without adequate drinking water filtration systems, or through accidental exposure, these toxins can cause a variety of symptoms, such as abdominal pain, nausea, vomiting, diarrhea, sore throat and dry cough (Chorus and Bartram, 1999). Lake Erie, the shallowest of the Laurentian Great Lakes, has been particularly vulnerable to algal blooms and has experienced declining water quality in recent years as surface water temperatures and nutrient loading have increased (Wuebbles et al., 2019; d'Orgeville et al., 2014). Continued warming water and nutrient loading from agriculture operations suggest that the prevalence of algal blooms could further increase. To address this risk, the 2018 Canada-Ontario Lake Erie Action Plan identified more than 120 actions to help achieve the goal of reducing phosphorus entering Lake Erie by 40 % by 2025 (Environment and Climate Change Canada and the Ontario Ministry of the Environment and Climate Change, 2018).

The Great Lakes Basin provides habitat for more than 3,500 plant and animal species, including all three thermal guilds of fish species (cold-, cool- and warm-water species), as they co-exist in thermally stratified waters (Wuebbles et al., 2019; Milner et al., 2018a). Climate change impacts exacerbate non-climate ecological threats, such as habitat loss, pollution and invasive species resulting from human activity (Mortsch, 2016; McDermid et al., 2015b). These impacts will increase risks to fish, migratory birds and other native species that rely on healthy and resilient aquatic and coastal ecosystems (International Joint Commission Great Lakes Water Quality Board, 2017; Chu, 2015; McDermid et al., 2015b).

The physical impacts to the Great Lakes are projected to influence aquatic ecosystem function, impacting a range of processes, including nutrient cycles and uptake, phenological cues, lake productivity and turbidity and substrate conditions (Collingsworth et al., 2017; Alofs et al., 2014). Research indicates that the composition of fish communities in the Great Lakes will change as cold-water habitat becomes limited for native cold-water fish species and warm-water species expand their ranges northward (Collingsworth et al., 2017; Alofs et al., 2014; Sharma et al., 2008; 2007). There are several factors that could compound these impacts, including predator-prey mismatches, metabolism and growth rates of fish species, altered dissolved oxygen availability, and an increased incidence of disease, pathogens and invasive species (*see* Section 3.3; Collingsworth et al., 2017; Chu, 2015; McDermid et al., 2015b).

Changing lake dynamics and warming temperatures will increase the risk for the introduction of new species and the expansion of existing, invasive species (e.g., sea lamprey, zebra and quagga mussels, and phragmites), pathogens and diseases, as ranges shift northward (Wuebbles et al., 2019; Chu et al., 2015; McDermid et al., 2015b; Pagnucco et al., 2015). Coastal wetlands within the Basin have been labelled as some of the most vulnerable ecosystems to climate change in southern Ontario (*see* Section 3.3; Environment and Climate Change Canada, 2021; Chu, 2015; McDermid et al., 2015b).

3.4.2.2 Social and Economic Impacts

Climate change impacts cascade through social and economic systems within the Great Lakes Basin. They include impacts on ecosystem services (e.g., reduced soil erosion control, water purification); commercial and industrial activities (e.g., forestry, mining, shipping); agricultural productivity; tourism and recreation; infrastructure and assets, and disruptions to demand and delivery of natural resources (e.g., fisheries, energy production) (Brinker et al., 2018; Government of Ontario, 2016a; Bartolai et al., 2015; Chu, 2015; Abdel-Fattah and Krantzberg, 2014a, 2014b). Increased water level variability is projected to have significant economic implications for industry, shipping and navigation, hydroelectric generation, and agriculture and tourism (Wuebbles et al., 2019; Angel et al., 2018; Zamuda et al., 2018; Shlozberg et al., 2014).

Variable water levels and declining water quality stress and water treatment infrastructure. Some local water treatment systems in Ontario have reached capacity during extreme rainfall and flooding events, requiring the system to release untreated or inadequately treated water into the watershed (Wuebbles et al., 2019). These events have many social, health and economic implications for communities and ecosystems. Damage from extreme weather, including flood-related damage (e.g., water damage, erosion) can have physical and psychological impacts, affecting human health and well-being (Council of Canadian Academies, 2019; Hayes et al., 2019; Gough et al., 2016).

High water levels and lengthened ice-free periods in the Great Lakes Basin cause flooding and erosion that have resulted in significant property damage and economic costs (*see* Figure 3.11; IJC Great Lakes-St. Lawrence River Adaptive Management Committee, 2020; Zuzek, 2020; Moudrak et al., 2018).

Figure 3.11: Left: Eroding bluffs along Lake Erie at Wheatley Provincial Park in 2018. Right: August 27, 2019 flooding at Erie Shore Drive. Increased shoreline erosion and flood risk are attributed to changes in lake levels, ice cover and exposure to wave energy. Source: Zuzek, 2020.

Understanding of the cumulative and cascading impacts of climate change and other environmental stressors is limited (Wuebbles et al., 2019; Milner et al., 2018a). Cumulative impact assessments, which include social and economic components, are effective in examining how decisions related to land-use management and planning within the Great Lakes Basin interact with climate change (Milner et al., 2018a).

3.4.3 Resiliency and adaptation

Climate change presents new threats to the Great Lakes Basin, but opportunities for sustainable development and growth arise with effectively implemented adaptation measures. Adaptation planning and implementation have progressed across Ontario communities within the Basin over the past decade, with many different agencies, groups and partnerships participating (*see* Box 3.3). The governance of the Great Lakes is highly complex because of its transboundary, multi-jurisdictional nature. Over the years, various binational (e.g., International Joint Commission), national, provincial and state institutions and agencies have developed a number of initiatives and agreements to better protect and sustain the Great Lakes (e.g., the Great Lakes Water Quality Agreement; the Great Lakes and St. Lawrence Cities Initiative; the Great Lakes–St. Lawrence River Basin Sustainable Water Resources Agreement). Despite this, adaptation efforts across the Basin remain relatively piecemeal and fragmented, highlighting the recognized need for more coordinated and collaborative adaptation approaches amongst governing agencies (*see* Figure 3.12; International Joint Commission Great Lakes Water Quality Board, 2017; McDermid et al., 2015b).

Box 3.3: Mobilizing adaptation in the Great Lakes Basin

Adapting to climate change in the Great Lakes Basin requires transboundary leadership and coordination amongst all orders of government, organizations and agencies (International Joint Commission Great Lakes Water Quality Board, 2017).

The importance of adaptation is emphasized in Ontario's *Great Lakes Protection Act, 2015*, which states that the basin is "particularly vulnerable to the effects of climate change and, in the face of additional cumulative pressures such as development, population growth, loss and degradation of natural features, pollution and invasive species, three of Ontario's four Great Lakes are in decline" (Government of Ontario, 2015b). The Act calls for coordinated action, monitoring and reporting throughout the basin to identify impacts and improve provincial capacity to respond and to increase resiliency. The Act also mandates updating of Ontario's Great Lakes Strategy (Government of Ontario, 2016a) every six years to measure progress and identify knowledge gaps.

The Great Lakes and St. Lawrence Cities Initiative is an example of how local municipalities in Ontario, Quebec and several U.S. states are working together on pilot projects to advance local adaptation efforts and provide opportunities for building technical capacity (Great Lakes and St. Lawrence Cities Initiative, 2017). This binational initiative provides a platform to share climate data and adaptation resources (Great Lakes and St. Lawrence Cities Initiative, 2017).

In Ontario, Conservation Authorities (CAs) play an important role in implementing adaptation measures, and in monitoring and reporting on local conditions in their jurisdictions. With a mandate to support provincial and municipal responsibilities in resource management, CAs are key participants in provincial flood forecasting and in communicating flood warnings to local government and emergency responders. CAs also support municipalities to delineate natural hazards (e.g., floodplain mapping) as part of land-use planning. Several CAs are advancing the development, updating and implementation of natural infrastructure plans, shoreline erosion strategies, and stormwater management strategies that address climate change impacts for municipalities and others (Conservation Ontario, 2018). CAs across Ontario vary in size and capacity and, therefore, not all provide the same level of services to their municipalities and the province.

Shared Vision

- Common vision
- Clear call to immediate action
- Local and Indigenous engagement is critical
- Open declaration to be signed
- Message should be positive and inclusive

Coordinated Action

- A staffed, coordinated, binational network
- Collect, aggregate, and share science and best practices
- Framing documents to establish priorities
- Funding and capacity

Accountability

- Vulnerability assessment
- Baseline data
- Accountability will depend on the model used
- Adaptive management

Science / Info / Knowledge

- Aggregate and share research
- Incorporate traditional ecological knowledge
- Expand the Great Lakes Water Quality Board Annex 9 to include adaptation
- Legal tools needed
- Species and habitats at risk are a key knowledge gap

Implementation Considerations

- Shared vision is fundamental to implementation
- Sector specific implementation is needed
- Tools include: recognition, certification, and incentives
- Challenges include: adapting lessons learned across borders, coordinating across sectors and nations

Figure 3.12: Key elements of a binational approach to climate change adaptation and resilience, developed by the Great Lakes Water Quality Board. Source: International Joint Commission Great Lakes Water Quality Board, 2017.

Many conservation authorities, Indigenous communities, property owners, service providers and some regional and municipal governments in Ontario have adopted adaptive management principles in responding to climate impacts in the Great Lakes Basin (Conservation Ontario, 2018; Abdel-Fattah and Krantzberg, 2014a, 2014b; Andrey et al., 2014). Adaptive management involves continuous monitoring, evaluation and improvement of management plans, strategies and programs, and is designed to enhance resiliency in an ongoing fashion (*see* Water Resources chapter of the National Issues Report; Leger and Read, 2012; Gleeson et al., 2011). Examples of implemented adaptation measures in Ontario communities include the following: flexible fish harvest regulations (e.g., slot size limits, catch limits, season lengths) for species that are vulnerable to, or that benefit from, climate change; restoring banks and shorelines to reduce erosion and flood risks; and modifying municipal zoning and building codes to account for increased coastal flooding (Myers et al., 2017; Lenarduzzi, 2016; Moghal and Peddle, 2016; Abdel-Fattah and Krantzberg, 2014a; Huff and Thomas, 2014; Lemieux et al., 2014).

Many regional and sectoral vulnerability and risk assessments have been, and are being, completed across the basin to identify priority impacts and to begin planning and implementation of adaptive solutions (Perdeaux et al., 2018). While some of this work is driven by statutory and regulatory requirements (*see* Section 3.2.3), the number of climate change adaptation plans and strategies developed by local governments will increase as more communities experience the direct impacts of the changing climate (*see* Case Story 3.3). Even with these adaptation planning efforts, examples of adaptation implementation and evaluation remain limited (National Assessment Engagement sessions, 2019).

Case Story 3.3: Local adaptation in the Great Lakes Basin

Ontario communities within the Great Lakes Basin are increasingly experiencing impacts and risks associated with climate change. Coastal flooding, shoreline erosion and declining water quality have damaged public and private infrastructure and property, raised public health and safety concerns, decreased tourism and recreational opportunities, and caused productivity losses in local industries (e.g., shipping, agriculture, fisheries) (City of Thunder Bay, 2015; McDermid et al., 2015b; City of Kingston, 2014a; City of Windsor, 2012). Several municipalities have assessed local risks and vulnerabilities associated with climate change and identified adaptive solutions to minimize the impacts (*see* Figure 3.13; International Joint Commission Great Lakes Water Quality Board, 2017).

Thunder Bay, Windsor and Kingston (all members of the Great Lakes and St. Lawrence Cities Initiative) focused much of their adaptation efforts on planning and implementing low-impact development projects, conserving and restoring natural environments, and identifying areas of high vulnerability (*see* Figure 3.13; City of Thunder Bay, 2015; City of Kingston, 2014a; City of Windsor, 2012).

Figure 3.13: Three examples of low-impact development projects. a) Memorial Avenue biofiltration low-impact development in Thunder Bay. b) Green roof low-impact development on the Lou Romano Water Reclamation Plant in Windsor. c) Alwington Avenue bioswale project in Kingston. Sources: a) City of Thunder Bay, 2015; b) Courtesy of the City of Windsor; c) Courtesy of the City of Kingston.

The City of Thunder Bay's innovative Climate Adaptation Strategy (City of Thunder Bay, 2015) and associated Web portal have increased local communication and education on climate change. The City has moved forward with implementing measures to reduce local flood risk and improve the quality of stormwater runoff through various low-impact development projects, including a biofiltration facility. The City of Windsor, an early champion of adaptation, has promoted green roofs as a means to reduce risks associated with stormwater runoff and flooding, as well as heat events (City of Windsor, 2020). Since the release of their Climate Change Adaptation Plan, green roofs have been installed throughout the city on both private and municipal buildings. A recent study ranked the City of Kingston's Climate Action Plan (City of Kingston, 2014) as the top plan in Canada for effectively addressing both greenhouse gas emissions reduction and climate change adaptation (Guyadeen et al., 2019). Kingston has also begun investing in low-impact development projects to reduce climate risks. Projects include increasing usage of permeable pavement, implementing bioswale gardens, and increasing underground stormwater storage (City if Kingston, 2014). All three municipalities recognize the importance of adaptive management in their projects and have invested in monitoring performance over time (City of Thunder Bay, 2015; City of Kingston, 2014; City of Windsor, 2012).

As municipalities in the Great Lakes Basin continue to implement and monitor adaptation measures, governing agencies have highlighted the importance of sharing lessons learned between jurisdictions and increasing coordination across sectors and all orders of government (International Joint Commission Great Lakes Water Quality Board, 2017).

3.5 Adaptation improves forest health, carbon storage and biodiversity

Climate change impacts the composition, disturbance regimes, and timing of life cycle events in Ontario's forests and forested landscapes. Changes in drought, pests, and fire and wind regimes are of particular concern given the resulting cumulative impacts.

Impacts of climate change on Ontario forests include the northward spread of pests and diseases, and damage from extreme weather events, such as drought and wind. Earlier flowering or bud burst, lengthening of the growing season and changing forest composition have all been observed in Ontario's forested landscapes in response to increased temperatures. Overall, climate change has the potential to cause both direct and indirect (through enhanced proliferation of pests and disease) damage to Ontario's forests. Developing and implementing adaptation strategies, combined with supportive forest management policies and practices, help to reduce the vulnerability of Ontario's trees to climate change, while building a more resilient forest landscape. Sustaining a resilient forested landscape also creates benefits for carbon sequestration and storage, provides ecosystem services for a variety of plants and animals, and maintains habitat connectivity to accommodate species range shifts.

3.5.1 Introduction

Ontario's landscape is 66% forested and accounts for one fifth of Canada's forest area (Government of Ontario, 2021b). The area includes four broad forested regions: the Hudson Bay Lowlands in the North subregion, the boreal forest in North and Central subregions, the Great Lakes–St. Lawrence forest in the Central and South subregions, and the deciduous forest in the South subregion (*see* Figure 3.14; Government of Ontario, 2019a).

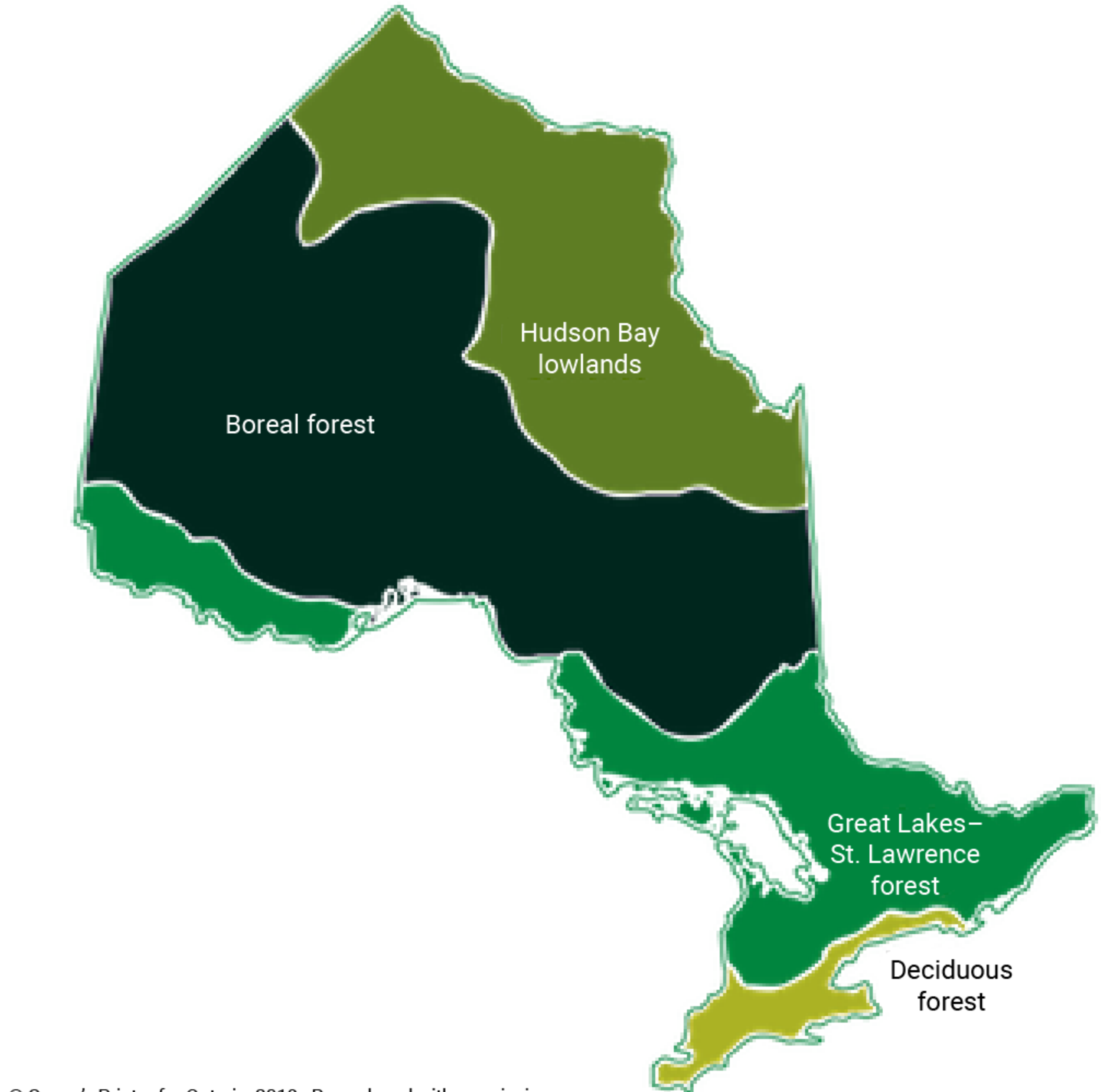


Figure 3.14: Forest regions in Ontario. Source: Government of Ontario, 2016b.

Ontario's forests support more than 147,000 direct and indirect jobs (Government of Ontario, 2020) and generated over $18.0 billion in total revenue in 2019 (Government of Ontario, 2020). Social and cultural benefits are harder to quantify, but Ontario's forests are a source of significant cultural, aesthetic and spiritual importance to Ontarians, especially to Indigenous Peoples (Natural Resources Canada, 2018). Recreational activities such as camping, hiking, berry picking and hunting are also supported by forests (Government of Ontario, 2020).

The unmanaged forests of the Northern subregion sequester significant amounts of carbon. Total carbon storage in this area is projected to increase by between 16.7% to 20.7% by the end of the century under all Shared Socio-economic Pathway scenarios (*see* Section 2.22 *in* Bush et al., 2022 for an explanation of these scenarios), but stands are heavily influenced by wildfire (Ter-Mikaelian et al., 2021). Carbon storage potential in managed forests in the province exceeds that of unmanaged forests, but both are heavily influenced by fire and other stressors (Ter-Mikaelian et al., 2021; Chen et al., 2018).

3.5.2 Impacts and vulnerabilities

Warmer winter temperatures have reduced the number of extreme cold days in Ontario, increasing the survival rate of forest pests, such as the emerald ash borer, forest tent caterpillar, spruce budworm and gypsy moth (Natural Resources Canada, 2019; Price et al., 2013; Candau and Fleming, 2011; Regniere et al., 2009). Warmer winters have also reduced resistance to cold and promoted earlier spring bud burst in boreal conifers, making them vulnerable to late spring frosts. For example, in northwestern Ontario in the spring of 2012, warm temperatures in March caused de-hardening, then were followed by freezing temperatures in April, resulting in a massive needle browning event, which affected more than 250,000 hectares of forest (*see* Figure 3.15; Rossi, 2015; Man et al., 2013). Recovery from browning may take several years, during which time the tree may be more susceptible to other stressors such as insects and disease (Man et al., 2013).

Figure 3.15: Aerial (left) and ground (right) views of damaged jack pine plantations near Upsala, Ontario, taken in May and June 2012. Source: Man et al., 2013.

Increasing summer temperatures accompanied by minimal increases in precipitation are projected to lead to drier conditions, more frequent drought and greater fuel loads (e.g., combustible organic matter) across the province, driving an increase in the frequency, intensity, extent, and timing and duration of forest fires (Wotton et al., 2017; Flannigan et al., 2016; Boulanger et al., 2014; Gauthier et al., 2014). The annual area burned from wildfires could double by the 2040s and increase eightfold by 2100, under a high-emissions scenario (Podur and Wotton, 2010). By the end of the century, the area burned by large fires (*see* Figure 3.16), the number of days where fire is likely to occur, and the number of days where fire intensities exceed suppression resources are all expected to increase significantly, creating challenges for wildfire management (Wotton et al., 2017; Gauthier et al., 2015). Wildfires have cascading impacts, affecting human health and well-being, and causing economic disruptions and losses (*see* Sector Impacts and Adaptation chapter of the National Issues Report; and the Natural Hazards chapter of the Health of Canadians in a Changing Climate). Fires can affect forestry operations and timber supply, while smoke from fires can taint the taste of agricultural crops such as grapes and berries, disrupt transportation and force evacuation of residents in proximal communities, notably Indigenous communities in the north of the province (*see* Figure 3.17). Forced evacuations by air from Indigenous communities without road access, such as those that occurred in Pikangikum, Deer Lake and Poplar Hill in 2021, are especially harmful to community members. Residents of Pikangikum were scattered between communities as far away as Cornwall, at a distance of 1,600 km, for almost one month (CBC News, 2021).

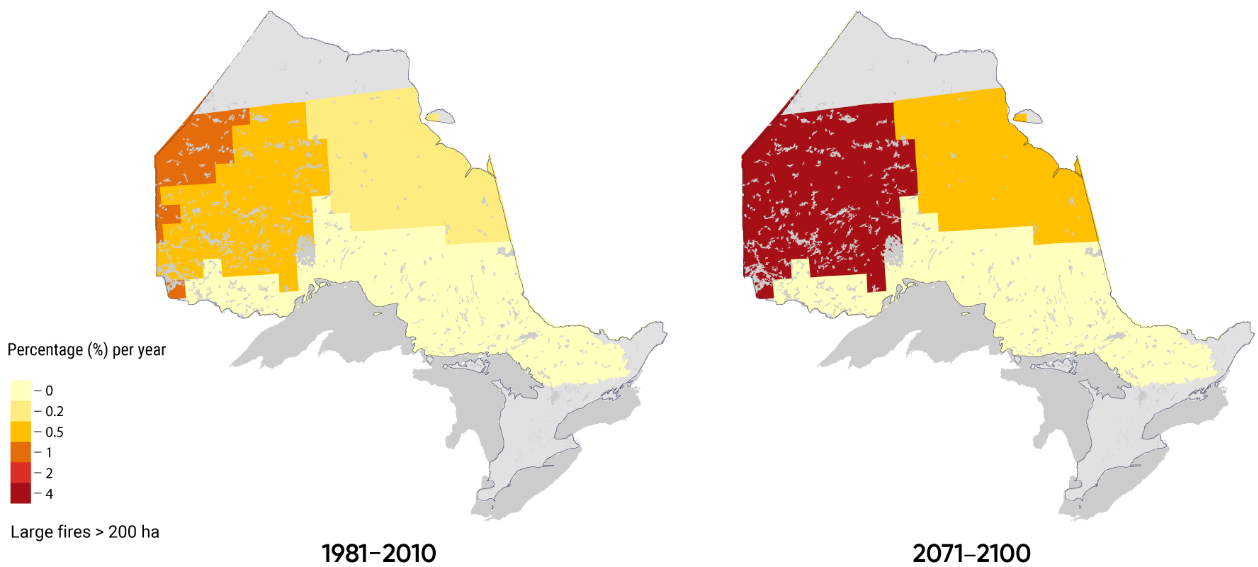


Figure 3.16: Mean annual area burned by large fires (fires larger than 200 ha) in Ontario from 1981 to 2010 (left) and projected mean annual area burned by large fires in Ontario near the end of the century (2071–2100) under a high-emissions scenario (RCP8.5) (right). Source: Boulanger et al., 2014

Figure 3.17: Glow and haze from wildfire during the evacuation of Pikangikum, July 10, 2021. Photo courtesy of Mandi Chan-Peters.

More frequent, severe and widespread outbreaks of pests and diseases are expected due to milder winter temperatures, with damage from pests increasing, particularly in the North and Central subregions of the province (Government of Ontario, 2019b; Candau et al., 2018; James et al., 2017; Pureswaran et al., 2015; Huff and Thomas, 2014; Regniere et al., 2009; Williamson et al., 2009). Damage to eastern spruce from budworm results in increased fire risk after defoliation, as breakage of dead tree tops and windthrow (trees uprooted or broken by wind) gradually build up an accumulation of "ladder fuels" that can lead to more forest fire ignitions, and allow the flames to extend higher into the forest canopy (James et al., 2017). Longer periods of moisture deficit driven by increased temperatures, lower seasonal precipitation and other factors, such as wind, will result in periods of decreased water availability, which also increase the risk of fire ignition (Candau et al., 2018; James et al., 2017).

Warming imposes constraints on the growth of several boreal species, including balsam fir and larch, which could restrict their survival by the end of the century under a high greenhouse gas emissions scenario (Yeung et al., 2019; Boulanger et al., 2017). Traits, such as sensitivity to drought-induced mortality and potential for migration failure, affect the vulnerability of tree species and populations to climate change (Aubin et al., 2018). For example, drought events in the southern part of the white spruce's range during the growing season in Ontario have exceeded the species' drought tolerance capacity, significantly increasing mortality and reducing growth rates (Sang et al., 2019). Projected temperature increases and the frequency and severity of the growing season drought will likely result in a gradual retraction of white spruce from its current southern range edge (Weng et al., 2019).

Resilient forests provide a range of ecosystem services to society (*see* Ecosystem Services chapter of the National Issues Report). The influence of climate change on forest disturbance regimes will have negative consequences for the provision of ecosystem services and carbon storage (Thom and Seidl, 2016). However, considering climate change projections and impacts in forest management planning will help to achieve management objectives, including biodiversity, productivity and carbon storage (Ontl et al., 2020).

At longer timescales, shifting climate envelopes will result in a general northward migration of tree species in Ontario, although the pace of climate change is likely to exceed the natural ability of forests to adapt (Brecka et al., 2018; Pedlar and McKenney, 2017; Janowiak et al., 2014; Huff and Thomas, 2014; Colombo, 2008). Some populations of northern conifers respond negatively to temperature increases and are expected to decline at the southern edge of their range, decreasing their dominance in the population by up to 30% (Candau et al., 2018; Pedlar and McKenney, 2017; Janowiak et al., 2014; Thomson et al., 2010).

3.5.3 Resiliency and adaptation

Initiatives to enhance the climate resilience of forests and forested landscapes are being undertaken at regional and local scales, and involve a wide range of actions. At the provincial level, the 2017 Ontario Ministry of Natural Resources and Forestry climate adaptation strategy includes forest-specific actions such as the following: 1) reviewing tree seed and nursery stock transfer policies to ensure that they are based on the best available science; 2) exploring opportunities to improve provincial monitoring programs to take stock of climate change impacts; and 3) improving knowledge about specific tree species and habitats known to be vulnerable to climate change (Ontario Ministry of Natural Resources and Forestry, 2017b).

In 2018, the Lake Simcoe Region Conservation Authority completed a comprehensive study of the impacts of climate change on tree planting and forest management, and identified ways that local programs might adapt (Lake Simcoe Region Conservation Authority, 2018). Their list of adaptation options included the following examples: 1) increasing the genetic and structural diversity of planted stock; 2) preparing for earlier planting time frames; 3) increasing post-planting tending activities; and 4) selecting climate-appropriate tree species (Lake Simcoe Region Conservation Authority, 2018).

Climate change adaptation to increase forest resilience can also help to achieve carbon storage objectives. A range of options has been documented that can help manage climate change risks on forested landscapes (Edwards et al., 2015). Some forest management measures that support ecosystem services and overall forest health also promote carbon storage (Swanston et al., 2016). The Practitioners Menu of Adaptation Strategies and Approaches for Forest Carbon Management provides a suite of 31 approaches using seven different strategies that provide broad responses to climate change (Ontl et al., 2020).

A key challenge for forest adaptation is addressing the fact that the pace of climate change is likely to exceed the natural ability of forests to adapt (*see* Section 3.5.2). Many jurisdictions across Canada are examining the potential value of assisted migration, i.e., human interventions to deliberately relocate species to new, more climate-suitable locations (Edwards, 2015; Eskelin et al., 2011). Since 2010, six assisted migration trials have been implemented in Ontario to compare locally sourced and more southern-sourced seeds (Forests Ontario, 2018). The movement of tree seeds beyond their current seed transfer zones requires approval from the Ontario Ministry of Natural Resources and Forestry (Ontario Ministry of Natural Resources and Forestry, 2017a). The Ministry is using SeedWhere to inform updates to the Ontario Tree Seed Transfer Policy (*see* Box 3.4; McKenney et al., 2009).

Box 3.4: SeedWhere – A climate matching tool for assisted migration

SeedWhere is a simple tool developed to assist in making seed transfer decisions for forest regeneration or other ecological restoration activities (McKenney et al., 2009; 1999). The tool identifies locations whose climate is similar to a point of interest and then uses two methods (the Gower metric and the Universal Response Function approach) to calculate climate similarity. SeedWhere can be used with any number of climate variables and was developed to incorporate climate changes. The tool can be used for both seed procurement and deployment (*see* Figure 3.18; Van Bogaert and Lorente, 2017).

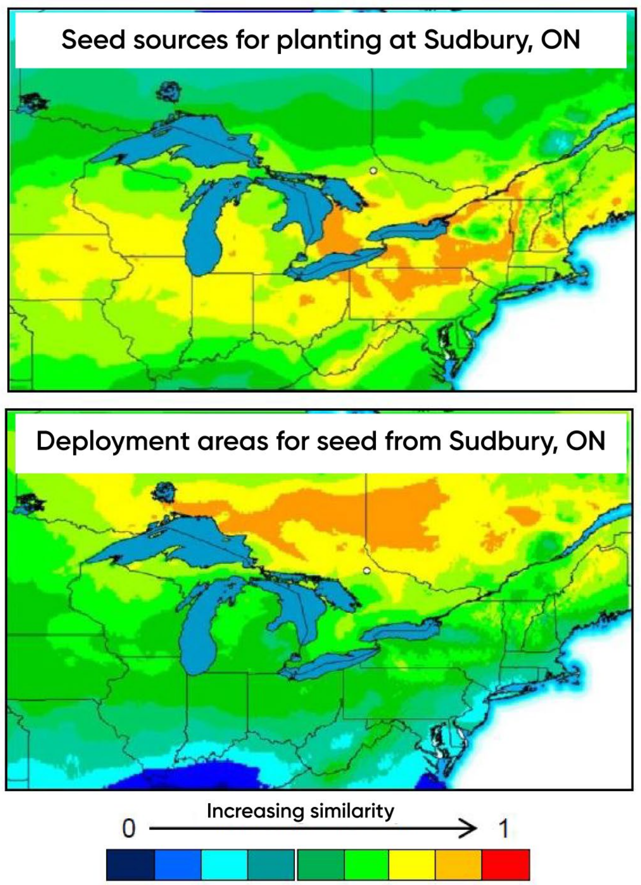


Figure 3.18: Sample output of SeedWhere, showing seed procurement and deployment for seeds in Sudbury, Ontario. Source: Van Bogaert and Lorente, 2017; “Seed sources for planting at Sudbury, ON” and “Deployment areas for seed from Sudbury, ON”, Canadian Forest Service, reproduced with the permission of the Department of Natural Resources Canada.

A range of actions has been documented to help improve forest resilience in the context of changing climate (*see* Table 3.4). These adaptive strategies will improve forest health for recovery and enable a transition to new stand structure (Sang et al., 2019).

Table 3.4: Examples of adaptation options for forests and forested landscapes

THEME	ADAPTATION OPTION	SOURCE
Assisted Migration/Seed Sources	Using seeds, germplasm and other genetic material from across a greater geographic range. This may entail importing seedlings from farther away that are better adapted to current/future climate conditions.	Swanston et al., 2012
Fire	Using prescribed burning or other fuel treatments to reduce fire risk, reduce forest vulnerability to insect outbreaks and prepare forest stands for regeneration.	Swanston et al., 2012; Gauthier et al., 2014; Huff and Thomas, 2014
Forest Management Planning	Developing flexible forest management policies, plans and practices capable of responding to changes.	Gauthier et al., 2014
Habitat Connectivity	Establishing or restoring forest cover along natural features, such as rivers or property lines, which may improve species' ability to naturally adapt and migrate.	Johnston et al., 2010; Swanston et al., 2012; Gauthier et al., 2014
Harvesting	Harvesting forests that are most vulnerable to disturbance (e.g., insect outbreaks) or general decline before they reach their otherwise optimal rotation age, which allows better adapted species or populations to move in.	Gauthier et al., 2014; Huff and Thomas, 2014
Monitoring	Evaluating the adequacy of existing environmental and biological monitoring networks for tracking the impacts of climate change on forest ecosystems, identifying inadequacies and gaps in these networks, and identifying options to address them.	Gauthier et al., 2014

THEME	ADAPTATION OPTION	SOURCE
Pests/Diseases	Increasing preparedness for insect and pest management, improving pest monitoring and maintaining or improving the ability of forests to resist the spread of pests and pathogens.	Johnston et al., 2010; Huff and Thomas, 2014
Wind	Varying the shape and size of clearcuts and leaving patches or stream buffers to reduce vulnerability to potential for increased windthrow disturbance.	Gauthier et al., 2014
Species Diversity	Active management of understory regeneration to help forests make the transition to new and better adapted compositions more quickly by reducing competition from undesirable, poorly adapted or invasive species.	Swanston et al., 2012
Education/ Communication	Engaging members of the public in a dialogue on forest values and management under a changing climate, and involving them in an assessment of forest management adaptation options.	Johnston et al., 2010; Gauthier et al., 2014

Knowledge of the rate, magnitude and location of changes in forest composition and distribution remains highly uncertain (Candau et al., 2018). Adaptation in forests is further complicated by the long timelines involved, as forest management decisions made today will have effects far into the future (Lemmen et al., 2014). It is also important that adaptation objectives align with other objectives, such as biodiversity and species-at-risk. Ultimately, a comprehensive and integrated systems approach that accounts for the full range of climate impacts and the interactions between them will best improve understanding of tree vulnerability to climate change and how to support the adaptation of trees (Johnson, 2009). Collaborative initiatives, such as the Forestry Adaptation Community of Practice (*see* Box 3.5), are helpful in this regard.

Box 3.5: Forestry Adaptation Community of Practice

The Forestry Adaptation Community of Practice (FACoP) is an online platform dedicated to advancing adaptation in Canada's forestry sector. The platform allows industry members, researchers, policymakers and others involved in Canadian forestry and climate change adaptation to share information and best practices. The FACoP features recent papers/articles on climate change and forests, upcoming forestry-related events, an online library with hundreds of resources, discussion forums with member-driven topics, recordings of webinars featuring a variety of forestry and climate change experts, and more. Membership in the FACoP is free.

3.6 Climate change brings threats and opportunities to Ontario agriculture and food systems

Longer growing seasons and warmer average temperatures will benefit the agriculture sector in some parts of Ontario. However, projected reductions in summer rainfall along with more severe heatwaves, higher frequency of precipitation extremes, and increased risks from pests and diseases threaten farm operations, as well as supporting activities, such as food processing and distribution. Increased capacity and adaptation across the sector would permit the seizing of opportunities and management of risks posed by climate change.

Warmer average temperatures and longer growing seasons present opportunities for agriculture in Ontario, including the expansion of production in some regions and increased potential for specialty crops. These benefits could be offset, and potentially overwhelmed, by negative impacts associated with extreme precipitation and increased drought, resulting in increases in soil erosion, moisture stress, crop damage and livestock fatalities. Resulting risks are increased by vulnerabilities in the food processing, distribution and retail systems that are dependent on critical infrastructure. Disruptions in supply chains caused by extreme weather events cascade through the broader supply chain, often impacting vulnerable populations with pre-existing food security and access challenges. Traditional mechanisms to deal with climate impacts, such as crop insurance, may not be sustainable, highlighting the need for accelerated action on adaptation. Achieving the full potential of resilience measures requires investments in areas such as infrastructure and labour, in addition to supportive policy in areas of agriculture, water management and land use.

3.6.1 Introduction

Agri-food is a multi-faceted sector that is inextricably linked to other economic sectors and is co-dependent on infrastructure components, such as electricity, transportation and telecommunications (*see* Sector Impacts and Adaptation chapter of the National Issues Report). According to the 2016 census, Ontario's agricultural sector employed over 800,000 people (approximately 11.5% of provincial employment) and contributed $39.5 billion to the provincial economy (OMAFRA, 2016). Ontario is also Canada's top agri-food exporting province (OMAFRA, 2016).

The province's prime agricultural lands are located mostly in the South subregion and provide current and future opportunities for agriculture. Farm-level agriculture is enshrined in the social fabric of rural communities throughout this subregion. Smaller, but potentially important areas for agriculture are found in the Central subregion, particularly the Great Clay Belt (Cochrane district), Manitoulin Island, Kenora, Rainy River, Dryden and Thunder Bay districts. Further expansion of growing areas in Ontario is possible with ongoing climate change (Robinson et al., 2020; Morand et al., 2017c).

The vulnerability of agricultural systems to climate change depends largely on the characteristics of local farming systems and the specific crops that are grown. Farmers frequently implement adaptive measures and seek new technologies in order to better manage on-site weather and climate risks (Holland and Smit, 2014). These measures often involve the use of crop-specific, commodity-specific and region-specific responses and tools to improve the productivity of farming operations, including cultivar selection, adjusting the timing of cropping operations, fertilizer and pesticide application, crop rotation, tillage practices, tile drainage and irrigation optimization (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021a; Ontario Cover Crops Steering Committee, 2017; Council of Canadian Academies, 2013).

3.6.2 Impacts and vulnerabilities

Observed increases in seasonal and annual temperatures in parts of Ontario are reflected by changes in agroclimatic indices, which show increases in average growing season length, the number of growing degree days (GDDs) and rates of average evapotranspiration (Bootsma, 2012; 2011). Continued warming and increases in accumulated crop heat units (CHUs: a temperature-based index used to determine growth potential of corn) will support new crop establishment and/or range expansion into other parts of the province, including in more northerly regions where water availability and soil conditions are suitable (Qian et al., 2012). For example, in the Great Clay Belt region, where just over 18% of the 1.8 million ha of prime agricultural land is currently used in agricultural production, growing season length is projected to increase from 160 days in the 2020s to over 180 days in the 2050s under a high-emissions scenario (Robinson et al., 2020; Morand et al., 2017b). However, such benefits of climate change may be offset, or potentially overwhelmed, by a range of negative impacts, including the increased frequency and intensity of extreme weather events, which can lead to enhanced soil erosion, increased moisture stress, crop damage and an increase in livestock fatalities (Motha and Baier, 2005). The rapid rate of climate change, particularly changes in extreme temperature and precipitation events, may challenge adaptation efforts (Kulshreshtha et al., 2010; Wall et al., 2007).

A wide range of climatic and non-climatic factors influences crop growth and yield. While key factors, including geographic location, soil type, weather patterns and extreme events, are outside the control of producers, responses such as the choice of cultivars, tillage, irrigation and fertilization practices and timing of major operations provide opportunities to improve yield in any given year (Morand et al., 2017c; Brklacich and Woodrow, 2016; Holland and Smit, 2013).

A large number of studies have examined how climate risks to crops and commodities could affect future productivity. These include impacts on maize (Qian et al., 2019; He et al., 2018; Morand et al., 2017a; Zaytseva, 2016; Gaudin et al., 2015), soy (He et al., 2018; Jing et al., 2017; Zaytseva, 2016), wheat (Qian et al., 2019; He et al., 2018), canola (Qian et al., 2019; Qian et al., 2018; Wu et al., 2018), grapes (Hewer and Gough, 2019; Shaw, 2017; Holland and Smit, 2014) and maple syrup (Sugar Maple) (Brown et al., 2015; Richardson, 2015). Dynamic crop models are often used to quantify climate change impacts on crop yields (*see* Table 3.5), enabling more focused impact assessments (Luo, 2011). Differences and biases in crop models, as well as the climate scenarios and downscaling methods used, create uncertainties in projected crop yield changes (Li et al., 2018). The use of multi-model ensembles reduces biases present in individual models and is recommended in assessments (Qian et al., 2020).

Table 3.5: Estimates of annual yield change under climate change for specific crops in Ontario

CROP	ANNUAL YIELD CHANGE	CLIMATE CHANGE MODEL AND SCENARIO	TIME FRAME	REFERENCE
Maize	+9–12%	CanRCM4 – RCP 4.5	2071–2100	He et al., 2018
	+13–17%	CanRCM4 – RCP 8.5	2071–2100	
	+41%	Multi-model ensemble – CANGRD – RCP 8.5	2041–2070	Morand et al., 2017a
Soybean	N/C	CanRCM4 – RCP 4.5	2071–2100	He et al., 2018
	N/C	CanRCM4 – RCP 8.5	2071–2100	
Winter Wheat	-15–16%	CanRCM4 – RCP 4.5	2071–2100	He et al., 2018
	-32%	CanRCM4 – RCP 8.5	2071–2100	
Canola	-21%	CanRCM4 – RCP 4.5	2041–2070	Qian et al., 2018
	-33%	CanRCM4 – RCP 8.5	2041–2070	
	-27%	CanRCM4 – RCP 4.5	2071–2100	
	-50%	CanRCM4 – RCP 8.5	2071–2100	

Notes: CanRCM4 is the Canadian Regional Climate Model large ensemble (Environment and Climate Change Canada, 2020). RCP 4.5 is a moderate emissions scenario, and RCP 8.5 is a high-emissions scenario.

Feed and pasture forage for livestock represents 10% of Ontario's agricultural production (Ontario Ministry of Agriculture, Food and Rural Affairs, 2016). Forage production, particularly in northern locations, is constrained by growing season length and the resulting number of harvests. Projected increases in forage yield will provide benefits to livestock farming (Payant et al., 2021; Thivierge et al., 2017) along with agricultural expansion opportunities in northern regions (Chapagain, 2017). Livestock are also negatively affected by exposure to extreme or prolonged heat (Smith and Eastwood, 2017; Bishop-Williams et al., 2015), and other weather-related factors including wildfire (Schultz and Lishman 2018), extreme cold (Tarr, 2015; Richardson, 2003) and extreme precipitation (Cheng et al., 2022; Rojas-Downing, 2017).

Climate change will lead to increased movement and establishment of invasive alien species, including pests, disease and competing plants, which will threaten agricultural production (*see* section 7.4 of the Sector Impacts and Adaptation chapter of the National Issues Report; International Plant Protection Convention Secretariat, 2021). Increased annual temperatures allow pests to expand the northern bounds of their range, while warmer winters allow proliferation of certain pests (Baute, 2020; Taylor et al., 2018). As climate envelopes shift northward to create or expand suitable temperature conditions, the southernmost areas of Ontario stand to be the first to experience new invasive alien species, particularly in areas where their movement may be facilitated by transportation across the international border. Earlier and longer growing seasons may provide a more abundant food source for pests and, in some cases, may warrant additional application of management techniques, such as herbicides or pesticides (Baute, 2020; Taylor et al., 2018).

Aspects of food processing, distribution and retail that complement primary agricultural production and that are dependent on buildings, transportation, electricity, telecommunications and fuel supply also face exposure to climate risks. Disruptions caused by extreme weather events cascade through the broader supply system and highlight the need for adaptation at many levels and by many actors (Toronto Medical Officer of Health, 2018; Zeuli et al., 2018). In many cases, impacts to the food supply chain cascade down to vulnerable populations with pre-existing food security and access challenges (Mbow et al., 2019; C40 Cities, 2018). A systematic review of food system vulnerability was commissioned by Toronto Public Health to identify risks to the food supply chain and impacts on public health, specifically for vulnerable populations. While concluding that Toronto's food system is relatively resilient to climate change, six main vulnerabilities were identified, along with recommendations to improve climate resilience (*see* Table 3.6; Zeuli et al., 2018).

Table 3.6: Vulnerabilities and adaptation options in the food supply chain of Toronto and surrounding areas

MAIN AREA OF VULNERABILITY	POSSIBLE ADAPTATION OPTIONS
Flood risk	Business continuity planning; forms of insurance; improved awareness of the potential for flood risk
Electricity, road network and fuel infrastructure	Backup power generation capacity; planned alternate routes; disaster support hubs
The Ontario Food Terminal	Power supply redundancy
Food access in inner suburban neighbourhoods	Business continuity planning; forms of insurance; backup power generation; local community food resilience action plans; food emergency response plans
Food insecurity and the food assistance network	Addressing of underlying issues that lead to food insecurity

MAIN AREA OF VULNERABILITY	POSSIBLE ADAPTATION OPTIONS
Coordination, collaboration, planning and preparedness	Defined roles for coordination oversight; promotion of emergency planning guidance

Source: Adapted from Zeuli et al., 2018.

3.6.3 Resiliency and adaptation

Principles for building climate resilience apply to the province broadly, with several province-wide programs serving to enhance climate change education, engagement and capacity support for the agriculture sector as a whole (Morand et al., 2017c). Programs such as the Canadian Agricultural Partnership (Agriculture and Agri-Food Canada, 2021), the Canada-Ontario Environmental Farm Plan (Ontario Ministry of Agriculture, Food and Rural Affairs, 2021b), and business risk management programs, delivered by the provincial agency Agricorp, provide access to clean technology funding, as well as mechanisms for promoting climate change adaptation and increased adoption of best management practices for soil health, water quality and other ecosystem goods and services.

Specific adaptation options are usually dependent on local-scale circumstances, and include actions such as diversifying crops, introducing different crop rotations, managing water on-site, and adjusting the timing of seeding (Qian et al., 2018; Morand et al., 2017a; Gaudin et al., 2015). Tender fruit growers use wind machines or frost fans to protect fruit against early spring frost, and hail nets and hail cannons to protect against hail storms (Ontario Apple Growers, 2018). Tender fruit, grain and oilseed growers are selecting new cultivars better suited to projected climate conditions (Hewer and Gough, 2018; He et al., 2017; Shaw, 2017; Holland and Smit, 2014). Understanding specific vulnerabilities and options to enhance climate resilience can be assisted by decision-support tools (*see* Case Story 3.4).

Case Story 3.4: Understanding and addressing agroclimatic risks and opportunities

The Ontario Climate and Agriculture Assessment Framework (Morand et al., 2017c) is a spatially explicit decision-support tool that assesses baseline and future agro-climatic risks and opportunities. It uses global climate model output to understand future crop suitability, as measured in growing degree days (GDDs), crop heat units (CHUs), potential evaporation and yield. It also gives a land suitability rating score under the influence of climate change, building on the Land Suitability Rating System developed by Agriculture and Agri-Food Canada (Agronomic Interpretations Working Group, 1995). The initial design of the OCAAF was tested and refined through application to two areas and production systems: forage-based beef production in Ontario's Great Clay Belt (looking specifically at timothy hay) and corn production in southwestern Ontario.

In both areas, climate change was found to bring opportunities to the agricultural sector through longer growing seasons, increasing growing degree days and crop heat units, and increased crop yields (*see* Table 3.7). However, climate change also presents risks that will require effective adaptation. For example, between the months of May and September in southwestern Ontario, the region is projected to see a 16% increase in potential evaporation, increasing moisture stress. Increased spring precipitation, high-intensity rainstorms and rain-on-snow events will increase risks of excess soil moisture in the Great Clay Belt, where soil drainage is already poor.

Table 3.7: Summary of changes projected by 2050 under a high-emissions scenario (RCP 8.5) for two regions of Ontario using the Ontario Climate and Agriculture Assessment Framework

	TIMOTHY HAY IN THE GREAT CLAY BELT	CORN IN SOUTHWESTERN ONTARIO
Temperature	Annual: +2.9°C Winter: +4.7°C Spring: +3.2°C Summer: +3.2°C Autumn: +3.3°C	Annual: +3.3°C Winter: +3.6°C Spring: +2.8°C Summer: +3.2°C Autumn: +3.1°C
Precipitation	Annual: +9% Winter: +19% Spring: +15% Summer: +1% Autumn: +7%	Annual: +6% Winter: +13% Spring: +13% Summer: no change Autumn: +3%
Growing season length	+50 days	+28 days
Growing Degree Days (GDD) 5* and Crop Heat Units (CHU)	GDD = +566 (40% increase)	CHU = +390 (25% increase)

	TIMOTHY HAY IN THE GREAT CLAY BELT	CORN IN SOUTHWESTERN ONTARIO
Land Suitability Rating System** scores	Shift from Class 5 (very severe limitations) to Class 3 (moderate limitations)	Shift from Class 1 (no limitations) to Class 2 (slight limitations)
Yield (kg/ha)	+2,160 (30% increase)	+3,300 (41% increase)

* GDD5 is a measure of the accumulation of days where the daily mean temperature is above 5 degrees Celsius.

** Land Suitability Rating System is a procedure for rating the suitability of land for agricultural spring-seeded small grains (and hardy oilseeds).

Source: Morand et al., 2017b.

Adaptation and policy options were developed for each region and production system, providing guidance on how to reduce climate risks and seize opportunities. For example, in southwestern Ontario, subsurface drip irrigation could help manage water at the farm level and reduce fluctuations in moisture availability. To capitalize on the improving growing conditions in the Great Clay Belt, incentives could be developed to attract new beef farmers to the area, with the goal of expanding the industry and strengthening food security in northern Ontario (Morand et al., 2017c).

The presence of mechanisms to support, enable or encourage adaptation does not necessarily result in uptake. In the absence of increased adaptation, traditional mechanisms such as agri-insurance programs may experience deficits and require additional investment by government to ensure their sustainability over time (Auditor General of Ontario, 2017). Efforts to adapt to climate change are frequently driven by economic opportunities, such as the expansion of grape production for wine, or land-use changes for the expansion of beef farming (Hewer and Gough, 2019; Morand et al., 2017b; Shaw, 2017; Beef Farmers of Ontario, 2014; Holland and Smit, 2014). Recognizing the full potential of these efforts requires investments in areas such as infrastructure and labour, as well as supportive policy in areas of land use, water and agriculture (Chapagain, 2017; Morand et al., 2017b; Barbeau et al., 2015).

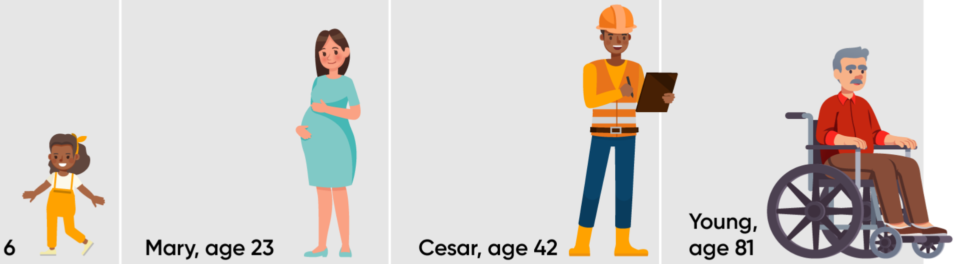
3.7 Existing human health inequities will be worsened by climate change

Many non-climate factors, including income, housing quality and employment, play key roles in determining the vulnerability of communities and individuals to the health risks of climate change. Marginalized and low socio-economic populations will experience disproportionate health impacts and will have increasing difficulty in coping and adapting. Regional and local assessments of climate change vulnerability that include consideration of health equity provide a foundation for stronger and more widespread adaptation action.

Determinants of human health include many interrelated social and demographic factors, such as income level, education, literacy, social status, gender, race and culture at the scale of individuals or communities. Priority populations for adaptation are groups of people with increased risk of poor health outcomes, and those who can benefit from public health interventions. Marginalized populations are disproportionately vulnerable to climate-related changes. Local or regional climate change vulnerability and adaptation assessments that include consideration of equity can help target short- and long-term adaptation interventions. Assessments completed for many areas of the province are leading to greater efforts to monitor changing risks, provide appropriate education and outreach to the public, and implement measures to improve climate change resilience. Actions to address the underlying social determinants of health are critical for decreasing social disparities and population vulnerability, as well as advancing adaptation.

3.7.1 Introduction

Climate change increases existing threats to population health and compounds existing pressures on key factors such as water quality, food security and shelter (*see* Health of Canadians in a Changing Climate; Decent and Feltmate, 2018; Watts et al., 2018; Zeuli et al., 2018; Gough et al., 2016; Berry et al., 2014b). Vulnerable and marginalized populations, including those with existing social and health inequities, existing or underlying health issues, or economic disparities, face a disproportionally larger burden from the impacts of climate change (*see* Figure 3.19; Expert Panel on Climate Change Adaptation and Resilience Results, 2018; Berry et al., 2014b).



Legend
- Risk factor (red)
- Protective factor (blue)

		Sasha, age 6	Mary, age 23	Cesar, age 42	Young, age 81
KEY HEALTH RISK		Asthma attack from pollution	Birth complications	Death from heatstroke	Heat-related heart failure
VULNERABILITY CATEGORY	SUSCEPTIBILITY	• Child • Asthma • Otherwise healthy	• Young adult • Pregnant • Healthy	• Middle age • High blood pressure • Medication increases heat sensitivity	• Older age • Heart condition • Medication increases heat sensitivity
	EXPOSURE	• Lives near sources of air pollution • Air pollution worsened by heat	• Apartment with poor insulation • Subway to work doesn't have A/C • A/C at work	• Works outside in the sun • No A/C at home	• Room on top floor • Poor A/C in nursing home
	ABILITY TO ADAPT	• Middle class • Good family support	• Poor • Lack of social support	• Undocumented immigrant • Good social support • Health insurance	• Middle class • Limited mobility
HEALTH OUTCOME		Visits emergency department for an asthma attack	Struggles to protect herself from heat but delivers a healthy baby	Develops heatstroke and nearly dies	Long hospitalization for heart failure
ADAPTATION ACTION		Real-time air quality surveillance program sends warnings to vulnerable residents when pollution levels are high	Doctor is further educated on how heat impacts clinical practice and proactively counsels on heat risk throughout pregnancy	Health officials institute new heat safety regulations to protect outdoor workers	Nursing home implements a heat emergency protocol to protect patients and invests in A/C improvements

Figure 3.19: Health vulnerabilities for different populations experiencing a heat wave. Source: Adapted from Salas et al., 2019.

Extreme weather has significant impacts on human health (Decent and Feltmate, 2018; Rajaram et al., 2016). These include direct impacts to health and safety, for example from heat events (e.g., heat stress), wildfires (e.g., loss of trees, homes, impacts on people), extreme wind (e.g., injuries from flying debris), and from heavy rainfall causing flooding (e.g., drowning) as well as indirect impacts (e.g., illness from poor water quality or exposure to mold, psychosocial trauma) (*see* Figure 3.20; Council of Canadian Academies, 2019; Gough et al., 2016; Paterson et al., 2012). The impacts of extreme weather events on mental health include incidences of post-traumatic stress disorder, depression, anxiety and grief (*see* Figure 3.21; Hayes et al., 2019; Hayes et al., 2018). The threat of climate change itself can lead to emotional distress, including "ecoanxiety," "ecoparalysis" and "solastalgia," which refers to the distress and isolation resulting from the transformation and degradation of one's home environment (Galway et al., 2019; Hayes et al., 2018; Albrecht et al., 2007).

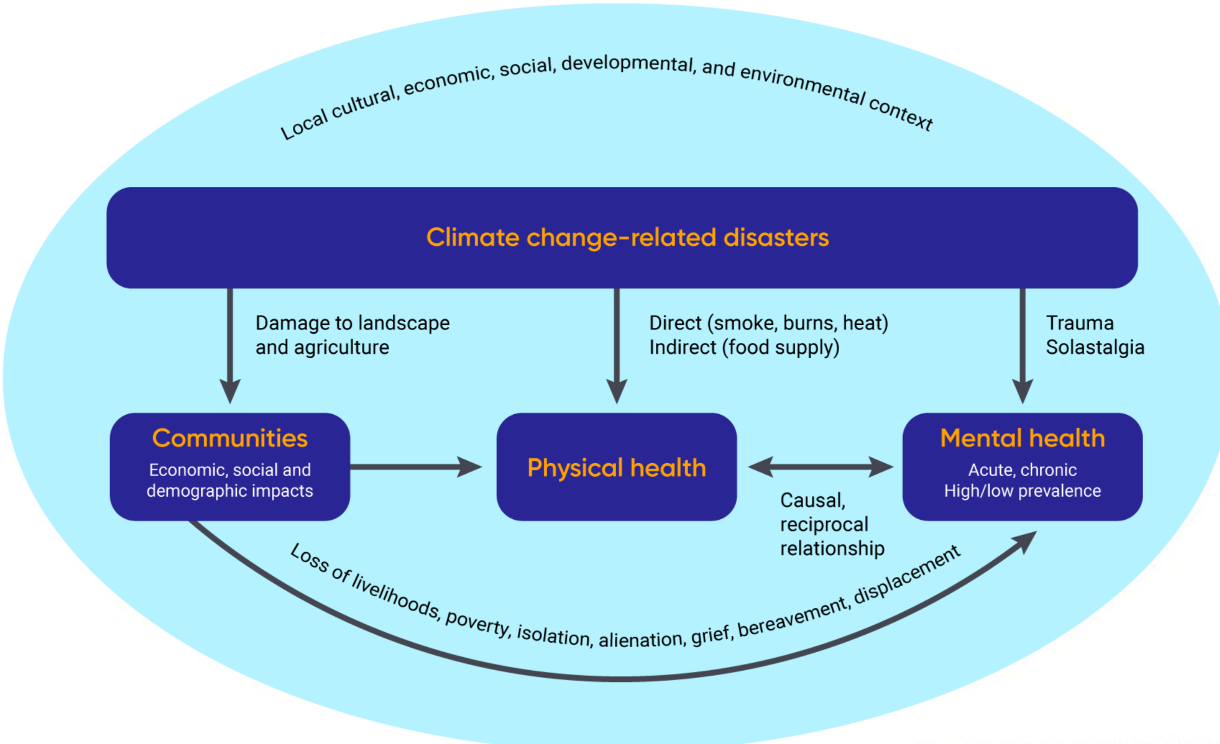


Figure 3.20: Linkages between climate change-related disasters and human health impacts. Source: Council of Canadian Academies, 2019.

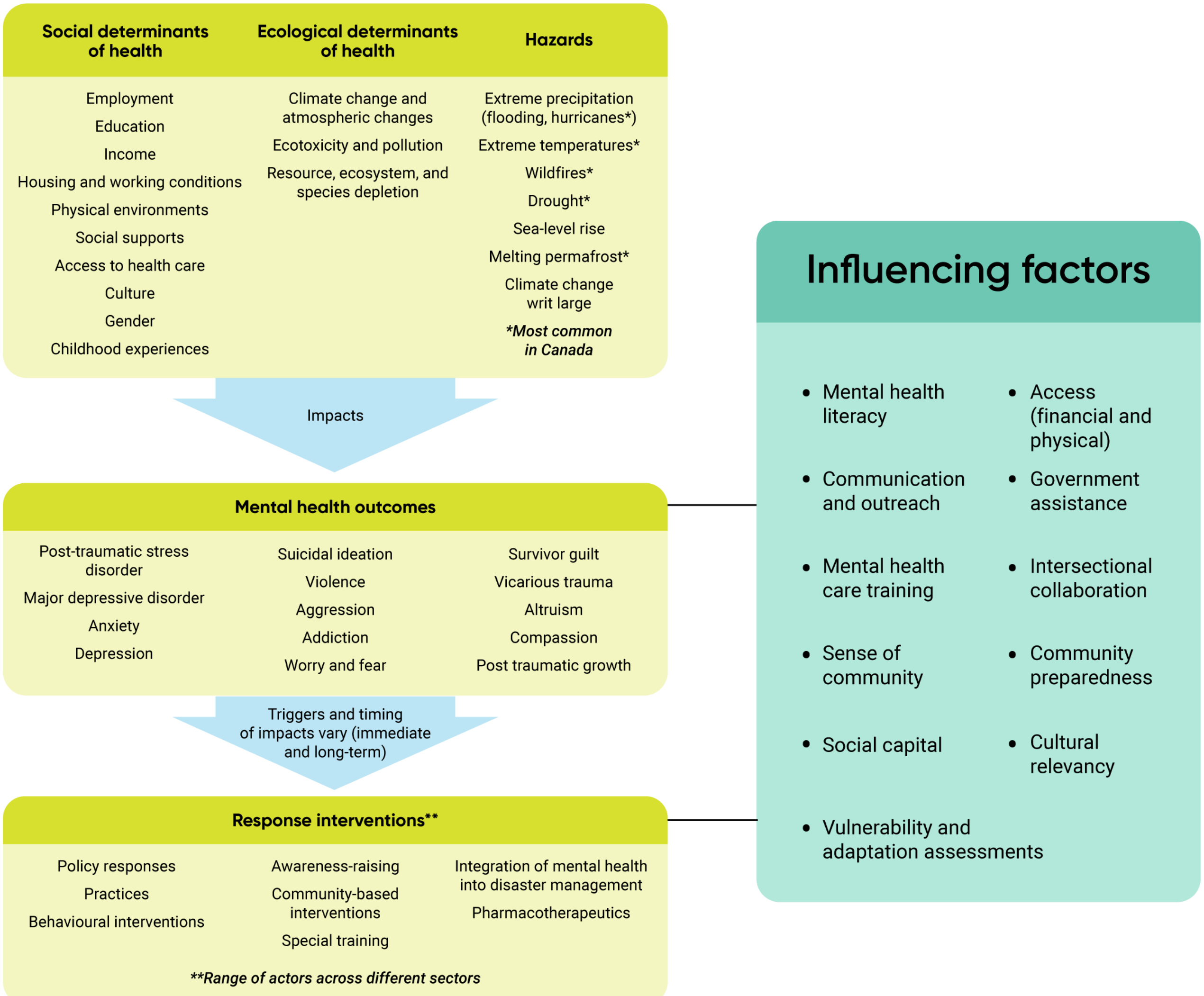


Figure 3.21: Factors influencing the psychosocial health impacts of climate change. Source: Hayes et al., 2019.

3.7.2 Impacts and vulnerabilities

Extreme heat

Extreme heat events are projected to continue to increase with climate change (Zhang et al., 2019), leading to increased risk of heat-related illness and excess deaths (Chen et al., 2016; Gough et al., 2016; Margolis, 2013). By 2100, under a high-emissions scenario, Ontario would see 38 (*28.1–44.5*) more hot days each year, while under a low-emissions scenario there would be 4.7 (*2.8–6.8*) (Zhang et al., 2019). Extreme high temperatures are associated with increased rates of hospitalization for coronary heart disease and stroke (Bai et al., 2018), diabetes (Bai et al., 2016), increased respiratory related deaths (Chen et al., 2016), and more emergency room visits for mental and behavioural illness in Toronto (Wang et al., 2014). Ontario public health officials ranked extreme heat as their biggest concern among climate change impacts (Paterson et al., 2012). Heat warnings are triggered by regional (northern, southern and extreme southwestern) data on temperature intensity and duration, and also include humidity thresholds (Ontario Ministry of Health and Long Term Care, 2016). During a baseline period from 1971 to 2000, the frequency of a heat event (three consecutive days of maximum temperature greater than 32°C– Ontario Ministry of Labour) in all Public Health Units (PHUs) was less than one per year. By 2050, the vast majority of PHUs (28 out of 36) will experience at least one heat event annually and, by the 2080s, 33 out of 36 PHUs will see more than one extreme heat event per year (Gough et al., 2016). Windsor-Essex has noted a relationship between extreme temperature-related illnesses and increasing emergency department visits as the number of record heat days increases (Windsor-Essex County Health Unit, 2019).

Heat levels are intensified in urban centres where extensive concrete and paved surfaces produce an Urban Heat Island effect (Mohsin and Gough, 2012; Gough et al., 2001). In the absence of expanded adaptation, increased temperature extremes will lead to greater risk of heat-related illness and mortality, particularly among vulnerable populations, such as the elderly, young children, physically disabled, those living alone and those who work outdoors (Bai et al., 2018; 2016; Guo et al., 2018; McDonald et al., 2016). Projections of extreme heat in Ontario show significant increases in high temperatures over the current century (*see* Table 3.8; Canadian Centre for Climate Services, 2019).

Table 3.8: Projections of the number of days with maximum temperatures above 30°C for Thunder Bay, Sudbury, Toronto, Niagara Falls and Windsor to the middle and end of the century under moderate- (RCP 4.5) and high- (RCP 8.5) emission scenarios

NUMBER OF DAYS WITH MAXIMUM TEMPERATURE >30 °C

	HISTORICAL	ANNUAL VALUES							
	1950–2005	2050s				2080s			
		RCP 4.5		RCP 8.5		RCP 4.5		RCP 8.5	
	MEDIAN*	MEDIAN	RANGE	MEDIAN	RANGE	MEDIAN	RANGE	MEDIAN	RANGE
Thunder Bay	2	12	1–21	12	4–27	18	8–28	35	14–53
Sudbury	4	17	4–22	22	11–37	27	10–36	47	20–62
Toronto	11	35	20–53	47	21–61	51	29–71	74	46–90
Niagara Falls	7	31	19–54	45	19–65	50	26–67	75	43–95
Windsor	18	48	33–67	61	31–82	68	43–93	94	67–105

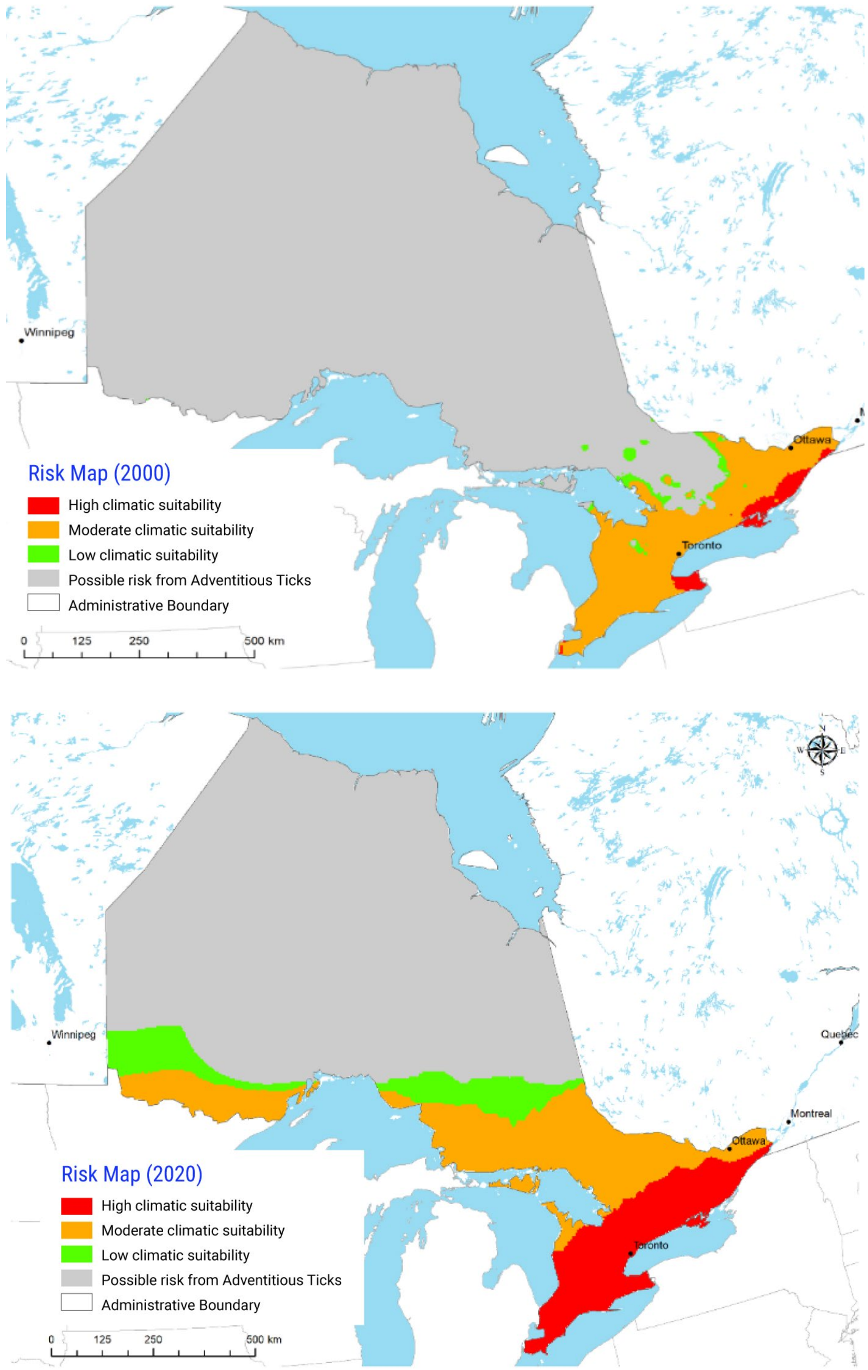
*Historical median values determined by calculating the median of annual values from 1950 to 2005.

Source: Environment and Climate Change Canada et al., 2019.

Vector-borne diseases

Warming temperatures and resulting shifts in bioclimatic envelopes have contributed to the expansion of certain disease vectors, including animals, ticks and insects (Gough et al., 2016; Berry et al., 2014b). Mosquito-borne diseases have increased by approximately 10% in Canada in the last two decades (Ludwig et al., 2019). Some of these diseases, including the Chikungunya virus, which has historically been limited to travel-related cases, could expand to parts of southern Ontario as temperatures increase and conditions become more favourable for transmission (Ng et al., 2017). The observed northward expansion of the blacklegged tick in Ontario, which is responsible for transmitting Lyme disease, is in part due to temperature increases (Cheng et al., 2017; Clow et al., 2017; Werden et al., 2014). The number of confirmed and probable

Lyme disease cases observed in Ontario PHUs was three times higher in 2017 than the average from 2012 to 2016, and twice as high in 2018 (Ontario Agency for Health Protection and Promotion, 2019; Nelder et al., 2018). Northward and westward expansion of the distribution of blacklegged ticks and the associated risk of Lyme disease are projected to continue throughout this century in response to changing climate (*see* Figure 3.22; Gasmi, 2019; Sagurova et al., 2019).



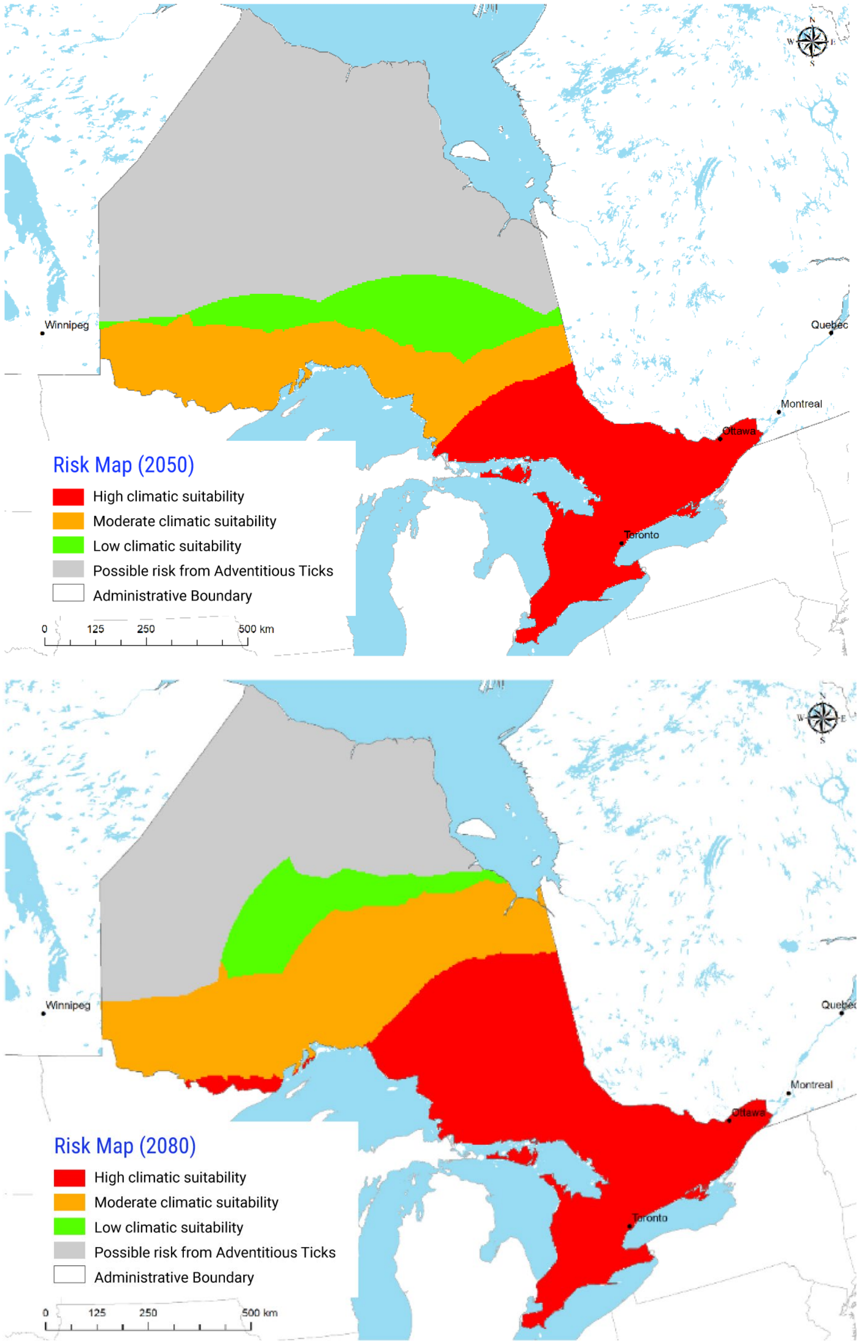


Figure 3.22: Risk maps for populations of the blacklegged tick (Ixodes scapularis) vector of Lyme disease historically (1971–2000) and under future emissions scenarios (2020s, 2050s and 2080s). The climate data was derived using the Canadian Regional Climate Model version 4.2.3 and was forced by a high (A2) emissions scenario. Red = areas of high risk, orange = areas of medium risk, green = areas of low risk and grey = areas of no risk of tick populations. Within "no risk" areas, there is a low, but real risk of acquiring Lyme disease due to adventitious ticks dispersed by migratory birds. Source: Courtesy of Nick Ogden.

Health impacts in the North subregion

Indigenous communities in Ontario's North subregion have experienced flooding on several occasions. Whether driven by rapid snow melt, rain on frozen ground or ice jams in the large rivers, flooding in the spring season can bring significant anxiety. Extreme weather and flooding increase the risk of water contamination, water-borne illness and vector-borne disease, and can disrupt critical health care services in hospitals and clinics, as well as in other institutions (Giordano et al., 2017; Clarke, 2009; Brunkard et al., 2008; Cretikos et al., 2007). Anxiety and other mental health conditions are also triggered through evacuations related to wildfire, as well as flooding, and when critical transportation and energy infrastructure is disrupted, highlighting how impacts cascade through an interdependent system (Cunsolo 2018; 2014). These conditions can reverberate over time in the form of post-traumatic stress disorder, emotional fatigue, substance misuse and a lost sense of place (Bourque and Cunsolo Willox, 2014).

Food insecurity is also causing health impacts. Moose, a major source of wild food for many central and northern Ontario First Nations, is in decline in much of the region (Arsenault et al., 2020). Climate change, through later frost onset and earlier spring warming, is increasing exposure to fatal parasites transferred from white-tailed deer (Priadka et al., 2022). Deer are expanding northward in response to shorter winters and decreased snow depth allowing easier movement and access to browse (the leaves, twigs, and buds that deer eat) (Dawe and Boutin, 2016). Alteration of habitat by human and climate influences that reduces the density of the forest canopy is amplifying the impacts on moose by allowing easier access for predators and increasing the accumulation of snow on the ground, making it more difficult for younger animals to negotiate the snow and find browse (Priadka et al., 2022). In Biigtigong Nishnaabeg (Pic River) First Nation, on the north shore of Lake Superior, residents are adapting to the northward shift in the moose population by using a mobile app to pass on information to others about moose sightings, as well as signs of visible parasitic diseases on moose in their Traditional Territory (Popp et al., 2018).

People in thirty-one First Nation communities in the North subregion rely on winter roads to travel south in winter (*see* Section 3.2.2) for medical services from specialists and in hospitals, as well as to obtain food and other essential supplies (Ontario Ministry of Energy, Northern Development and Mines, 2019). Winter roads transect the traditional territories of most communities in the Nishnawbe Aski Nation and many in Grand Council Treaty #3. Personal snowmobile travel on frozen lakes and rivers supports hunting and fishing, which are not only integral components of subsistence living, but are also fundamental to Indigenous culture (Cunsolo Willox et al., 2014). However, safety is increasingly compromised by thin ice during warmer winter weather, notably in sections that span large water bodies (Hori et al., 2018a; 2018b). Unreliable access for heavy transport vehicles limits commercial food deliveries, making healthier food options such as fresh fruit and vegetables either not available or too expensive. In response, many have begun to develop family and community gardens, taking advantage of a lengthening growing season, and are also building greenhouses (Sioux Lookout First Nations Health Authority, 2019).

3.7.3 Resiliency and adaptation

Public Health Units (PHUs) across the province are, to varying extents, already assessing and managing the impacts of climate change on human health (Paterson et al., 2012). Addressing public health risks from climate change and extreme weather is mandated through the Ontario Public Health Standards, which references climate change in sections related to population health assessment, healthy environments, and prevention and control of infectious and communicable diseases (Ontario Ministry of Health and Long-Term Care, 2018b; Paterson et al., 2012). Some PHUs (e.g., Peel Region, London Middlesex, Simcoe Muskoka and Grey-Bruce) have undergone comprehensive studies and have published climate change vulnerability assessments and adaptation plans (Grey-Bruce Health Unit, 2017; Levison et al., 2017; Berry et al., 2014a; Region of Peel, 2012). These analyses detail local risks, highlight improvements to monitoring and implementation of adaptation measures, and consider how climate change goals can be aligned with health equity (Buse, 2018).

The Ontario Climate Change and Health Toolkit contains guidelines (Ebi et al., 2016) and a workbook (Paterson et al., 2016) for conducting climate change and health vulnerability and adaptation assessments, as well as a climate modelling study (Gough et al., 2016) that forecasts key health impacts for PHUs. A complementary National Climate Change and Health Workbook and Knowledge Primer to guide adaptation planning for health professionals is currently in development.

Early warning systems and associated response measures are a key feature of health adaptation initiatives in Ontario. The provincial harmonized heat warning, established in 2016, provides a consistent approach and methodology for monitoring weather forecasts, identifying signals of a potential localized heat event and notifying PHUs that, in turn, can provide targeted, heat-related warnings and messages (Ontario Ministry of Health and Long-Term Care, 2016). The standardized messaging provided by these alert systems include details about the event itself (onset, intensity, duration), as well as response messaging, for example about who is at risk and potential symptoms of heat stress or stroke (Ontario Ministry of Health and Long-Term Care, 2018b). PHUs can escalate heat warnings and, alongside emergency management and municipal stakeholders, implement additional measures to protect vulnerable populations from extreme heat. Implementation of these heat alert systems in Hamilton, Toronto, Sudbury, Kingston and Windsor provides valuable lessons learned (*see* Case Story 3.5; Guilbault et al., 2016).

Case Story 3.5: Local actions to address extreme heat

A series of 20 case studies examined how cities across Canada are adapting to extreme heat (Guilbault et al., 2016). The analysis identified core elements of heat alert and response systems designed to reduce the risk of illness and fatality during extremely hot days (*see* Figure 3.23). It also highlighted the following seven lessons learned:

- **Many communities are taking action now.** Actions include Heat Alert and Response Systems, as well as preventative actions like incentivizing urban greening through green or cool roofs that reflect or absorb sun rays, and tree planting programs to increase the urban tree canopy and reduce heat island effects (e.g., Toronto Public Health).
- **A culture of prevention is the trigger for action.** While decision-makers are often motivated to implement resilience measures after a major event such as a flood or wildfire hits a community,

some communities have taken action to prepare for extreme heat before fatalities occur after witnessing impacts outside of their community.

- **There is great value in existing networks and partnerships.** Public health officials can work alongside existing networks and partnerships, including with city officials, emergency services, school boards, seniors' homes and community members, to assess risks, implement preventative measures and develop robust planning responses. In Ontario, many PHUs, including the Northwestern, Middlesex-London, Peel, and Simcoe-Muskoka health units, have leveraged relationships with their communities and other partners to conduct vulnerability assessments and develop adaptation plans.
- **Evaluation and continuous innovation are essential.** There are opportunities to assess the efficacy of existing plans and systems, and to identify innovations tailored to the individual community.
- **Focus preparedness on the most vulnerable.** Programs need to focus on assessing vulnerability and ensuring that strategies are aligned with high-risk populations, like seniors who do not have access to air conditioning.
- **Invest in prevention to reduce the risk of loss.** There are opportunities to invest in multifaceted solutions that extend past traditional public health interventions, like urban planning policies.
- **National and provincial leadership supports local preparedness.** Support includes funding, education and a community of practice where lessons learned can be shared across jurisdictions (e.g,. Health Canada's HealthADAPT program).

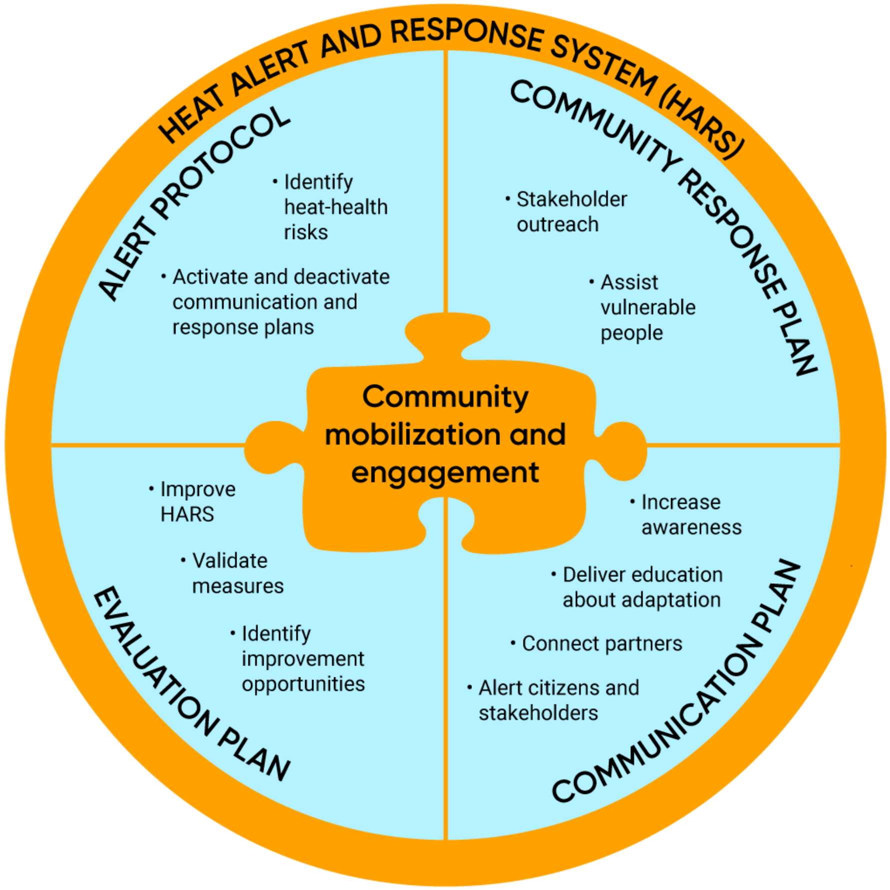


Figure 3.23: Core elements of heat alert and response systems. Source: Guilbault et al., 2016, published by the Institute for Catastrophic Loss Reduction.

Warning systems are also in place to identify mosquito-borne disease outbreaks like West Nile virus. Such systems can be adapted and improved to incorporate weather forecasting to supplement conventional public health surveillance techniques, similar to those piloted by the Peel Region Public Health Unit (Ogden et al., 2019; Wang et al. 2011).

The strong linkages between a population's social and economic circumstances and its health (Keon and Pépin, 2009) are recognized as key factors in determining vulnerability to climate health impacts (City of Toronto, 2016; Toronto Public Health, 2015; Berry et al., 2014b; Toronto Public Health, 2008). Programs that target the underlying causes of inequity will lessen climate risks and improve overall quality of life (Buse, 2018). Institutional capacity to protect vulnerable populations through the provision of emergency services, access to hospitals, cooling and warming centres, and other actions contributes significantly to reducing health-related impacts of climate change. The presence of green spaces is also associated with improved health outcomes, including improved air quality and provision of shade for cooling (Kingsley and EcoHealth Ontario, 2019; Mitchell and Popham, 2008).

3.8 Progress on adaptation remains limited in Ontario

Levels of climate change adaptation planning and implementation vary considerably across Ontario, with the primary focus still placed on the assessment of risk and vulnerability. Although there are examples of implementation, there is little evidence of adaptation being mainstreamed into decision making broadly. Systems for monitoring and evaluating adaptation action and effectiveness remain inadequate in most jurisdictions.

Climate change assessments completed across the province paint a clear picture of the risks to society as a whole. Data, research, knowledge and information products on climate change impacts have improved awareness about the need to adapt in conjunction with significant efforts to reduce greenhouse gas emissions. While various tools, frameworks and supporting mechanisms have been developed and applied to support the adaptation process, adaptation action in Ontario remains primarily focused on defining climate change risks, with relatively few examples of implementation. Regions and cities, public health units, conservation authorities and some Indigenous communities are leading in addressing climate change within their jurisdictions. Scaled-up adaptation implementation, as well as concrete and systematic ways to measure and report on the effectiveness of adaptation actions that have been implemented are important.

3.8.1 Introduction

Implementation of adaptive measures and the mainstreaming of adaptation into existing decision-making processes initially require efforts to methodically build knowledge and assess risks (*see* Figure 3.24; Ministry of Environment and Climate Change Strategy, 2019; ICLEI, 2016; Canadian Council of Ministers of the Environment, 2015; Douglas et al., 2011; Gleeson et al., 2011; Black et al., 2010). The core elements of a risk-based approach for climate resilience are consistent with international standards such as ISO 31000 (2018), ISO 14090 (2019) and ISO 14091 (2019). These processes, supported by appropriate expertise and resources, provide a backdrop for planning and implementation to occur (*see* Case story 3.6).

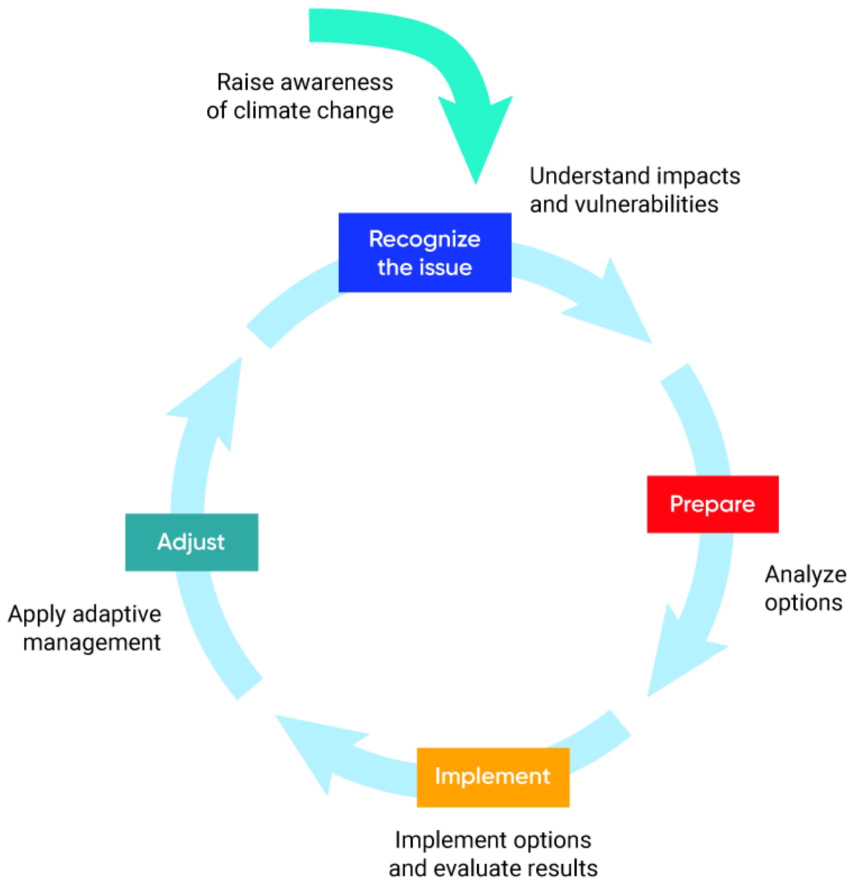


Figure 3.24: The adaptation cycle as presented in the Blackfeet Climate Change Adaptation Plan. Source: Wagner et al., 2018.

Case Story 3.6: Climate change adaptation by the Georgina Island First Nation

Georgina Island First Nation, located along the east shore of Lake Simcoe, is dealing with a number of climate change impacts that have disrupted the community. Warmer winters have negatively affected the ability to travel from the island to the mainland via the ice road, and more frequent strong winds have damaged houses and other infrastructure. In response, the First Nation embarked on a community-based project in 2012 that collected and used Indigenous Knowledge as the foundation for climate change adaptation planning and for reducing greenhouse gas emissions. Risks and vulnerabilities associated with current and future climate change were identified, and recommendations were developed using a multi-step assessment framework.

An advisory committee comprised of Elders, youth and community members was established to provide project oversight and guidance. The committee met several times over the course of the project to learn about progress, provide advice on community priorities and review project results. A community adaptation liaison, hired from within the First Nation, worked closely with the community and partners throughout the project. Through one-on-one interviews with the liaison, community Elders, adults and youth shared their knowledge about changes in weather and climate, and how these changes have impacted their community. Bingo information sessions, interactive workshops and day-to-day interactions with community members provided opportunities to learn and provide feedback about the project and results (*see* Figure 3.25). Keeping the community informed and engaged was a fundamental part of the adaptation planning process.

Figure 3.25: Interactive risk assessment workshop with Georgina Island First Nation community members.
Source: Photo courtesy of Kerry Ann Charles.

The project developed 67 recommendations, all of which were vetted by the community, and a plan to implement them. One of the first recommendations to be implemented was the restoration of a creek that at one time flowed for nine months of the year, but had dried up in recent years. Because this creek was seen as a key location to alleviate potential flooding caused by intense precipitation, the community worked with property owners, a team of experts and individual community members to restore the creek. Since its restoration, the previous flora and fauna have reappeared and function to moderate the high volumes of water associated with heavy rainfall. Monitoring of the site by the Waabgon Gaming students, the First Nation Environment Department and project partners is ongoing. As monitoring proceeds, adjustments will be made to ensure that the creek remains functional and can be enjoyed by future generations.

Following the success of the project in their own community, Georgina Island First Nation reached out to neighbours within their Tribal Council and, using the same model, the community adaptation liaison and project partners have helped four other First Nation communities to start the climate change adaptation planning process (Charles, K.-A. 2019).

3.8.2 Adaptation planning

Adaptation planning in Ontario varies in scale and scope. Multi-themed assessments (e.g., Lalonde et al., 2012; Douglas et al., 2011) identify risks across broad landscapes, while more technical and in-depth analyses (e.g., Tu et al., 2017), often employing geographic information systems and climate change information, delineate risks at finer scales.

The institutional arrangement of Conservation Authorities (CAs) in Ontario has proven successful at advancing adaptation planning at watershed scales, particularly as it relates to flood risk. As watershed and ecological stewards with jurisdictions stretching across many municipal boundaries, CAs participate in municipal and regional climate change initiatives in addition to having their own climate change plans (e.g., Lake Simcoe Region Conservation Authority). CAs have undertaken research to advance the climate change knowledge base, established best practices for managing climate change risk, and developed tools to assist adaptation decision making (e.g., the Risk and Return on Investment Tool (Credit Valley Conservation, 2020) and the Source Water Protection Tool (Milner et al., 2018b)). CAs are also key partners in the development and implementation of municipal or regional adaptation plans, including those in Kingston (City of Kingston, 2014), Thunder Bay (City of Thunder Bay, 2015), Windsor (City of Windsor, 2020; 2012) and Durham Region (Durham Region, 2016). All of these plans reflect the collective input of many partners contributing expertise or experience to mobilize adaptation across multiple themes and sectors.

3.8.3 Implementation, monitoring and evaluation

Despite significant progress with respect to adaptation planning, the level of implementation of adaptation actions in Ontario remains low. Climate resilience planning has not kept pace with the rate of climate change, and the adaptation deficit in Ontario (Environmental Commissioner of Ontario, 2018a) continues to grow.

Many provincial government policies have the potential to support adaptation and climate resilience. The Provincial Policy Statement (Ontario Ministry of Municipal Affairs and Housing, 2020), environmental assessment guidelines (Ontario Ministry of Environment, Conservation and Parks, 2014), asset management planning guidelines (Ontario Ministry of Infrastructure and Ministry of Transportation, 2012), the Northern Ontario Growth Plan (Ontario Ministry of Infrastructure and Ministry of Northern Development, Mines and Forestry, 2011) and other policy instruments signal recognition of climate change impacts and the need for adaptation.

Barriers that impede progress on the planning, implementation and evaluation of adaptation in Ontario include financial constraints, lack of expertise and access to data, limited political will, support and mandate for action, and uncertainty associated with roles and responsibilities (*see* Box 3.6; Abdel-Fattah and Krantzberg, 2014a; Gregg et al., 2011). Addressing these barriers would help mainstream adaptation into policy and planning processes.

Box 3.6: Reported barriers to adaptation action

A state-of-play report on climate change adaptation and infrastructure (AMEC Foster Wheeler and Credit Valley Conservation, 2017) and engagement sessions conducted in Ontario in 2019 to support development of this chapter highlighted several perceived barriers to adaptation action. These include the following:

- Inconsistent guidance or lack of guidance and direction from the provincial and federal levels related to climate change;
- Need for municipal direction on how to define risk tolerance, particularly within existing urban areas;
- Need for municipal direction on how to set design goals for infrastructure to meet the needs of future climate within its lifespan;
- Lack of defined roles and responsibilities for water infrastructure, which creates confusion and a lack of integrated adaptation strategies;
- Insufficient collaboration among departments;
- Lack of engineering tools to support optimization of adaptation measures or financial tools to make an effective business case for adaptation action;
- Insufficient funding to implement adaptation initiatives; and
- Lack of streamlined climate change data and resources to accelerate implementation.

The inherent complexity and diversity of climate change impacts, the multiple scales and cross-cutting nature of some adaptation actions, and other factors make tracking the success of adaptation challenging (Expert Panel on Climate Change Adaptation and Resilience Results, 2018). Indicators for province-wide monitoring and evaluation of adaptation implementation would help define pockets of inaction, create examples of success and inspire further action.

While progress has been made on adaptation planning in Ontario, action is fragmented and has not been conducted in a systematic way. This is not necessarily a negative, as a variety of approaches are required to determine best practices. Planning to date has primarily been undertaken in larger regions or cities where there is greater capacity and resources, disadvantaging smaller communities. Stronger coordination and governance among those implementing adaptation planning processes can improve information sharing and expedite climate resilience.

3.9 Moving forward

Assessing progress on adaptation in Ontario remains challenging. Registries or databases of climate change risks in various sectors and regions, such as those that exist elsewhere (e.g., BC Ministry of Environment and Climate Change Strategy, 2019; UK Government, 2017), establish a baseline for measuring progress and help to prioritize adaptation actions. In Ontario, province-wide inventories of climate change impacts, risks and adaptation actions are not yet in place. As adaptation implementation increases, registries would help document changing climate risks and provide examples of sector- or region-appropriate adaptation actions.

In addition to those major gaps, a number of key, and in some cases new, issues would benefit from additional research. These include governance, data availability, reducing uncertainties, risk transfer, cultural impacts and funding mechanisms.

3.9.1 Governance

Governance of climate change issues is complex due to the range of authorities, including national, provincial and local governments, Indigenous communities, the private sector, civil society and other actors who work in this space. Coordination among all these parties on aspects of climate change adaptation can be challenging. A centralized information-sharing platform that includes climate science, climate change data, impacts, risk levels and adaptation would help facilitate access to information and increase coordination between actors, while also defining research opportunities related to cumulative impacts and interdependencies within the region (Angel et al., 2018; Milner et al., 2018a).

The issue is compounded in the Great Lakes Basin by the international dimension involving two countries and multiple provinces and states. Within the Basin, and under mandate from the Government of Canada and the United States Government, the International Joint Commission has engaged with local, state and provincial governments to coordinate action on climate change (International Joint Commission Water Quality Board, 2019; 2017) and will seek to advance elements of a binational climate change adaptation and resilience strategy in 2022 (International Joint Commission, 2020).

3.9.2 Access, format and interpretation of climate change data

While climate data has become more accessible over the last few years, particularly with the launch of the Ontario Climate Data Portal (Zhu et al., 2018) and the Canadian Centre for Climate Service's Climate Data platform (Environment and Climate Change Canada et al., 2019), actionable climate information continues to be identified as a barrier for communities and others who undertake assessment or adaptation planning processes. Even when practitioners have access to local climate information, there is often a lack of understanding of the data, including which datasets are most useful for specific decisions (Milner et al., 2018a). The utility of climate datasets could be improved by including interpretation summaries that highlight general data trends (Milner et al., 2018a). The development of climate science communication pathways (e.g., data-sharing platforms and forums) would allow for information to be effectively communicated among various sectors and stakeholders, and would contribute to improving the use of climate science information for informing adaptation decisions (Milner et al., 2018a; International Joint Commission Great Lakes Water Quality Board, 2017).

3.9.3 Uncertainty of climate change impacts on lake water balance

Climate change affects the quantity of water in lakes and rivers, primarily through changes in temperature, precipitation and evaporation. The balance of these influences is difficult to assess, and this becomes even more challenging in the context of climate change. In the case of the Great Lakes, there are divergent views on future water-level trends (Bonsal et al., 2019; GLAM Committee, 2018; Angel and Kunkel, 2010). Recent experience with both high lake levels (Lake Ontario and Lake Erie in 2017 and 2019) and low lake levels (Lake Huron and Lake Michigan in 2013) indicate that extremes in water levels can vary considerably within relatively short periods (Gronewold and Rood, 2019), which reveals the need for resilience measures that can accommodate both high water and low water scenarios over time.

3.9.4 Regional risk transfer to the Great Lakes Basin stemming from climate change

Climate change impacts elsewhere in North America, and elsewhere in the world, could stimulate migration to seemingly water-abundant areas like the Great Lakes Basin (American Society of Adaptation Professionals, 2021; Great Lakes Now, 2021). Research concerning transboundary climate change impacts and the migration of people into the area remains limited. Research into the impacts of climate change on other domestic and international regions, and into subsequent effects on the Great Lakes Basin, is warranted.

3.9.5 Climate change impacts on Indigenous culture and mental health

Long-term climate change can have magnified impacts on Indigenous culture, particularly in northern Indigenous communities. As climate change affects all aspects of the biosphere, cultural aspects that are intimately tied to the environment are also affected. Knowledge about the impacts of climate change on the mental health of Indigenous Peoples in Canada (Cunsolo and Ellis, 2018) continues to evolve, but with few examples coming from Ontario. Short-term displacements, like community evacuation in the event of a flood or wildfire, can compound levels of stress among displaced people, further increasing vulnerability within communities. Given the significant social and economic challenges that exist within northern Indigenous communities, programs to monitor and address impacts to mental health are important.

3.9.6 Innovative financial mechanisms

The impacts of extreme weather events, combined with infrastructure and adaptation deficits, have led to increases in insured and uninsured losses in Ontario. Large asset holders, including investment firms, property holding companies and pension funds, have yet to mobilize on climate change adaptation in a significant way. These sectors are increasingly reporting on climate risk for their own portfolios, but also have a role to play in mobilizing or unlocking financing for adaptation investment (*see* Climate Disclosure, Litigation and Finance chapter of the National Issues Report). There is a need to further mobilize the investment community and researchers to use innovative financial mechanisms that promote adaptation action and can assist in disaster recovery.

3.10 Conclusion

The signs of climate change in Ontario are clear, both from the observations of Indigenous peoples and other citizens as well as from records of temperature, precipitation and other climate variables. Despite strong understanding of ongoing and projected future climate change impacts, proactive, evidence-based adaptation remains limited in virtually all sectors and regions of the province. Even where adaptation planning is occurring, the lack of broader coordination results in missed opportunities for expanding this work.

Rapid and widespread population growth and urbanization are expected in the Greater Toronto Area and the Greater Hamilton Area, as well as in other pockets of the province; these will further fragment and stress ecological habitat. Healthy and intact ecosystems remain fundamental to having healthy communities and addressing climate change. Human interventions to assist nature in its capacity to adapt to climate change bring significant benefits in the form of ecosystem services. Communities that use incentives and policy tools to increase low-impact development and natural infrastructure will see resilience dividends.

Continued population growth and urbanization could also lead to higher and disproportionate levels of climate risk for vulnerable populations. Addressing the fundamental determinants of human health, particularly those related to equity, and prioritizing the adaptation needs of vulnerable populations will contribute to achieving benefits that exceed the findings of traditional economic analyses.

Flooding in heavily urbanized areas remains one of the most significant climate-related impacts because it can disrupt numerous critical services. Updated information that helps to delineate high-risk areas can inform climate-smart decisions for development, including the location of future critical infrastructure and retrofitting of existing stock.

Cooperation and coordination between levels of government to support climate resilience planning and decision making makes adaptation more efficient. Continued training in professional planning, engineering, health, architecture, conservation and finance will help ensure that climate change is mainstreamed into practice for different professions. This training will help make climate resilience an inherent component of economic growth.

The strong business and financial community in Ontario presents an opportunity to assess economic risks associated with climate change, mainstream climate change into enterprise risk management systems and business decision making, and ensure that financial holdings and investment portfolios are adequately disclosing climate risks to shareholders and investors.

Since climate change is a "society-wide" issue, consideration of adaptation is not limited to government or private sector decision-makers and professional institutions. Increasing awareness of the need for adaptation among homeowners and the general public will expand the scope of adaptation actions and support their successful implementation.

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