VULNERABILITY ASSESSMENT

Community Services and Assets in Peel Region: Port Credit Case Study

Prepared for:

Region of Peel
working with you

Prepared by:

Toronto and Region Conservation
for The Living City

ONTARIO CLIMATE CONSORTIUM

RSI
RISK SCIENCES INTERNATIONAL

Action on Climate Change in Peel Region

Addressing climate change is nothing new for the Region of Peel. The two regional Conservation Authorities, Toronto and Region Conservation Authority (TRCA) and Credit Valley Conservation (CVC), have been actively involved in climate change adaptation and mitigation initiatives for the past decade. The Region recognizes the importance of working together to build resilience and adaptive capacity to climate change at a local scale. In 2011, it partnered with the TRCA and CVC, as well as lower tier municipalities (Brampton, Mississauga and Caledon), to develop the Peel Climate Change Strategy.

The Strategy serves as a roadmap for addressing climate change impacts in Peel Region through the following:

- proactive and responsive planning and leadership
- actions to reduce greenhouse gas emissions
- targeted and proactive adaptation actions
- shifting to a green economy
- increasing awareness of, and engagement in, climate issues in Peel
- ongoing research and adaptive risk management

Peel commissioned the development of the vulnerability assessments to investigate the impacts of climate change on a variety of systems. The information gained in these assessments will help identify opportunities for adaptation to climate change and reduction of its negative effects.

This vulnerability assessment was completed in 2016 to assess the impacts of climate change on critical services and assets that support community well-being in Port Credit, as a case study which can be extended to other communities in the Region. The following summary of that assessment was prepared by Hutchinson Environmental Sciences Ltd. and Shared Value Solutions Ltd., in collaboration with the Toronto and Region Conservation Authority, Ontario Climate Consortium and the Region of Peel.

Note: Please refer to the full technical report for all source material used in the assessment and this summary.

Suggested citation for the full technical report:

Harris, S., Hazen, S., Fausto, E., Zhang, J., Kundurpi, A., Saunders-Hastings, P. 2016. **Climate Change Vulnerabilities of Community Services and Assets in the Region of Peel. A Case Study in Port Credit.** Toronto, Ontario: Toronto and Region Conservation Authority and Ontario Climate Consortium Secretariat.

Preparing for the Future

Climate change is one of the greatest challenges humans face in the 21st century. As the planet warms, we are witnessing more extreme and variable climate patterns, which are leading to unprecedented impacts for society and natural environments worldwide. The warming trend is no longer reversible, which means that even if we drastically curb greenhouse gas emissions today, we will still continue to experience devastating climate change effects for decades to come. Adaptation is needed at all levels, from local to global, to adjust to the new reality under our changing climate.

Calls to Action

The results of this vulnerability assessment, summarized over the following pages, make it clear that we must act now:

- ✓ Start or continue adaptation planning, leveraging this and other existing community assessments, to incorporate system thinking and enable evaluation of impacts at the property level.
- ✓ Protect and restore natural areas to strengthen flood resiliency and heat resiliency, including reducing the heat island effect.
- ✓ Evaluate impacts to infrastructure at a system and property level, ensuring more variable and unpredictable water levels are reflected in plans and design.
- ✓ Promote collaboration and support the implementation and communication of emergency preparedness and response initiatives, which involve health care workers, emergency responders, police and public health agencies.
- ✓ Promote collaboration and knowledge transfer with utilities and the public to better understand interdependencies, how climate change may affect them and what solutions may be supported (such as backup power and alternative power sources).
- ✓ Build public awareness of the hazards and impacts of climate change (such as heat waves, flooding).

The purpose of this assessment is to understand climate change impacts on critical services and assets that support community wellbeing in Port Credit, as a case study that can be extended to other communities in the Region.

STAKEHOLDER ENGAGEMENT

A wide range of public and private sector organizations work together to plan for, design, and operate services and assets that support the well-being of citizens in Port Credit and other communities in Peel. As a result, it was important to gain input from a cross-section of these stakeholders for the assessment process. Participants included representatives from Environment and Climate Change Canada, the Ontario Climate Consortium, Peel Region, the City of Mississauga, Toronto and Region Conservation and Credit Valley Conservation.

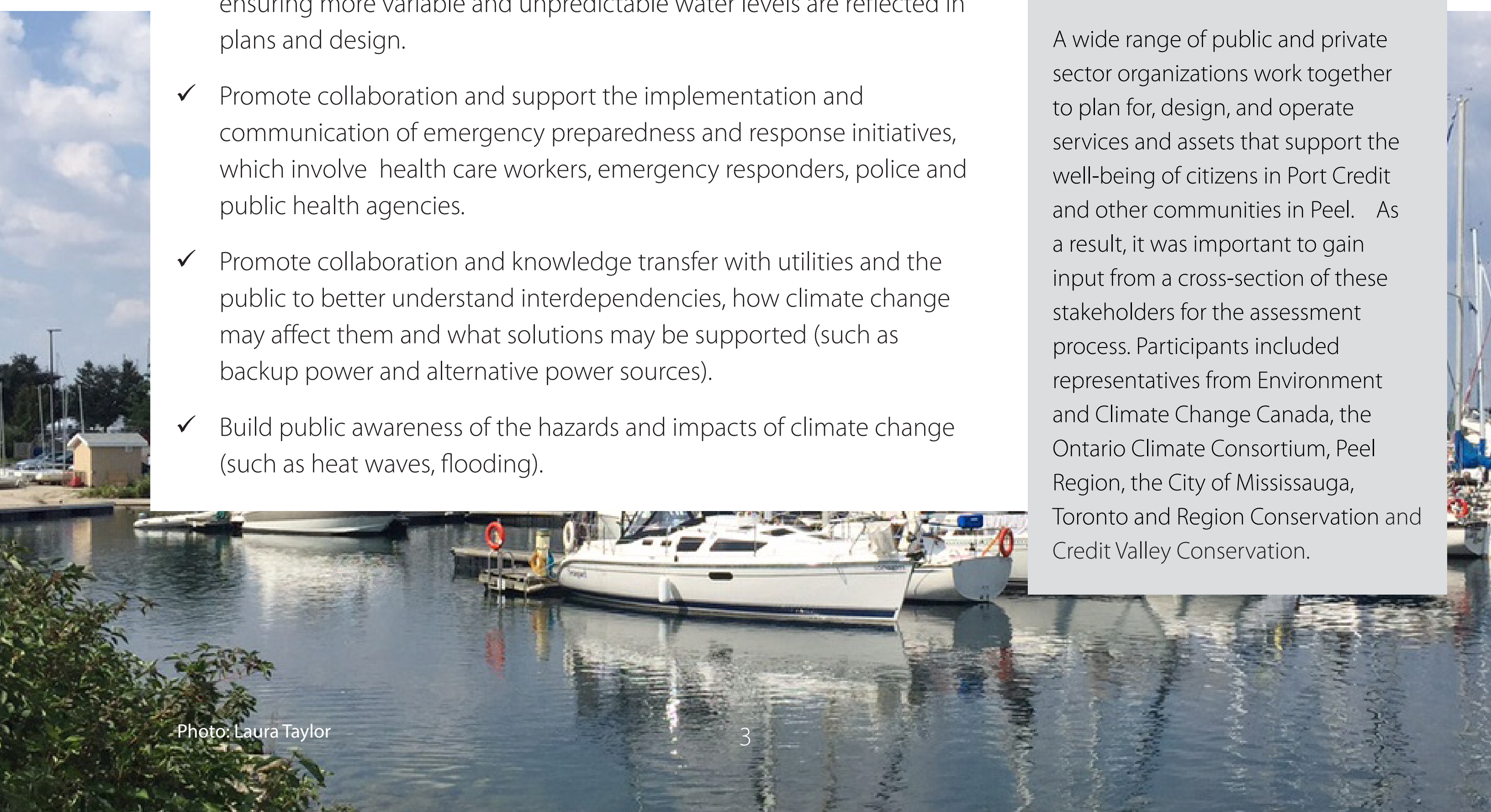


Photo: Laura Taylor

DEFINING VULNERABILITY TO CLIMATE CHANGE

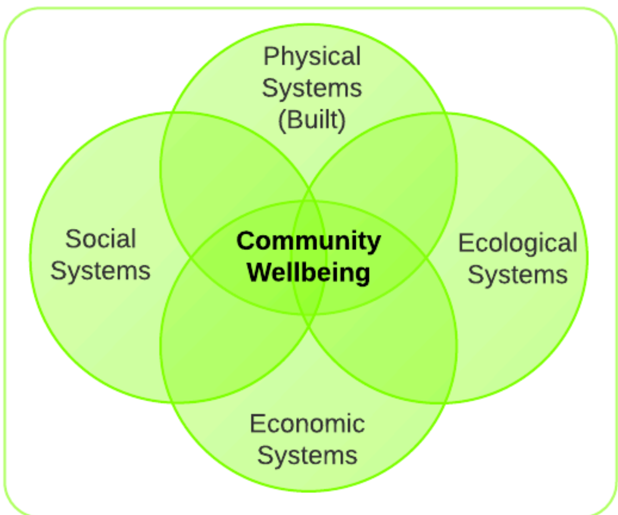
Many definitions of vulnerability to climate change exist. For the purposes of this assessment the definition from the Intergovernmental Panel on Climate Change was used:

"Vulnerability encompasses... sensitivity or susceptibility to harm and lack of capacity to cope and adapt."

How Does Climate Change Affect Community Services and Assets?

Climate and weather affect the large number of services and assets that combined provide the broader social, physical, ecological and economic systems that support community wellbeing. The planning, design and operation of services and assets consider climate and weather in many ways. For example, the timing and budgeting for snow removal, outdoor recreation, public heath campaigns (flu season, for example), and tree plantings are all dependent on expected climate and weather. Infrastructure and building designs meet codes and standards to withstand likely temperature, wind, precipitation, humidity and other climate conditions. As the climate changes, so will the effectiveness of past assumptions about weather and climate that have driven the planning, design and operation of community services and assets.

SYSTEMS SUPPORTING WELLBEING



Community Services and Assets Affected by Climate and Weather

- Housing and Built Forms
- EMS and Fire Services
- Police
- Emergency Planning and Management
- Public Health
- Culture and Tourism
- Finance, Legal and Administration
- Economic Development
- Planning and Zoning
- Port and Coastal Management
- Parks, Recreation and Education
- Waste Collection
- Agriculture and Food Security
- Environmental and Ecosystem Management
- Water and Wastewater
- Energy
- Transportation
- Telecommunications

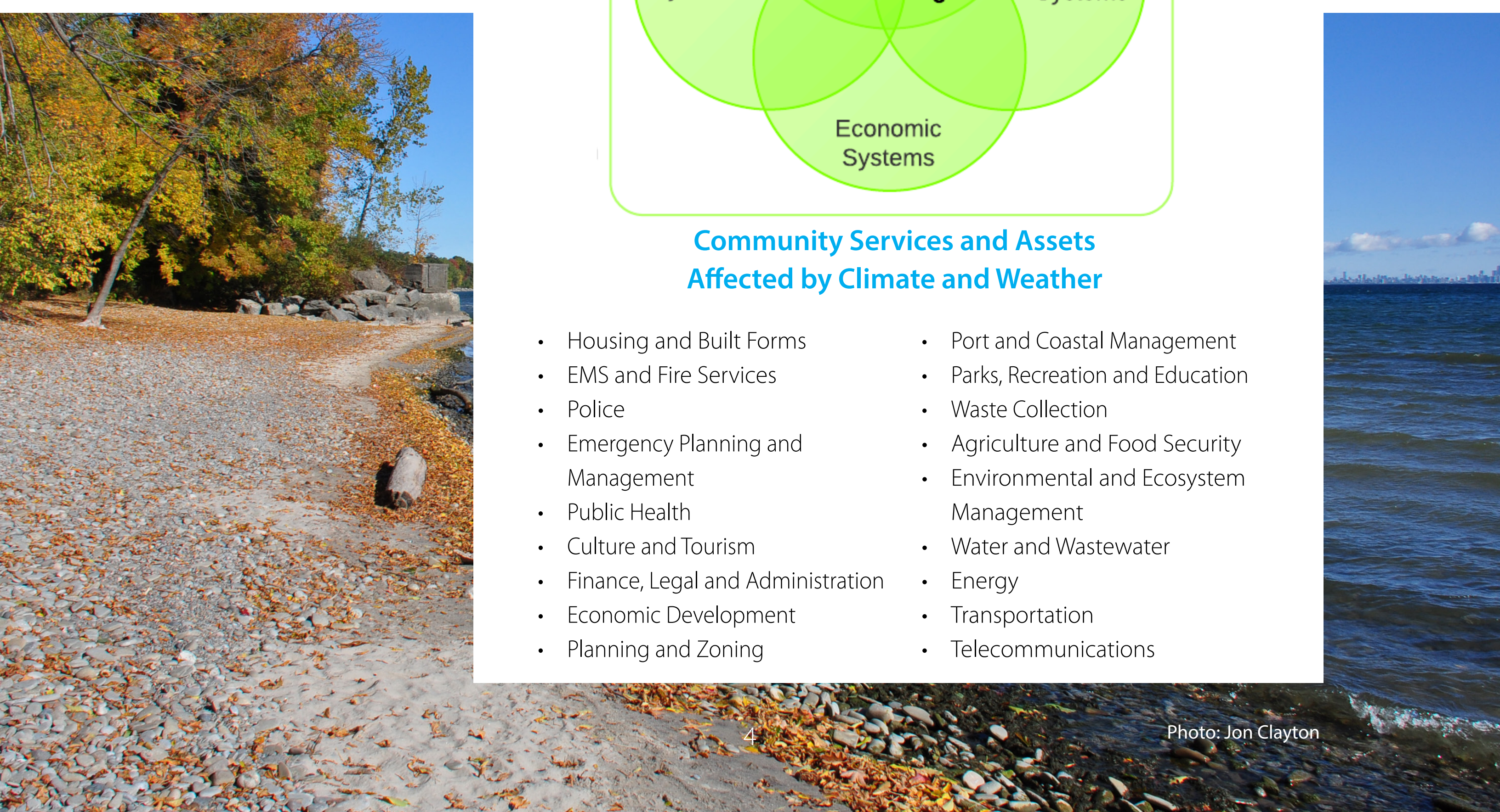


Photo: Jon Clayton

Port Credit

The Port Credit planning area of the City of Mississauga is located on the shore of Lake Ontario surrounding the mouth of the Credit River. It spans an area of 227 hectares with a population of approximately 12,500 people.

Land use in Port Credit is predominantly residential, but includes important lake-based commercial and recreational areas, and an abundance of green space for recreation and wildlife habitat. There are several critical pieces of infrastructure in Port Credit, including the Lorne Park Water Treatment Facility, the GO Transit station and Canadian National Railway line, several large community recreation facilities and three large marinas.

Port Credit has undergone a long-term visioning and revitalization process as part of the City of Mississauga's Official Plan Review. This process has resulted in several planning and land re-development projects that present opportunities to address climate change adaptation, such as the Port Credit Local Area Plan Review, Inspiration Port Credit and the Lake Ontario Integrated Shoreline Strategy.

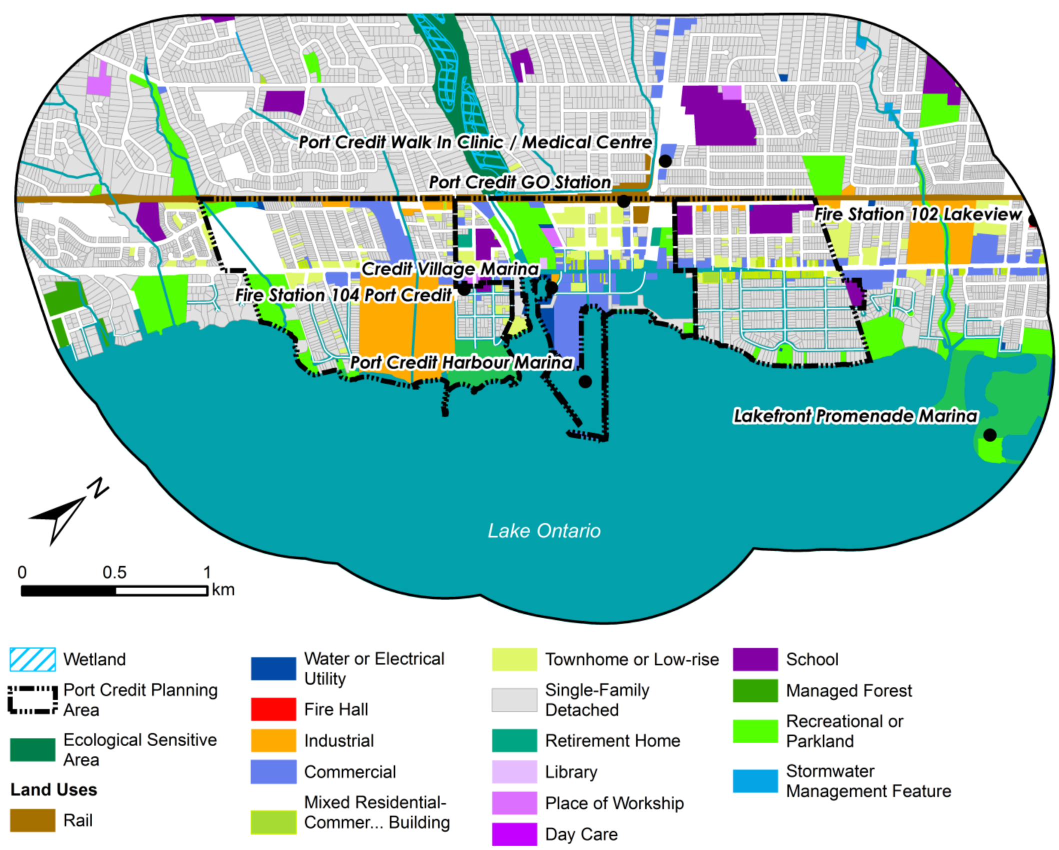
Port Credit was selected as the focus for the vulnerability assessment because it satisfied criteria set by the stakeholders. Specifically, Port Credit is a shoreline community that supports a diversity of community services and assets. It has ongoing policy and decision-making processes that could benefit from climate change analysis and an active community to participate in stakeholder engagement.

DEFINING RESILIENCE AND ADAPTIVE CAPACITY TO CLIMATE CHANGE

The vulnerability of community services and assets to climate change will depend in large part on their resilience and adaptive capacity.

Resilience refers to a system's ability to cope with and recover from disturbance.

Resilience is closely tied with the concept of **adaptive capacity,** which is the ability to adjust and respond to changes.



Land use and major community assets in Port Credit

Past Climate and Weather Impacts in Port Credit

Historically, most climate impacts to Peel community services and assets have been caused by extreme weather events (such as drought, extreme heat and extreme rainfall), rather than by seasonal climate conditions (such as shifts in temperature and precipitation, freeze-thaw patterns, and changes in snow cover). Extreme precipitation and large storms have been the primary drivers of these impacts.

Climate causes a wide diversity of impacts to community services and assets. Many impacts are caused by multiple climate conditions, and affect many or all services and assets (such as damage to infrastructure, damage to urban tree canopy, loss of service capacity). Overall, 189 different types of climate impacts that affect Peel services and assets were identified by stakeholders. Impacts of particular importance to Port Credit include the following:

Electricity

Electrical outages have widespread impacts on almost every service area.

Public Health

A healthy population is key to community well-being. Climate affects people's health directly, as well as indirectly through disruption to public health and emergency response services.

Port and Coastal Management

The Lake Ontario shoreline is a critical cultural, recreational and economic asset for Port Credit. Variability and extremes in lake levels due to climate can cause impacts to shoreline properties, municipal infrastructure, ecosystems and recreational uses.

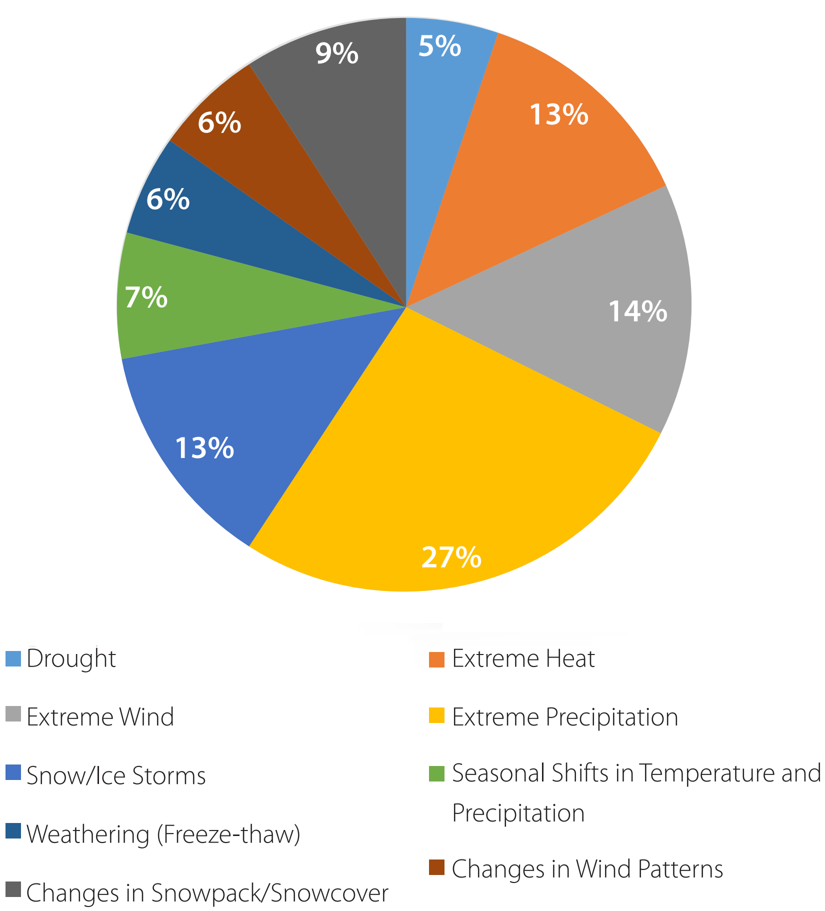
Transportation

Transportation infrastructure (such as roadways and the GO Transit rail line) are critical to day-to-day life in Port Credit. Damage to these systems can result in significant disruptions to a range of other services, and can be especially problematic during emergency situations.

Environmental and Ecosystem Management

Natural systems support many critical functions in urban environments. Compromised ecosystem health can affect everything from water supply, to provisioning of shade, to recreational opportunities and air quality regulation.

Breakdown of Impacts Associated with Different Extreme Climate Events and Seasonal Weather Conditions



Possible Futures Under Climate Change

Climate Trends in Peel Region

Predicting future climate is not an exact science, but trends can be forecasted based on a range of future greenhouse gas emission scenarios. Under business as usual, Peel Region is expected to be hotter at all times of year, with changes to seasonal precipitation patterns, more rainstorms and more heat waves. Winter, spring and fall will likely be wetter, while summer will be drier on average, but punctuated by heavy storms.

What the Storylines Tell Us

A series of four storylines present the major climate vulnerabilities to services and assets in Port Credit. The storylines link research on critical climate change impacts with current conditions to identify vulnerabilities at the community scale.

Storyline 1: Multiple Causes of Flooding in Port Credit

Storyline 2: A More Variable Lake Ontario Shoreline

Storyline 3: The Future of Power Outages in Port Credit

Storyline 4: Preparing Populations for Extreme Heat

FUTURE CLIMATE TRENDS IN PEEL REGION

A study of predicted climate trends for Peel Region found that

By 2050

- Annual mean temperature will rise by 2°C
- The number of extreme heat days (over 30°C) will more than double
- The intensity of extreme storms will increase by 28-51%
- The growing season will be 20% longer than today

By 2080

- Annual mean temperature will rise as much as 5°C from current levels
- There will be up to five times more extreme heat days
- The intensity of extreme storms will increase by 46-90%
- The growing season will be 30% longer than today

Photo: Laura Taylor

Storyline 1: Multiple Causes of Flooding in Port Credit

Port Credit is exposed to different types of floods, including flash floods, gradual riverine floods, lake-based coastal floods, and urban drainage system floods. Climate change may increase the likelihood of floods, with different areas of Port Credit being at higher risk. The vulnerability of services and assets to flooding depends in large part on where they are located within the community. Specific characteristics of assets also determine their vulnerability to damage during flood events.

What areas are most at risk?

Floodplains and areas along the Lake Ontario shoreline are at greatest risk of flooding in Port Credit because of their low elevation and proximity to water. There are many important community assets in these areas including schools, fire and police stations, health care and retirement facilities, recreational facilities, parks, and transportation, water and electrical infrastructure.

Urban flooding can also occur if storms exceed the design capacity of the drainage system (storm sewers, catch basins, ditches and culverts). Many areas of Port Credit were built prior to 1970, and their drainage systems may not be performing well because of age, leakages and poorly graded properties. In addition, much of the community is paved and built up, which prevents water from soaking into soils. As a result, there is more overland flow of water in these areas, making urban drainage systems more vulnerable.

What assets are vulnerable to damage during floods?

Physical damage to assets and property by flooding is the major cause of disruptions to community services. When a flood occurs, some assets are more vulnerable to damage than others. The extent of damage depends on a host of physical processes — pressure and wearing action of water, impacts from debris, and the growth of mold and bacteria, for example — and how long they are experienced.

In Port Credit, characteristics of many homes make them more vulnerable to impacts during floods:

- 80% of properties are single-family homes, which are more vulnerable than multi-unit buildings
- 60% of homes are more than 45 years old and may have lost structural integrity over time, although home improvements may lessen this vulnerability
- 1/3 of households are rented properties, which may not be maintained as regularly as owned properties

Building heights, construction materials and foundation types also contribute to the vulnerability of buildings to floods. Property-scale studies are needed to better evaluate homes in Port Credit to determine their resilience to flooding.

Storyline 2: A More Variable Lake Ontario Shoreline

Significance of Port Credit's Shoreline and Coastal Management

The Port Credit shoreline is a valued cultural, recreational, economic and ecological asset to the community and to Peel Region as a whole. As such, there are many planning efforts underway to ensure the long-term sustainability of the Port Credit shoreline, and implications of climate change is a key consideration. This storyline identifies coastal processes that are sensitive to climate conditions, and thus likely to change in the future, presenting vulnerabilities for coastal management.

Several coastal processes and characteristics of the shoreline area in Port Credit are sensitive to climate conditions. Extreme winds drive flooding, erosion and movement of sediments and debris along the shoreline. Mild winters reduce lake ice cover that protects the shoreline from erosion, while cold winters can cause ice to build up along the shoreline leading to ice jams in the Credit River and subsequent floods and erosion. Changes in regional precipitation and heat patterns lead to extreme high and low water levels in Lake Ontario. These climate impacts can result in a wide range of damage to assets and disruption of services on private properties, marinas, piers, beaches and natural shoreline areas.

Water levels in Lake Ontario have been regulated since the 1950s and have varied by up to two metres over this period. This variation has declined to less than a metre and a half in recent years. A new regulation plan by the International Joint Commission (which works to protect the Great Lakes) aims for a more natural management approach, and greater variability in water levels. Under the new plan, lake levels are expected to rise and fall beyond targeted levels under very wet or very dry conditions. Several projections suggest that levels will decline overall, but there is less confidence in these predictions as new studies emerge, and it remains unclear how water levels might vary from year to year. Uncertainty in climate change predictions has implications for coastal management of Lake Ontario water levels. Strategies will need to consider many possible lake level scenarios, and adaptive strategies will need to be able to respond to higher and lower lake levels than were seen in the past.

Photo: Jon Clayton

Storyline 3: The Future of Power Outages in Port Credit

Port Credit's Electrical Grid and Outages

The electrical grid is a critical asset in Port Credit. It distributes power throughout the community by a network of aboveground power lines, switches and transformers. The consequences of power outages can be serious, including high costs of repairing equipment, electrical safety hazards, loss of business, loss of power to households and issues for the management of many critical services and assets.

Extreme wind and buildup of snow and ice cause most damage to the Port Credit grid, or cause trees to damage it. Outages also occur because of deterioration of grid structures from weathering. Climate change is anticipated to produce more frequent storms and extreme weather that cause these types of outages.

What Makes the Grid Vulnerable?

Physical and management characteristics affect the capacity of Port Credit's electrical grid to withstand storms and extreme weather conditions that can cause power outages and damage the grid. Critical factors that make the grid more or less vulnerable include design, age and construction materials of the grid, and exposure to trees.

Components of the grid are designed, in part, to bear the stress of climate conditions. For example, the Canadian Standards Association Overhead System standards require that structures are able to withstand wind gusts of 94 km/hr at air temperatures greater than 25°C in dry conditions. Weather events that are outside of the design range can cause damage to components of the grid. Damage can also occur because of material imperfections, design flaws, improper maintenance, or other hazards.

Age increases the vulnerability of the electrical grid to climate events. Over time, weathering and normal break down of materials can degrade or damage systems. While electrical grids are designed to last between 35 and 65 years, design standards change over this period. Older systems may not be designed to the same standards as newer systems making them more vulnerable to climate events. The average age of the Port Credit grid components is 25 years, but some components were installed or upgraded in the 1950s.

Construction materials influence vulnerability of the electrical grid to climate in different ways. For example, wood utility poles are more vulnerable if they are tall and old, or located in wet areas where they are prone to rotting. In Port Credit, 6% of wood utility poles are considered more vulnerable, because they are more than 35 feet tall and more than 45 years old (3%), or they are in flood hazard zones (3%).

CAUSES OF POWER OUTAGES, JULY 2009 TO JANUARY 2014

- Weather events caused 54% of power outages.
- Trees caused 29% of power outages, often because of weather events.
- Most outages caused by weather and trees occurred in the summer.
- The extent of outages (number of transformers affected) was greatest due to weather events.
- Tree damage caused the greatest number of days with outages.
- An average of five outages occurred per transformer, but more occurred in eastern areas of Port Credit and in areas to the southwest within the buffer zone (Clarkson area).

Electrical grids are exposed to damage from trees (tree limbs hitting conductors, for example), especially if the trees are deciduous or old, and if the canopy is dense. Most trees in Port Credit are likely deciduous (as in Mississauga in general) and relatively old (over 60% of the properties are more than 55 years old and many trees are likely to be the same age), making older areas in the community likely to be more vulnerable.

Storyline 4: Preparing Populations for Extreme Heat

Heat waves are long periods of extreme heat, which can cause serious and widespread human health problems. There are many heat-related illnesses, including heat cramps, fainting, heat exhaustion, and heat stroke. In some cases, exposure to heat waves can lead to death. Climate change is anticipated to produce stronger heat waves that occur more often, increasing the risk of heat-related health hazards.

Some people in Port Credit are more vulnerable to heat waves because of health, age and social factors that make them more likely to become ill or prevent them from knowing about heat warnings and acting on them to reduce the risk. Key factors include the following:

- Pre-existing health conditions (heart disease, mental illness, diabetes, obesity, respiratory illness, for example)
- Use of certain medications and drug or alcohol abuse
- Age (infants, children less than four years old and adults over 65 years old are more vulnerable)
- Lifestyles (working outdoors, playing sports or running outside, for example)
- Communication barriers (language barriers, for example)
- Social isolation (for example, no internet or cell phones; living alone)

The built environment can influence a person's vulnerability to impacts of heat waves. For example, the top floor of an apartment building without air conditioning can be much hotter than the ground level.

Built environments can also exacerbate the impacts of heat waves. Areas heavily covered by pavement and buildings retain more heat than natural areas such as forests and greenspace, and cause the Urban Heat Island (UHI) effect. UHIs can be up to five degrees warmer than surrounding areas, but areas with good tree canopy cover and the cooling effect of Lake Ontario help to lessen the effect of UHI in Port Credit.

Heat waves also worsen air quality (smog) as heat contributes to development of ground level ozone, greater pollen production and the spread of particulate matter (dust), which can cause respiratory illness, lower cardiovascular function and make pre-existing health conditions worse, especially breathing conditions such as asthma. Between 2003 and 2013, there were 58 smog advisories issued by the Ministry of the Environment and Climate Change for Peel Region.

> Ongoing climate monitoring and evaluation of measures to reduce vulnerability will be key to a successful adaptive management approach.

Where Do We Go From Here?

Information is key to effective adaptive management. Regular data collection will help improve our understanding of climate change and its effects on community services and assets, and this increased knowledge can then inform wise decision making. In particular, ongoing climate monitoring and evaluation of measures to reduce vulnerability will be key to a successful adaptive management approach.

This vulnerability assessment describes key critical impacts of climate change (floods, variable Lake Ontario water levels, electrical power outages and heat waves) on many community services and assets. Decision makers will need more information on other supporting systems, trade-offs among impacts and the effect of cumulative impacts (the combination of past, present and future impacts) to rank the importance of different impacts and prioritize management strategies.

Results of the vulnerability assessment highlight opportunities for adaptive management of climate change impacts on community services and assets in Port Credit.

Opportunities to address vulnerability to floods:

- Encourage municipalities, businesses and residents to assess and mitigate lot-level flood vulnerabilities
- Maintain and clear debris from drainage systems
- Address threats to transportation networks (Go Transit station and main highways), water and wastewater utilities (pumping stations and the water supply network) and critical community and emergency services (health care clinics, food supply, financial services) in more detail

- Protect and restore natural areas to strengthen flood regulation

Opportunities to address vulnerability to variable Lake Ontario water levels:

- Evaluate plans and designs to ensure they reflect more variable and unpredictable water levels, particularly for Inspiration Port Credit, the Waterfront Parks Strategy and the Lake Ontario Integrated Shoreline Strategy
- Evaluate impacts at an infrastructure and property level

Opportunities to address vulnerability to electrical power outages:

- Study design and maintenance of the electrical grid components to determine how lifespans of equipment may change
- Consider use of other power sources (solar, wind and other renewable, low-carbon energy sources)

Opportunities to address vulnerability to heat waves:

- Build public awareness of the health hazards of heat waves and how to prevent them
- Tailor messages to a diverse audience
- Provide and assess the use of public cooling stations
- Prepare emergency response plans that coordinate activities of health care workers, emergency responders, police and public health agencies
- Protect and restore natural areas to combat urban heat island effect

Climate Change Vulnerabilities of Community Services and Assets in the Region of Peel

A case study in Port Credit

Complete Technical Report

Prepared for:

Region of Peel
Working for you

Prepared By:

Toronto and Region Conservation for The Living City — Ontario Climate Consortium — RSI Risk Sciences International

RECOMMENDED CITATION

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1. Ontario Climate Consortium Secretariat
2. York University
3. Risk Sciences International

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ACRONYMNS

ACCCRN	Asian Cities Climate Change Resilience Network
AQI	Air Quality Index
CMIP5	Fifth Coupled Model Inter-comparison Project
CSA	Canadian Standards Association
CVC	Credit Valley Conservation
DA	Census Dissemination Area
GCM	Global Climate Model
GHG	Green House Gases
GLISA	Great Lakes Integrated Sciences and Assessments Centre
GTA	Greater Toronto Area
IDF	Intensity Duration Frequency Statistics
IJC	International Joint Commission
IPCC	Intergovernmental Panel on Climate Change
LID	Low Impact Development
LOISS	Lake Ontario Integrated Shoreline Strategy
MNR	Ontario Ministry of Natural Resources and Forestry
PCCS	2011 Peel Climate Change Strategy
PM	Particulate Matter
RCP	Representative Concentration Pathways
SPA	Special Planning Area
TRCA	Toronto and Region Conservation Authority
UHI	Urban Heat Island
WMO	World Meteorological Organization

1. INTRODUCTION

The purpose of this project is to understand the meteorological, biophysical and human factors that mediate the effects of climate change on multiple classes of community assets and services in Port Credit. In order to reduce the impacts and take advantage of opportunities presented by climate change, stakeholder response should support effective adaptation and mitigation strategies. This assessment aims to characterize current and future opportunities and vulnerabilities associated with climate change, with a focus on adaptation. This report is intended to be used by regional and municipal officials, decision makers and interest groups within Port Credit and the Region of Peel for planning purposes.

1.1. Adaptive Management

Adaptive management is recommended by the Intergovernmental Panel on Climate Change (IPCC) as an effective framework for responding to climate change at the local scale (IPCC 2014). In accordance with this guidance, Adaptive Management has been selected as the central framework for responding to climate change in the Region of Peel. Figure 1 represents a conceptual framework of the five milestones identified by the International Council for Local Environmental Initiatives (ICLEI) as constituting the key steps of adaptive management, and this framework is specifically intended to inform municipal planning (ICLEI 2011). This framework shows the cyclical nature of Adaptive Management and the importance of research as an input to the planning phase. Milestone 2 of the ICLEI framework (i.e., “Research” step in Figure 1) specifically identifies climate risk and vulnerability assessments as a critical task needed to inform the identification of potential responses to climate impacts and risks, termed “adaptation alternatives” (ICLEI 2011). Appendix A defines each milestone’s purpose and ultimate outcomes in more detail, including Milestone 2. This assessment is a direct contribution to Milestone 2 in the ICLEI (2011) framework.

Figure 1: Adaptive management cycle (from ICLEI, 2012)

1.2. Peel's Climate Change Planning Process and Strategy

This report has been prepared to align with the objectives and actions specified in the 2011 *Peel Climate Change Strategy* (PCCS) and ongoing climate adaptation processes being led by the Region of Peel. The Region of Peel, in partnership with the cities of Brampton and Mississauga, Town of Caledon and the Credit Valley and Toronto and Region Conservation Authorities, developed the PCCS as a roadmap for addressing climate change impacts locally (Region of Peel 2011). Currently, the strategy is in the process of being updated with refined information on sector-specific climate change effects, primarily focused on risks and vulnerabilities. This information will feed into community consultation and policy analysis designed to synthesize the findings from these reports into an integrated climate change strategy update for the Region of Peel. This synthesis/update process is an important step in the adaptive management process being used to respond to climate change and other policy pressures in the Region of Peel.

The original PCCS identified six major objectives to mitigate and adapt to climate change, as follows:

1. Proactive and responsive planning and leadership;
2. Actions to reduce greenhouse gases (mitigation);
3. Targeted and proactive adaptation actions;
4. Making the shift to a green economy;
5. Increasing awareness and level of engagement throughout Peel; and
6. Ongoing research and adaptive risk management.

For each objective, the strategy identified specific actions that stakeholders could undertake to support effective mitigation of, and adaptation to climate change. A timeframe, thematic focus area, and set of responsible stakeholders were identified for implementing each action. In order for several of these individual activities and adaptive management more broadly to proceed, substantial work to characterize climate change impacts and system vulnerabilities was identified as important prerequisite within Action 1.1. This report aims to contribute directly to this action.

Action 1.1 mandates the completion of "a vulnerability risk assessment of all infrastructure, of the community and of natural heritage" within the PCCS goal of "proactive and responsive planning and leadership". Together, this goal and action provide the foundation for adaptive management within the region of Peel.

1.3. Assessment Objectives and Scope, and Limitations

This assessment is designed to feed directly into the process of adaptive management being implemented in the Region of Peel to plan for climate change. Specifically, this report falls within Milestone 2: Research phase of the ICLEI (2011) framework, which is intended to provide the information needed for developing an adaptation plan in Milestone 3. Give this context, the assessment objective is to understand the climatic, biophysical and human factors that influence climate change impacts and vulnerabilities for various classes of community assets and services critical to Port Credit. This information is then used at the conclusion of the report to identify considerations that should be kept in mind while seeking alternative options to develop the adaptive capacity of the area, with respect to the impacts presented through the report. These considerations are not meant to be a prescription for addressing community impacts and vulnerabilities, but rather it is intended to advance dialogue on adaptation that will be required as adaptation plans are refined during Milestone 3 of the ICLEI adaptation process (i.e., “Plan” step in Figure 1).

More specifically, this assessment seeks to address the following questions:

- What are the climate change impacts relevant to community assets and services in Port Credit, and by extension, the Region of Peel?
- What are the processes and factors that influence vulnerability to climate change with respect to the various community assets and services under consideration?
- What are the current adaptive capacity resources that contribute to reducing vulnerability to climate change?
- What are some considerations that should be kept in mind while further increasing adaptive capacity to reduce vulnerability and take advantage of opportunities?
- What key questions related to climate vulnerability and adaptation in Port Credit still need to be answered?

To address the objectives and research questions posed, this assessment emphasizes characterizing current climate vulnerability in the Region of Peel in order to identify the most salient factors that influence the extent, magnitude and overall character of climate and weather impacts on community assets and services today (IPCC 2014). Future climate scenarios are also considered, and are used to assess how this current vulnerability might change under the influence of climate change. This analysis refers to what the IPCC defines as “outcome vulnerability” (referred to in this report as “future vulnerability”) (IPCC 2014). This approach of considering current vulnerability first and then using future climate scenarios to determine which climate conditions are most critical to municipal services and assets today and in the future is presented in Figure 2. It is also consistent with approaches to vulnerability assessment presented in various other assessments relevant to municipalities, such as Engineers Canada (2011), Gleeson et al. (2012), and UKCIP (2013).

It is recognized that many other systems and contextual factors contribute to the effects of climate change on community services and assets beyond the systems themselves, such as community socio-economic and cultural factors, fiscal and political constraints, ecosystem health, among many others. It is however, beyond the scope of this report to examine all of these other elements and their effects in detail. Many of these systems are currently undergoing climate change assessments that can be consulted during subsequent planning processes requiring more detailed information.

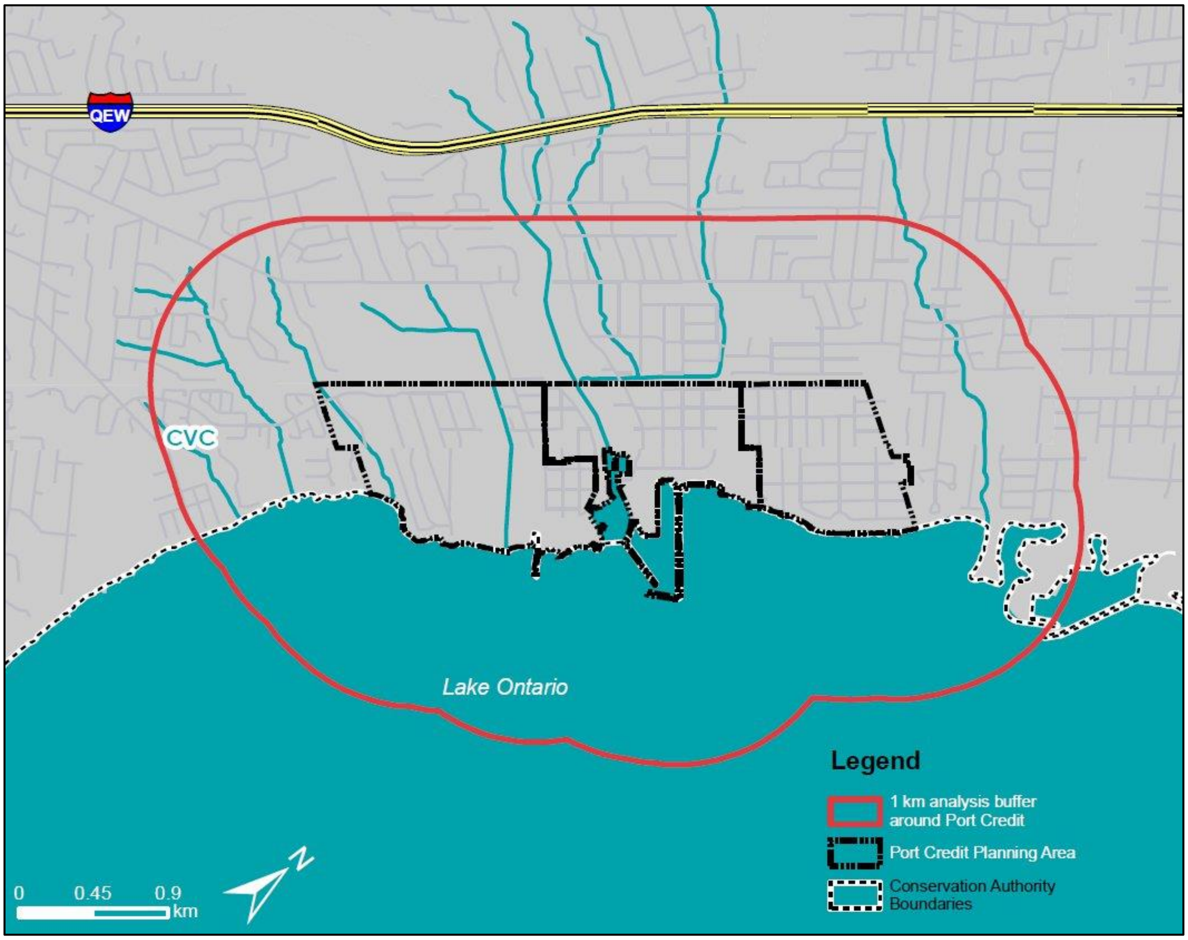

Figure 2: Geographic Scope included Port Credit's Planning Area plus a 1km buffer.

Given the large number of community assets and services in Port Credit, it was not possible to assess all potential impacts at the highest level of detail. Only the impacts deemed to be the most most critical were assessed in great detail. It should be recognized that these detailed analyses were based on stakeholder identification as being important. As such, additional work is needed to assess other impacts that may not have been currently prioritized by stakeholders, but may emerge as priorities during the synthesis process or other analyses. The geographic scope of this this assessment is also a key limitation. Since this assessment is meant to be a community-scale scale case study, analysis is focused exclusively on the Port Credit Planning Area plus a 1 km

buffer (See

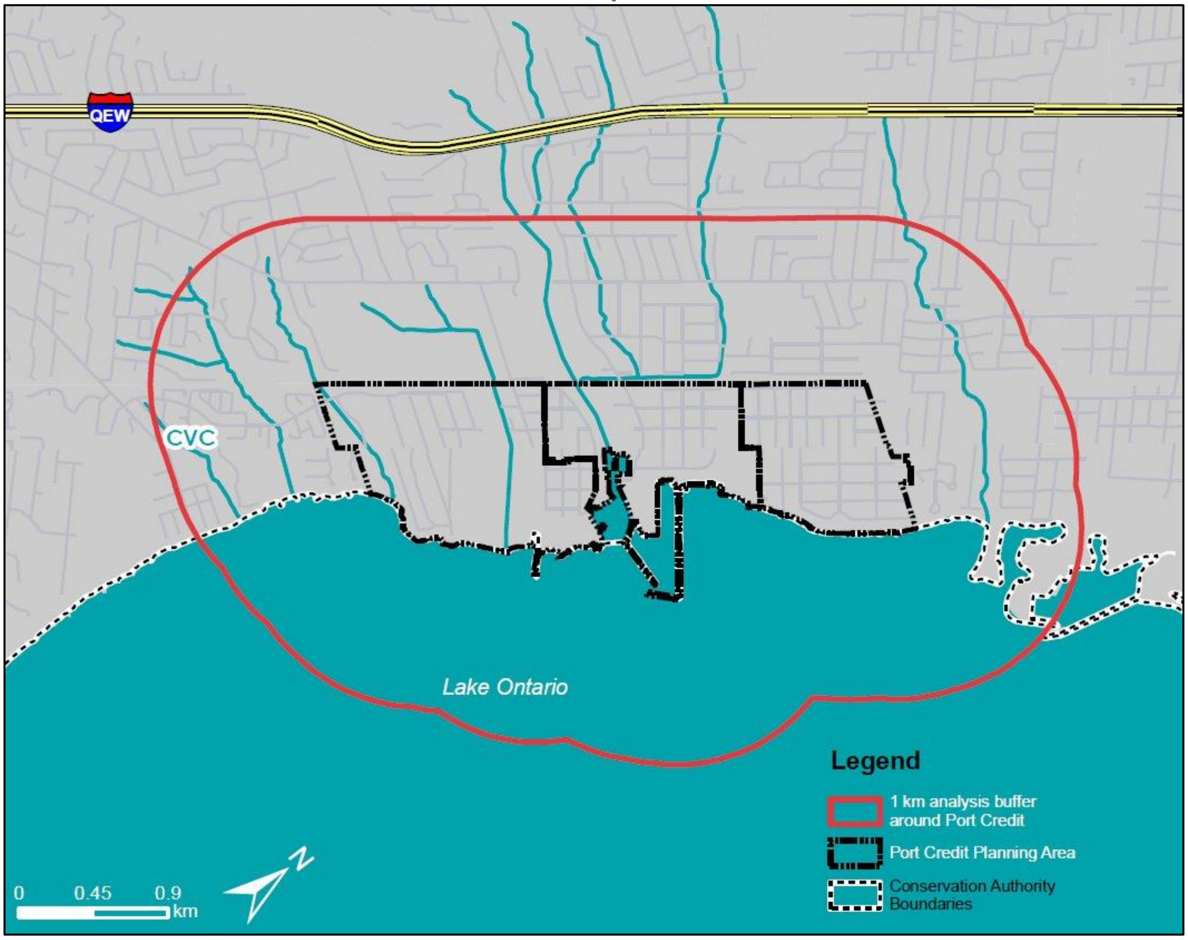

Figure 2: Geographic Scope included Port Credit's Planning Area plus a 1km buffer.. As this is a localized area, it is currently unclear how applicable these results will be to other communities in Peel. Where possible, the storylines contain descriptions of how impacts in Port Credit may affect Peel as a whole. Additionally, due to the small scale of analysis, variability in vulnerability in Port Credit is lower compared to Peel as a whole and is likely not representative of other planning areas with different characteristics.

1.4. Intended Audience

This technical report is intended to be used for planning purposes by regional and municipal officials, decision makers and interest groups involved in the design and operation of community services and assets in Port Credit. The report is focused on understanding the major effects of climate change to various classes of community assets and services in the community. An emphasis is placed on understanding the integrated nature of climate change effects on various assets and services. Given that this kind of integrated analysis requires focusing on the community as a whole, many of the findings are directly relevant to other stakeholders, such as citizens, interest groups and the local business community.

By understanding the anticipated implications of climate change on community assets and services, decision makers can identify and prioritize alternative responses that represent viable adaptations. Such adaptation measures may be implemented through adjustments to operational practices, design of new systems, administration of broader policies and programs, and by building adaptive capacity within the range of stakeholders that comprise the community of Port Credit. Ultimately, the aim of any adaptation initiatives and the role of decision makers are to foster more resilient communities.

1.5. Issues and Needs

1.5.1. *Climate Change Impacts on Municipal Services and Assets*

The most recent assessment of climate change (see definition in Box 1) by the Intergovernmental Panel on Climate Change (IPCC) concluded “with certainty” that human influence has been the main cause of recently observed global temperature increases (IPCC 2013). The IPCC found that if global GHG emissions are not significantly reduced, warming trends will continue, leading to a shift in the overall timing, magnitude, variability and frequency of temperature, precipitation and seasonality, as well as more intense and recurrent extreme weather events. Through its 2014 report, the IPCC group of scientists warned that at the current rate of warming, significant impacts to a variety of human dependent systems are likely, even if GHGs are curbed (IPCC 2014). One area of particular importance within the Region of Peel is the impact of climate change and extreme weather on the operation, design and planning of services and assets that support community wellbeing.

Within the Region of Peel, numerous public and private sector organizations contribute to community well-being through the maintenance of physical assets and provisioning of goods and services. These include, but are not limited to electrical, transportation, and water management infrastructure, recreation and tourism facilities, economic goods and services across an array of sectors, ecosystem management, emergency response, education and health care. Climate and weather considerations are embedded in the design, operation and planning for these assets and services in

Box 1: Definition of climate change

For the purpose of this study, climate change refers to a change in the state of the climate by changes in the statistical properties (e.g., mean and/or the variability) in weather and atmospheric conditions that persists for an extended period, typically decades or longer.

(IPCC 2014)

Box 2: Definitions of weather, climate and climate change

Weather and Climate: Weather is defined as the state of the air and atmosphere at a particular place and instant in time. Climate is a larger-scale expression of the weather conditions for a particular location and period of time, including variations and extremes. (Adapted from WMO 2011)

Climate Change: For the purpose of this study, climate change refers to a change in the state of the climate by changes in the statistical properties (e.g., mean and/or the variability) in weather and atmospheric conditions that persists for an extended period, typically decades or longer. (IPCC 2014) many ways. For instance, all infrastructure and buildings are designed in accordance with codes and standards that mandate withstanding temperature, wind, precipitation, humidity and other climatological loads. The timing and budgeting for operation activities, such as snow removal, outdoor recreation, public health campaigns (i.e., flu season), and tree plantings are all dependent on climatic variables either directly or indirectly. The occurrence of extreme weather events can significantly damage assets, disrupt services, and result in anticipated and unforeseen consequences. As the climate changes, so will the effectiveness of historical assumptions about weather and climate that have driven the design and operation of community assets and services in the Region of Peel.

Although there is high confidence in global projections of climate change, local-scale effects are more complex due to both the variability in local climate and the multifaceted interactions and dependencies among assets, services and community characteristics. Given this, effectively managing multiple and interacting effects of climate change at the community-scale requires information on the variability in responses to climate change at the local scale, knowledge of the capacity and resources for managing u, and the uncertainty related to predicting impacts (Adger 2010; Adger et al. 2005; Laukkonen et al. 2009). Such analyses can enhance collective understandings of the potential threats and opportunities of climate change so they can be managed through adaptive strategies. This report aims to advance this understanding in the Region of Peel by providing information on a range of climate change vulnerabilities at the community scale, focusing on a case study in Port Credit, Mississauga. This analysis could eventually be expanded to other communities, asset classes, or services in Peel.

1.6. Defining Vulnerability to Climate Change

Definitions of vulnerability with respect to climate change are quite varied (Polsky et al. 2007; IPCC 2012), though consensus has generally formed around the concept of "potential for loss" within a given system (Cutter et al. 2009). For this assessment, the IPCC's 2015 definition has been adopted, which defines vulnerability as:

> *"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt"* (IPCC 2014, p. 1775)

The IPCC (2015) further suggests that vulnerability can be characterized in two manners, as (1) "contextual, or current vulnerability" and (2) "outcome, or future vulnerability". Current vulnerability is defined as:

> "*A present inability to cope with external pressures or changes, such as changing climate conditions... a characteristic of social and ecological systems generated by multiple factors and processes"* (IPCC 2014, p. 1762)

Future vulnerability is defined as:

"…the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability" (IPCC 2014, p.1769)

With respect to a managed system such as the community assets and services in Port Credit, the aforementioned definitions suggest that vulnerability can be thought of as being comprised of three categories of factors that influence the overall potential for impacts, or vulnerability (Figure 3):

(1) The climate itself;
(2) Biophysical factors that influence how climatic conditions are translated into impacts to specific systems; and
(3) Human, or management, factors that further mediate how climate influences the systems in question, and abilities to adapt to changing conditions.

As the climate changes and hazardous climate events and conditions occur in greater frequency, intensity and duration, the vulnerabilities in a given system can become more severe if sources of current vulnerability are not addressed. It is often recognized in climate change adaptation guidance that vulnerabilities can be addressed by increasing the adaptive capacity of a given system. This concept is explored further in Section 1.6, but is shown conceptually in Figure 3.

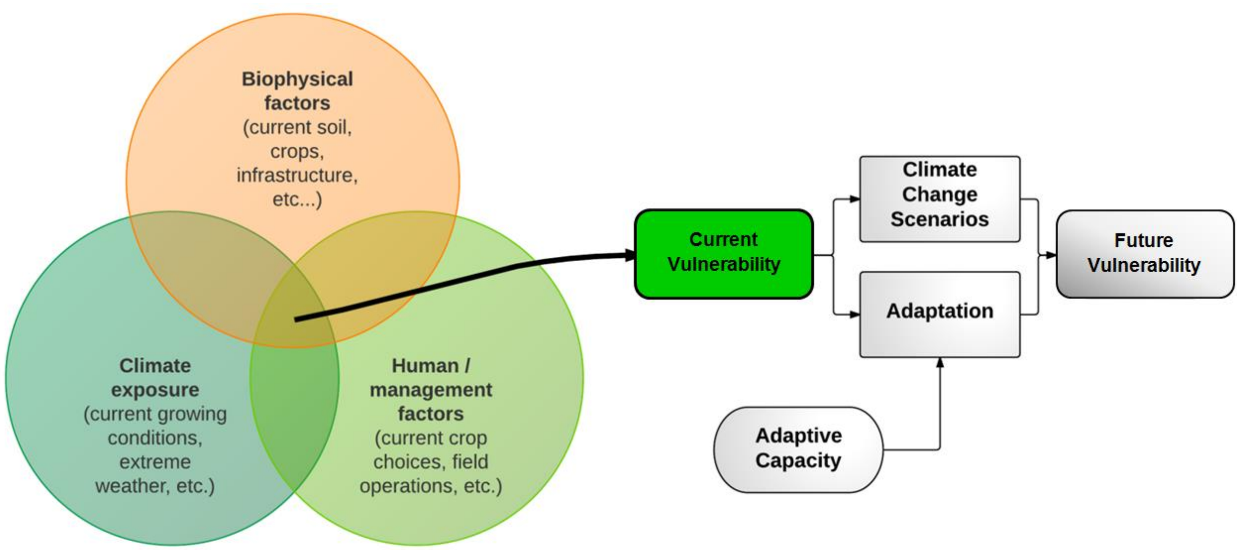

Figure 3: Conceptual diagram showing the factors that contribute to current vulnerability, the role of adaptive capacity in influencing adaptation, in combination with climate change scenarios that ultimately influence future vulnerability for agricultural systems.

1.7. Adaptive Capacity and Resilience: Frameworks for Responding to Climate Vulnerability

Many of the assets and services that function to preserve and advance community wellbeing are inherently sensitive to climate and weather (based on their designs and operational policies). The degree to which an overall community is vulnerable to impacts from changes in climate is therefore directly proportional to the ability of its infrastructure, assets, services and populations to withstand those climate conditions and weather events. Based on the definitions provided in Section 1.6, the vulnerability of those assets and services is a function of both biophysical and management factors.

Ultimately, vulnerability to changes in temperature, precipitation, or impacts from extreme weather events depends on the assets' or services' ability to cope and remain productive under a range of different and highly variable conditions, including climate hazards. This ability is often referred to as resilience, which is tied directly to a system's ability to absorb and recover from climate stresses. The ability to cope is also related to the system's adaptive capacity, which is thought of as its capacity to adapt to changing conditions over time (Gallopin 2006). The most recent version of the IPCC's definition of adaptive capacity is: "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2014, p. 1758). Adaptive capacity has a focus on the concept of "adjustment" or "system learning", while resilience refers more broadly to a system's ability to cope with negative climate impacts while maintaining its key functioning and abilities, including adaptive capacity. IPCC (2014) defines resilience as "the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation." (p. 1772).

The concepts of climate change resilience and adaptive capacity can be regarded as two system properties that reduce vulnerability (Reed et al. 2013; Wamsler et al. 2013; Tyler and Moench 2012; Lowe et al. 2009; Gallopin 2006). As such, responses to climate change often rely on building resilience and adaptive capacity (Reed et al. 2013; Tyler and Moench 2012) directly related to the biophysical properties of a system, but also to the way in which the system is managed. It is evident that building both resilience and adaptive capacity are essential strategies for addressing climate change vulnerabilities. This concept is presented graphically in Figure 4, which shows that influence of climate on managers and institutions responsible for the decisions and management of the services and assets, and the community services and assets themselves, are mediated by adaptive capacity and resilience.

Based on the assumption that climate change and extreme weather events will continue to increase in magnitude and frequency and will likely have implications for community services and assets, enhanced adaptive capacity and climate resilience are becoming increasingly recognized as key objectives in municipal decision making (Reed et al. 2009). Adaptive capacity and resiliency-based decision making aim to reduce climate risk by understanding and responding to the underlying factors that contribute to a system's vulnerability, such as the biophysical processes, community assets, socio-economic status, health of ecosystems (Cabell and Oelofse 2012; Rival 2009). Such approaches also rely on developing integrated strategies that simultaneously target multiple sources of vulnerability and which have co-benefits to other management objectives. These strategies have been effectively applied in large municipalities globally through initiatives such as the Asian Cities Climate Change Resilience Network (ACCCRN), and regionally through the Great Lakes and St. Lawrence Cities Initiative's Municipal Adaptation and Resiliency Service, the adoption of the ICLEI (2011) adaptation planning framework, and other numerous local initiatives. Example on-the-ground initiatives have included the integration of green infrastructure to manage stormwater and reduce the urban heat island (UHI) effect[1], low-impact land development guidelines[2], enhancements to urban ecosystems and greenspace[3], diversification of local economies[4], and enhanced disease and health monitoring systems[5].

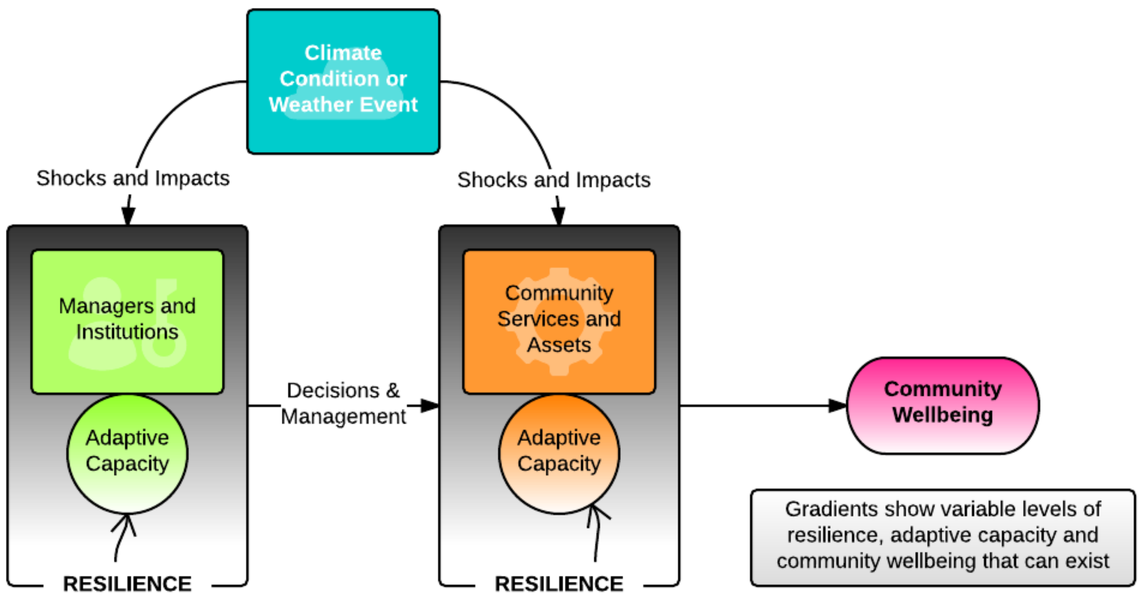

Figure 4: Conceptual diagram showing how enhanced resilience and adaptive capacity ultimately influence community wellbeing by mediating climate impacts. Adaptive capacity and resilience are variable across a community (adapted from: Djalante et al. 2013; Tyler and Moench 2012)

1.8. Assessment Report Structure

This report is structured to gradually provide the reader more detailed analysis of the interaction between climate and community services, and assets in Port Credit. Section 2 (Background)

[1] https://coast.noaa.gov/digitalcoast/sites/default/files/files/publications/04062014/GLPilots_Final_5-5-14v2.pdf
[2] http://www.creditvalleyca.ca/wp-content/uploads/2014/04/LID-SWM-Guide-v1.0_2010_1_no-appendices.pdf
[3] http://greatlakesresilience.org/case-studies/habitat-environment/considering-climate-western-lake-erie-habitat-restorations#strategy
[4] Tyler and Moench (2012)
[5] http://acccrn.net/sites/default/files/publication/attach/ACCCRN_ProjectsInsightsPaper.pdf

provides the necessary background on how the system of multiple assets and services is defined and its relation to climate in general, in addition to qualitatively describing the decision-making framework(s) that may support adaptation. Section 3 (Methods) describes the detailed analytical methods used, and is supported by additional detail in several appendices. Section 4 describes some fundamental limitation of this work, which readers should keep in mind in interpreting the results. Section 4 presents an analysis of the key climate effects and sources of vulnerability for the systems in question, it also describes some fundamental limitations of this work which readers should keep in mind in interpreting the results. This section presents the results of the analysis by first identifying and prioritizing impacts (4.1), then describing how climate variables relevant to the systems in question are likely to change in the future (4.2), followed by an identification of the critical factors that make Port Credit's community assets and services vulnerable to climatic changes, including detailed descriptions of specific critical impacts through "Storylines" (4.3). The report concludes by characterizing the current sources of adaptive capacity in Port Credit (Section 5), in addition to identifying some potential adaptation alternatives that might be considered in building climate resilience in Port Credit (Section 6).

2. BACKGROUND

2.1. Study Area Description

The Port Credit Planning District, as officially defined in the City of Mississauga's Port Credit Local Area Plan Review consists of three distinct sectors located on the shore of Lake Ontario, surrounding the mouth of the Credit River (Figure 5). The central planning sector, called the Port Credit Community Node consists of mixed residential, commercial, recreational and greenspace land-uses and surrounds the Credit River. Residential neighborhoods exist on both sides of the Port Credit Community Node. Based on these boundaries, the Port Credit planning area is 227 ha and has an approximate population of approximately 12,500 people[6]. For the analyses completed in this study, a 1 km buffer was applied around the Port Credit planning area.

[6] http://www.mississauga.ca/portal/residents/mississaugadata

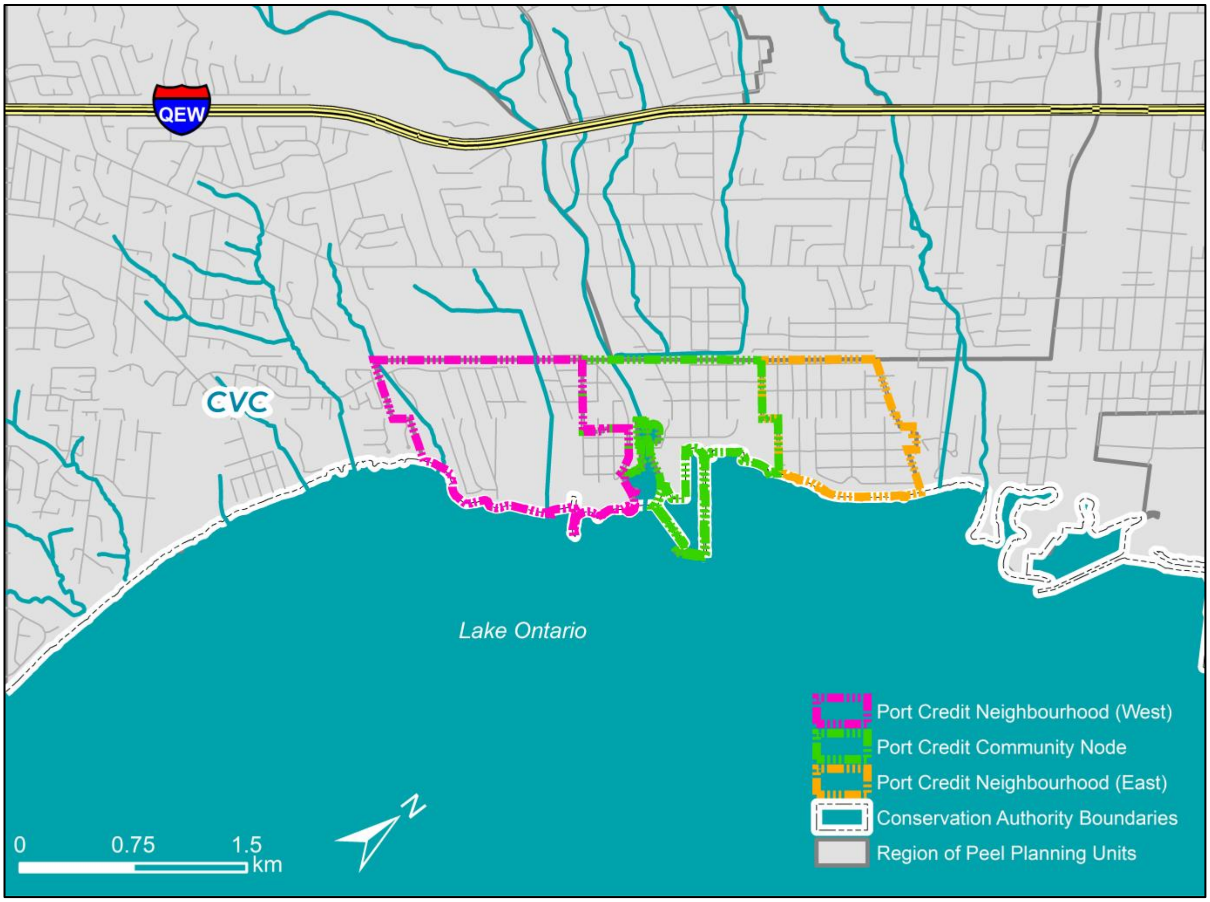

Figure 5 Map identifying the three Port Credit planning sectors.

Port Credit has substantial local cultural significance due to its long history as a destination for lake-based commercial and recreational activities. Additionally it is a hub for transit, cultural and recreation facilities, with several ecologically sensitive areas associated with the Credit River and Lake Ontario. As part of the City of Mississauga's Official Plan Review, Port Credit has undergone a long-term visioning and revitalization process, which has defined the vision for the area as "an evolving urban waterfront village with a mixture of land uses, a variety of densities, pedestrian and cycling friendly transit supportive urban forms, a significant public realm, public access to the waterfront and development that incorporates high quality built form". There are several specific policy and land re-development projects designed to help achieve this vision both within and surrounding Port Credit that present important opportunities to address climate change adaptation within the community. These are:

- **Port Credit Local Area Plan Review** (within the Mississauga Official Plan Review)[7]: Review of and amendments to current land uses, designed to achieve the overall vision for Port Credit.

[7] http://www.mississauga.ca/portal/residents/portcreditreview

- **Inspiration Port Credit** (property redevelopment project)[8]: Visioning process to determine potential uses for two large properties scheduled for redevelopment – a marina property at 1 Port Street East, and a vacant lot at 70 Mississauga Road South.
- **Lake Ontario Integrated Shoreline Strategy (LOISS)**[9] (shoreline ecosystem protection study and planning process): Shoreline conditions assessment and planning process focused on protecting and enhancing terrestrial and aquatic ecosystems in the south Credit River and shoreline areas.
- **Lakeview Waterfront Connection Project** (coastal park development)[10]: Creation of a new natural waterfront park in the Lakeview neighborhood east of Port Credit designed to enhance aquatic and terrestrial wildlife habitat and provide public access to the waterfront.
- **Port Credit GO Transit Station Redevelopment** (creation of a transit hub)[11]: The Port Credit GO Transit rail station was designated as a "transit hub" by Metrolinx and will undergo substantial redevelopment to upgrade station infrastructure, enhance access and multiple modes of transportation, and optimize mixed working and living conditions.

Currently, the land use within Port Credit is predominantly residential, however there is an important commercial district spanning the full length of Lakeshore Road. The Credit River valley, Lake Ontario shorelines, numerous smaller stream corridors, and patches of greenspace provide important wildlife habitat and recreational space in and around Port Credit. There are several critical pieces of infrastructure, including the Lorne Park Water Treatment Facility, the GO Transit station and Canadian National Railway line, several large community recreation facilities, 3 different large marinas (Figure 6).

[8] http://www.mississauga.ca/portal/residents/inspirationportcredit
[9] http://www.creditvalleyca.ca/watershed-science/living-by-the-lake/cvcs-shoreline-strategy-loiss/
[10] http://www.creditvalleyca.ca/planning-permits/planning-services/environmental-assessment/lakeview-waterfront-connection/
[11] http://www.metrolinx.com/en/aboutus/mediarelations/news/20150302_Port_Credit_Station_Redevelopment.aspx

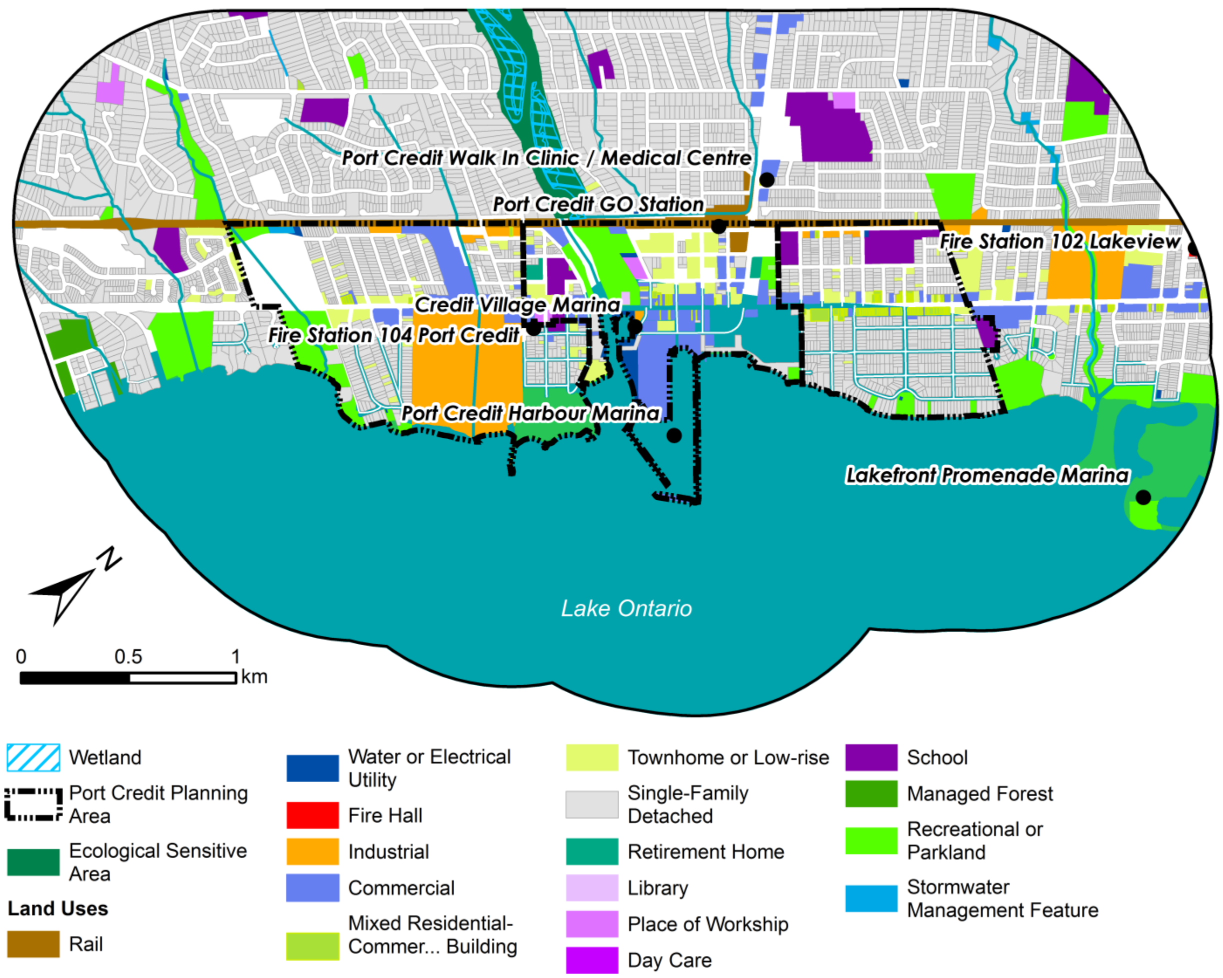

Figure 6 Land use and major community assets in Port Credit

2.2. Defining Community Services and Assets

In order to assess the climate change vulnerabilities to community services and assets in Port Credit, it is first necessary to define the system under consideration. ICLEI (2011) provides a breakdown of municipal service areas that could be considered within a city-wide climate change adaptation planning exercise. This breakdown was slightly modified to represent the "system" of community assets and services present in Port Credit and is shown in Figure 7. Within this framework, the community services and assets (shown as grey box and text in Figure 7) represent the tangible management areas aimed at ensuring that social, physical (i.e., built form), ecological and economic systems are robust and ultimately able support community wellbeing (shown as green venn diagram in Figure 7). Each community service and asset represents a unique operational system that is comprised of built or natural infrastructure, and is managed and influenced by public agencies/government, the private sector, community organizations/interest groups, and private citizens (shown as orange text and arrows at the bottom of Figure 7).

It should be noted that all of the assets and services directly on the shoreline and related to coastal activities were included under the scope of coastal management. This includes shoreline parks managed by the City of Mississauga, private marinas and boating operations, naturalized areas (beaches, dunes, etc.), hardened shoreline protection and breakwater infrastructure, and private property fronting Lake Ontario. The characteristics of the entire Region of Peel shoreline have been characterized in detail as part of the LOISS characterization study (Aquafor Beach Limited 2011; GHD 2013), the Port Credit Memorial Park (West), Marina Park and JC Saddington Park redevelopment processes following from the 2008 City of Mississauga Waterfront Parks Strategy (Brooks McIlroy 2008), Inspiration Port Credit (Stoss 2013), and the shoreline hazard mapping (Shoreplan Engineering 2005).

The conceptual diagram below recognizes that individual assets and services influence one another in complex ways that ultimately affect the broader social, physical, ecological and economic systems which support community wellbeing (shown as grey ellipses and arrows at the bottom of Figure 7). Finally, this framework identifies that community assets and services are all exposed to the climate system, which in-turn affects their functioning and ability to satisfy broader objectives.

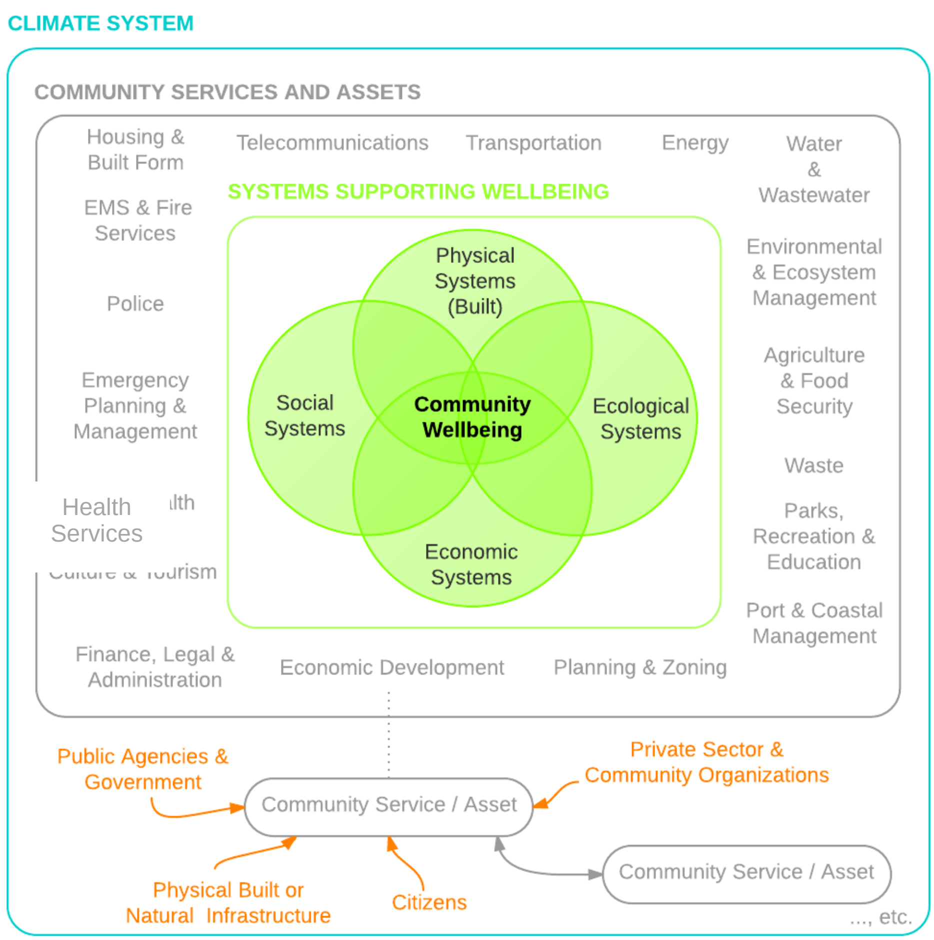

Figure 7 Conceptualization of the community assets and services comprising the social, economic, ecological and physical systems that support wellbeing in Port Credit. Solid arrows denote important influences on community assets and services.

2.2.1. *Climate Impacts to Community Services and Assets*

Within a community such as Port Credit, climate and weather can have a wide range of direct and indirect impacts. An example of a direct impact would be a windstorm damaging the electrical grid. An example of an indirect impact to the same electrical grid could be a heat wave resulting in extensive usage of air conditioning, straining the electrical supply, causing a brown-out. In both cases, the ultimate outcome is a negative impact to the electrical grid, which is a core community asset and which in turn has consequences for the community – loss of electrical supply and downstream effects, along with unforeseen and opportunity costs to the utility associated with repairing damage. Any given asset or service can be affected over short-term and long-term periods. For example, extreme precipitation may result in a flood event, which represents a short-term impact having consequences to various assets and services. An example of a long-term impact may be gradual declining summertime precipitation, resulting in lower water levels on Lake Ontario, which could have an array of impacts on water quality, recreational access, and shoreline geomorphology. These aforementioned examples of single community assets being impacted by weather or climate are over-simplified, but provide helpful illustrations of the range of potential nature of direct and indirect climate impacts that need to be planned for in the short and long-term.

If assets are damaged or services strained due to either instantaneous weather-related impacts, such as extreme events, or in the long term due to changing climate conditions, community needs and objectives may be unmet. Short-term consequences are typically characterized by disruptions to services or damage to assets and threats to populations, which require an immediate response and can strain financial, staff and other resources. Long-term consequences of climate impacts are generally associated with longevity of assets and the effectiveness of operational policies and procedures under changing frequencies of weather events or climatic conditions.

Under many climate and weather conditions, multiple assets and services are impacted simultaneously. Impacts to one asset or service can have effects on others, translating to cumulative and unpredictable consequences at the community scale. As such, the analysis of climate impacts is not necessarily straightforward, and requires understanding the chain of events that begin with a climatic condition or weather event, and ends with the ultimate consequence of interest (Smith et al. 2014; Pramova et al. 2013; Eggen and Waldmueller 2012; Fellmann 2012; Fussel and Klein 2006). With respect to Port Credit and the objectives of this assessment, the ultimate consequences of climate impacts pertain to the ability of assets and services to perform their intended functions, which ultimately contribute to the wellbeing of the community (see Figure 7). Whether short or long term, direct or indirect, impacts to community assets and services ultimately impact their ability to function and to satisfy the wellbeing of the community.

3. ASSESSMENT METHODS

3.1. Overall Approach

This analysis of climate impacts in Port Credit was carried out using a phased approach, with a focus on engaging local stakeholders and iteratively refining analysis as new information was produced or became available at each step. The phases were focused on generating information needed to assess the various factors influencing current vulnerability (Figure 3).These specific phases of analysis were based on guidance for conducting climate change risk and vulnerability assessment in ICLEI (2012), UKCIP (2003), Gleeson (2011) and Engineers Canada (2011). The cities of Toronto, Chicago, London, Vancouver, Halifax, New York, Los Angeles, and regions such as the State of Wisconsin, the Okanagan Valley and parts of the western Canadian plains all provided helpful guidance in completing climate or extreme weather risk and vulnerability assessments, as they all drew upon the aforementioned documents. The following key features have been adopted in the current study, as they are common in all these example jurisdictions and in the broader body of literature in adaptive management and climate resilience:

- Stakeholder engagement was used to drive the entire vulnerability assessment process, specifically in identifying climate and extreme weather variables of interest, learning from prior experiences with climate impacts, risk management, and adaptation, and the prioritization of vulnerabilities and opportunities for detailed analysis;
- Meteorological variables (e.g. temperature, precipitation) downscaled to the Region of Peel were used to characterize how the exposure of community assets to climate conditions is projected to change in the future in comparison to current variability. Results were interpreted considering the uncertainty of climate projection datasets. The projections of future climate based are based on the high-forcing RCP 8.5 scenario, and were analyzed for the time frame of 2041-2070 (Auld et al., 2015).
- A combination of qualitative and quantitative methods were used for characterizing the relationship between climate, vulnerabilities, primary physical impacts, and cascading secondary impacts, ultimately affecting community assets. These relationships are presented in this report through “storylines”. Information describing impacts and vulnerabilities was synthesized from a systematic literature review and input from the community obtained through a workshop.

Figure 8 provides a more detailed overview of the steps involved in the analysis employed in this assessment, and it is consistent with others completed in the Region of Peel on themes of the natural system, agriculture, public health, and the economy. While Figure 8 presents the project phases as linear, it should be noted that certain steps proceeded in parallel, for example “system characterization” and “climate impact identification”, “climate drivers” and “climate indicators”, as well as “vulnerability factors” and “vulnerability indicators”. Sections 3.2 through 3.8 provide more details on how each phase was completed.

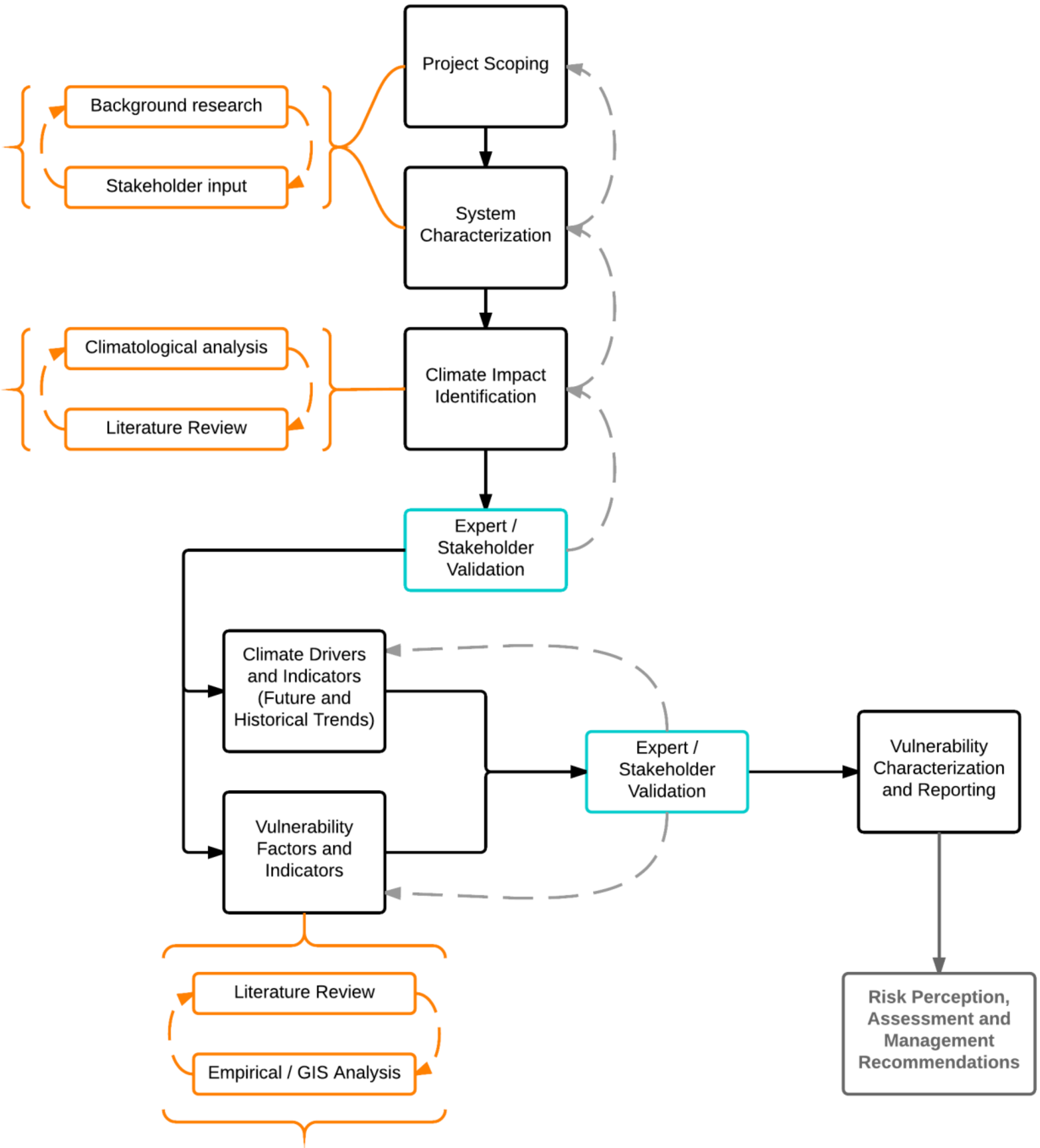

Figure 8 Flow chart illustrating overall flow and individual phases

The analysis steps were completed in order to develop the information needed to assess current and future vulnerability, although it was beyond the scope of this study to fully assess the latter. The first set of steps is identifying the scope of vulnerability analysis, which is followed by defining the systems and their components to be assessed. These steps were informed by background research, in addition to seeking feedback from stakeholders. The second set of steps involved elucidating, and where possible quantifying, historical or potential future climate impacts to the system defined previously. This impact information was cross-validated using a combination of local stakeholder perspectives, literature information and empirical data. Following the identification of impacts, a systematic literature review was conducted to identify key vulnerability "factors" and associated metrics, or "indicators" used to characterize vulnerability for the most critical impacts locally in Port Credit. The outputs of these steps were then synthesized into a series of “storylines” describing the most important vulnerabilities. This information identifies potential adaptation alternatives that could be pursued to address root sources of vulnerability.

3.2. Stakeholder Input

Stakeholder engagement and input was a core contribution in the project, particularly in the scoping and for validating results of literature-based vulnerability analysis. This was accomplished through a combination of project meetings, formal and informal interviews and focus-group workshops. Initially two meetings were held with stakeholders to develop a refined scope of this assessment and a harmonized approach for linking the overall project to the PCCS. These meetings provided the first opportunity to decide upon the study areas and seek input on the level of detail required of information used for adaptation-based decision making locally. These meetings resulted in an initial terms of reference for the project, and most importantly an identification that stakeholders were seeking “decision-ready” information, which was defined with the following attributes:

- Information should support and fit within current decision-making frameworks;
- Analysis should be scientifically defensible; and
- Outputs should effectively address and communicate the uncertainty associated with predicting future climate.

Workshop participants were then asked to provide feedback on preliminary lists of system vulnerability indicators developed through a literature review. During the exercise, participants were first asked to individually rank the perceived importance of the different vulnerability factors, and were then guided through a discussion to arrive at a group consensus and explain the rationale for their ranking. A summary of the key stakeholder engagement processes conducted subsequent to the initial project scoping session within each case study is presented in Table 1.

Table 1 Timeline of Stakeholder Engagement for the Port Credit Assessment

Jan, 2013	Assessment scoping meeting	The purpose was to refine the focus of the assessment by hosting a brainstorming session with key stakeholders on the project team; this included a presentation on historical weather/climate issues identified in the Region to date through forensic impact analysis (Appendix B). This was helpful in defining key issues of concern for consideration at the workshop.
Feb, 2013	Scoping follow-up teleconference	Update on the status of the project with key stakeholders to decide upon scope and agenda for the workshop.
Jun, 2013	Workshop I: Issues and Climate Driver Exploration	The lessons learned from the run-through streamlined the workshop and helped us develop a more interactive program that borrowed from elements of *World Café (see Appendix C for workshop materials)*.

Jul, 2013	Update webinar	With a view to keeping key stakeholders informed of progress to date, the project team provided an update detailing initials findings from the workshop and next steps.
Aug to Oct, 2013	Interviews with municipal staff and stakeholders for documentaries	Interviews focused on a variety of issues identified at the June workshop, including the impact of climate change/extreme weather on Lake Ontario, including recreational/business perspectives; human health vulnerabilities and the role of climate change on municipal stormwater management infrastructure and ultimately the management of such vulnerabilities to public and private property.
Nov, 2013	Workshop II: Exploring Vulnerability Results and Developing Adaptation Recommendations	The follow-up Port Credit workshop provided an opportunity to share the results from preliminary literature reviews and analysis of climate vulnerabilities. It also provided the opportunity to discuss potential adaptations and upcoming work focused on natural heritage management and climate change adaptation.

3.3. Project Scoping

The first phase of this assessment was solidifying the scope of the vulnerability analysis to be undertaken, including defining geographies of interest, target systems and scales of focus within the overall study area, timeframes for future vulnerability assessment, and key decision-making processes for consideration within adaptation alterative research. The scope of this assessment was established over a number of initial meetings in the fall of 2012 and winter of 2013 with key stakeholders that had been involved in the development of the concept for this case study. These stakeholders included Environment Canada, the City of Mississauga, the Credit Valley and Toronto and Region Conservation Authorities, and the Region of Peel. Table 2 presents a summary of the key aspects of the study scope.

The following criteria were used to select a case study, and it was ultimately determined that Port Credit effectively satisfied these:

- **Shoreline community:** Study area needed to be a small community on the shoreline of Lake Ontario
- **Produce "decision-ready" information:** In order to produce relevant outputs, the study area needed to have ongoing policy and decision making processes that could benefit from climate change analysis.
- **Diversity of community services and assets:** The study area should have a good variety of community assets and services, including infrastructure, cultural and recreational landmarks, a productive natural heritage system, and a mix of land uses that would enable for a unique analysis of different systems.
- **Engaged Community for Effective Stakeholder Participation:** Government, the private sector, citizens and interest groups should be active in the community in order to engage in workshops and participatory assessment processes.

Table 2 Summary of study scope parameters decided following initial background research and stakeholder discussions

Geography for Analysis	Port Credit planning zone, with a buffer of 1 km
Timeframe	Priority 1: Current, or current vulnerability, to climate conditions to understand current profile of climate impacts and how they could be managed with adaptation, with an emphasis on flooding Priority 2: 30-50 years for future-oriented vulnerability pertaining to strategic decision (infrastructure, land redevelopment, investments, etc.)
System	Initial focus on all municipal services and asset class Detailed analysis of key priority systems: shoreline, private properties, roadways, human health, electrical distribution system
Scale	Neighborhood and asset classes
Potential decision-making & policies implicated	Municipal operations and large land and shoreline redevelopment projects (see Section 2.1 for a description of major policy initiatives in Port Credit)

3.4. System Characterization

In order to effectively complete vulnerability analysis it is critical that the boundaries of the system in question are well defined (Engineers Canada 2012). Section 2.2 previously described the key community assets and services that constitute the "components" defining the "community system" in the Port Credit. While such a breakdown can be regarded as a simplification of and reductionist approach to analyzing a complex system, such as the community services and assets in Port Credit, it is often helpful to understand sources of vulnerability and the processes through which climate events or conditions result in impacts. The breakdown used in this project was based on the municipal service areas defined in ICLEI (2011) and is consistent with similar breakdowns used in Tyler and Moench (2012), the City of Toronto's Resilient City Strategy[12] and the City of Thunder Bay's climate adaptation plan[13].

3.5. Climate Impact Identification

A key step in the vulnerability assessment process is to understand the range of potential impacts to the system and its components under consideration (IPCC 2014). Several different pieces of information and approaches were used to identify key climate impacts of relevance to the systems under examination in Port Credit. The first phase of work involved conducting background research to identify a range of historical and potential future climate impacts pertaining to the systems in Port Credit. This was accomplished through a combination of stakeholder consultation and forensic analysis of historical climate impacts in the Mississauga area in recent history, with an emphasis on events in the last 20-30 years (since 1980). This forensic analysis was completed by reviewing periodical reports, media reports, and locally

[12] http://www.toronto.ca/legdocs/mmis/2014/pe/bgrd/backgroundfile-70623.pdf
[13] http://www.thunderbay.ca/Assets/Earthwise+Assets/docs/Climate+Adaptation+Section+of+Sustainability+Plan.pdf

relevant literature following the guidance for impact identification described in Milestone 2 of ICLEI (2011).

A subset list of climate events was also presented to stakeholders at a focus group workshop to elicit their perspectives and prioritize impacts associated with specific climate drivers that would require more detailed vulnerability factor and indicator analysis (Appendix E). This is consistent with a “bottom-up” approach to climate vulnerability analysis (Brown et al. 2012)

During the focus group workshop, participants were asked to provide further detail on the cascading chain of impacts associated with climate conditions and weather events deemed to be of priority importance. This activity was first completed individually and then in a group consensus using the Institute for Cultural Affairs’ “consensus workshop” method described in Stanfield (2002). Participants were also facilitated in a group discussion designed to address questions pertaining to the types of information needed to assess impacts, existing policies, programs, and design elements to add adaptive capacity, along with perspectives on synergies between different hazards (see Appendix C for workshop materials).

3.6. Climate Indicators

Climatological indicators are used to inform the exposure element of vulnerability, and characterize potential hazards (IPCC 2014). Historical analysis of climate variables along with future projections relevant to agriculture in the Region of Peel are presented in Section 4.1 and 4.2 of this report and further detail on trends and projections is presented in Auld et al. (2015). Table 3 summarizes the variables selected to represent the main climate hazards and opportunities employed during the stakeholder consultations. For each variable, historical baseline and future trends and statistics were analyzed to inform current and future vulnerability.

Table 3 Summary of climate indicators used to represent various climate conditions prioritized by stakeholders

Climate Condition / Event	Indicator
Seasonal Temperature	Mean monthly temperature [°C]
Seasonal Precipitation	Total seasonal precipitation [mm]
Wind Patterns	Mean seasonal surface windspeed [m s^{-1}]
Extreme Winds	No local indicator data available
Extreme Precipitation Intensity	1-day maximum precipitation accumulation [mm]
	5-day maximum precipitation accumulation [mm]
Extreme Precipitation Frequency	Total annual precipitation in the 95^{th} percentile [mm]
	Total annual precipitation in the 99^{th} percentile [mm]
Extreme Heat	Mean maximum temperature [°C]
	Days with daily maximum temperature > 30°C
Snowpack / Snowcover	No local indicators available
Drought	Moisture index (precipitation – evapotranspiration) [mm]
Weathering (Freeze-Thaw)	Days with maximum temperature > 0 and minimum temperature < 0

For variables based directly on temperature and precipitation, datasets from McKenney et al (2011) produced by the Canadian Forest Service were used as the baseline. In brief, this dataset interpolates Environment Canada climate station data and produces a spatially continuous climate surface at daily intervals. This dataset is often used as a baseline for climatological studies, as its residuals are quite low. Interpolated values showed average annual residual value of 0.36°C, 0.66°C and 4.7mm compared to the observed maximum temperature, minimum temperature and total annual precipitation normal for 1981-2010 period for the Pearson International Airport Station. A key benefit of using gridded data was that it provided information on the spatial trends in the Region of Peel. A key limitation with the McKenney et al (2011) dataset however, is that it tends to mute the signal of climate extremes (Razavi et al. 2015). For humidity and wind velocity variables it was not possible to obtain historical gridded data. As such, station-based records from the Pearson International Airport Station were used, as they represent the closest station with information pertaining to these variables, in addition to having the longest period of record. Auld et al. (2015) contains additional information on historical trends.

An ensemble approach to generate future climate projections for the Region of Peel, as documented in Auld et al. (2015) was used for this report. The key purpose for using an ensemble is that it captures the full range of uncertainty associated with Global Climate Models (GCM) that are used as the fundamental input for all other downscaled datasets. The ensemble used in this study consisted of the GCMs that comprise the Fifth Coupled Model Intercomparison Project (CMIP5), which represents the same dataset used by the IPCC in its Fifth Assessment Report (AR5). This ensemble consists of forty one different GCMs that are run using four different future climate scenarios, termed Representative Concentration Pathways (RCP). For this project, the high-forcing emission scenario, RCP8.5, was analyzed, as it represents a conservative estimate of potential future climate (Taylor et al. 2012). To generate localized projections for the Region of Peel, a time series of monthly output for temperature, precipitation, along with annual time series for several extreme indicators were obtained for each GCM within the CMIP5 ensemble for the grid cell containing the Region of Peel. Since each GCM has a slightly different grid configuration, a linear re-gridding procedure was first employed to align the grids of each GCM. After re-gridding, the following future monthly ensemble statistics were computed for each ten-year period beginning in 2011 through 2100: Mean, median, standard deviation, 10th percentile, 25th percentile, 50th percentile, 75th percentile and 90th percentile. Each statistic's value was then subtracted from the baseline CMIP5 ensemble average to generate a "delta", or change, value for each period. For the 2050s, the period of 2041-2070 was used. To obtain spatially disaggregated information in Peel, these deltas were then added to baseline historical spatially gridded data from McKenney et al. (2011) for the corresponding month.

With its most recent report, the IPCC has become much more confident in the findings about climate change at the global scale, however, confidence at the local scale is much more limited. This is due to critical scale and parameterization limitations in global climate models, gaps in historical climate data, and fundamental limitations in understanding within climatology and climate impact assessment. The greatest confidence in climate variables is for regional-scale seasonal variables associated with temperature, precipitation and synoptic-scale atmospheric processes. More localized climatic changes that need to be characterized at finer spatial and temporal scales are more difficult to quantify. For example, there is great uncertainty within current climate science for projecting precise changes to the frequency and magnitude of extreme weather events. Additionally, many of the vulnerability indicators used to contextualize more generic processes and factors in Peel have not been ground-truthed. Although they have all been used in previous studies, highly precise interpretations of these indictors in Peel are not recommended. Additionally, while there is generally confidence with regards to the broad classes of impacts expected under scenarios of climate change, the scenarios themselves are uncertain (Moss et al. 2010). Consequently, the impacts discussed in this report should not be managed with approaches that require an assumption of precision or accuracy (Tyler and Moench 2012).

3.7. Vulnerability Factors and Indicators

Given that specific assets and the administration of services varies across Port Credit, so will the vulnerability of the community to climate change. Additionally, different climate conditions and weather events will have varying impacts. Therefore, any given neighborhood, element of infrastructure, or operational scenario will have varying vulnerabilities to climate change based on the biophysical and management factors (see Figure 3). For instance, different reaches of shoreline will experience varying levels of impact under the same storm conditions based on their physical properties, maintenance regimes and orientation relative to wind-driven waves. The identification of these factors and the relevant processes they influence are critical pieces of information for understanding current and future vulnerability, and are also essential to effective ongoing adaptation monitoring and evaluation (ICLEI 2011).

In this study, we use the concept of “Vulnerability Factors” to represent a quality or characteristic of a system that causes it to be more or less vulnerable to a given climatic condition or event. Such factors can represent either biophysical or human management aspects vulnerability. Given that many of the impacts of interest, for damage to community assets or disruptions in services, result from a series of impacts to intermediate processes, an important part of the understanding vulnerability is the elucidation of these, which are termed “Intermediate Impacts”, for this study. Vulnerability Factors and Intermediate Impacts were researched for several of the most critical impacts within Port Credit through a systematic literature review of existing studies on the interactions between climate and priority systems in question. A standardized series of Microsoft Excel ® templates, known as the Peel Climate Risk Analysis Framework and Templates (P-CRAFT), were used to extract information from individual studies and reports, and interpret commonalities in the information to determine and codify the most salient Vulnerability Factors, Intermediate Impacts, and their relationships. More detail is available in Appendix D.

Following the identification of vulnerability factors, metrics were selected for representing these factors locally in Peel, termed “Vulnerability Indicators”. These indicators were developed using a set of criteria described in Appendix E. Datasets were then collected and analyzed using a combination of spatial and statistical methods. The results are presented for the relevant "storyline" throughout Section 5. It is important to note that there may be some processes and factors not captured in this conceptualization, however the ones represented in this section are based on information with high confidence. While there may be some missing processes and factors, robust adaptive management will enable these to be identified and managed over time.

3.8 Characterization of Major Climate Variabilities in Port Credit

Several climate drivers were identified as priority influences on Port Credit vulnerability based on feedback from local stakeholders in Peel and through analysis of the future and historical climate trends associated with a range of climate variables. The conditions for identifying a variable as a priority for more detailed analysis were (1) whether stakeholders identified it as a critical influence historically, and (2) whether the associated climate variables are projected to intensify in frequency and/or intensity due to climate change (climatological analysis in Auld et al. 2015 and Section 4.2). The detailed analysis of the sources of vulnerability is characterized by the identification of "Vulnerability Factors", "climate impact chains" and narratives called "Storylines".

The narratives for each "Storyline" are drawn from the results of the systematic review of literature completed using the P-CRAFT templates (Appendix D) and when possible, supported by further analysis. Each impact scenario is derived from a conceptual diagram of the relationships between the climate driver and the ultimate impact of interest by way of a series of intermediate impacts. The analysis is based firstly on characterizing the biophysical processes through which climate conditions translate into disruptions to public services in Port Credit. The management, adaptive capacity and interventions used to manage those conditions are then superimposed by adding other "processes" and relevant vulnerability factors.

4. RESULTS

4.1. Historical Climate and Weather Impacts in Port Credit

It is evident from the breakdown of the historical climate conditions, weather events and their associated impacts uncovered for Port Credit through the background literature research, that the majority of climate impacts recorded historically pertained to extreme weather events, compared to seasonal climate conditions (Table 4). By far, the most number of events in this list pertain to extreme precipitation or large storms. In few cases, monetary cost estimates were available for these events and those available are provided in the "Description" column in Appendix D. The costliest historical climate impacts have been large winter storms and floods. Recently, the 2013 July flood and December ice storm are estimated to have cost over $1 billion[14] in insurable losses and $275 million[15] in damage to public assets, for those events respectively. Other notable events, such as Hurricane Hazel (1954) and the 1999 winter storm have estimated monetary costs of $1 billion and $122 million for the GTA, respectively[16]. While these monetary estimates of damage are important indicators, they do not capture the full range of impacts. Weather events such as these, in addition to changes in climatic conditions, can have a wide array of qualitative effects and implications for decision-making, planning and design pertaining to community services and assets.

Figure 9 provides a summary of the diversity of impacts to the various community services and assets under consideration in this assessment, broken down by their associated climate driver, and as identified by stakeholders in the focus group workshop. In total, 189 unique impacts were identified, representing a significant quantity (see Appendix F for full listing). Many impacts were also associated with multiple climate drivers, and several impacts pertained to every community asset and service. Table 4 presents a summary of the climate impacts that pertained to more than five climate drivers or all assets and services. While many of the impacts that pertain to all services and assets are related to general administration and planning (e.g., budgetary and resource considerations, damage, and loss of service), there are a few specific impacts that stand out. For instance, the urban tree canopy is associated with such a wide range of assets and services that damage to trees or loss of tree canopy coverage can exacerbate many other impacts, such as the urban heat island effect, or damage from windstorms. Challenges with snow removal are also a specific impact that pertains to almost all assets and services. Additionally, issues associated with predictability of and assumed vulnerability levels for climate conditions and flooding were also relevant to all assets and services.

[14] http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=5BA5EAFC-1&offset=3&toc=show
[15] http://www.mississauga.ca/portal/cityhall/pressreleases?paf_gear_id=9700020&itemId=2700082q
[16] http://globalnews.ca/news/1046844/worst-natural-disasters-in-canadian-history/

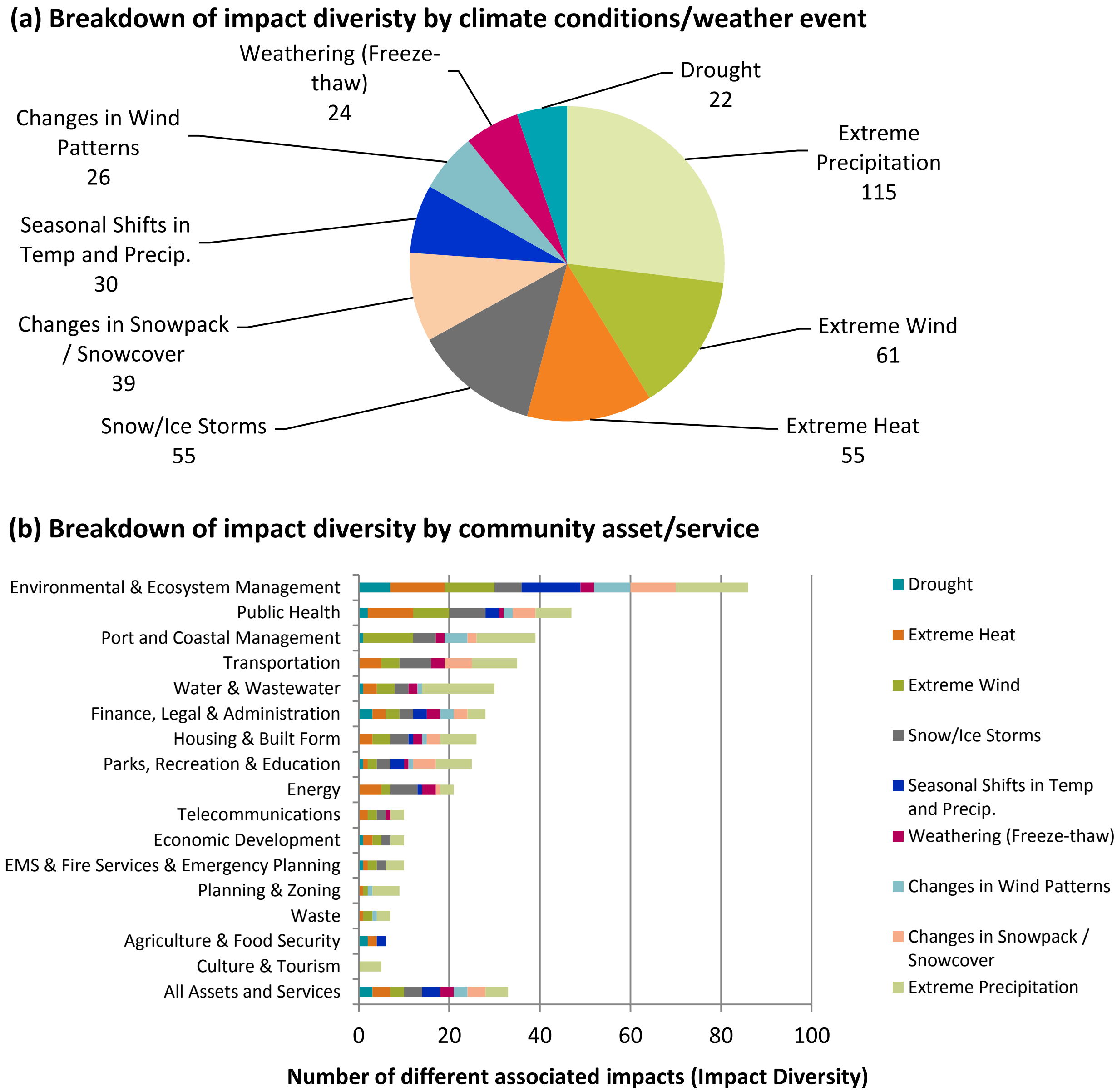

Figure 9 Total number of unique impacts identified by stakeholders broken down by (a) climate conditions/weather event and (b) community asset/service.

Table 4 Summary of climate impacts with relevance to all assets and services or more than 5 climate drivers.

Climate Impact	Community Asset /Service	Pertains to More than 5 Climate Drivers	Pertains to All Assets and Services
Additional energy and fuel needs	Energy	X	
Additional road and railway maintenance	Transportation	X	
Budget impact due to maintenance	Parks, Recreation & Education	X	
Changes and new invasive species	Environmental & Ecosystem Management	X	
Changes in operational practices and resource (staff, financial, time) needs	All	X	X
Damage/Loss of Infrastructure	All	X	X
Damage to urban tree canopy	All	X	X
Difficulty removing snow	All		X
Disrupted recreational access (boating, canoes, kayak, rowing, swimming, fishing)	Culture & Tourism	X	
Disruption to cultural and special events	Culture & Tourism	X	
Effectiveness of bylaws and operational policies	Finance, Legal & Administration	X	
Effectiveness of information-sharing and communications	Finance, Legal & Administration	X	
Enhanced UHI effect	All		X
Erosion of natural infrastructure (i.e., restoration projects)	Environmental & Ecosystem Management	X	
Greater injury risk	Public Health	X	
Impacts to biodiversity	Environmental & Ecosystem Management	X	
Less certainty flood frequency and impacts	All	X	X
Longevity of materials / infrastructure	All	X	X
Loss of tourism/visitors by boat	Culture & Tourism	X	
Loss or lowering of service capacity	All	X	X
Lower predictability of climate	All	X	X
Need for anticipating the unexpected in operations and design	All	X	X
Potential need for additional staff if issue is deemed a priority	All		X
Occupational health impacts	Public Health	X	
Shoreline erosion, including behind armour stones	Port & Costal Management	X	
Time needed to repair urban infrastructure	All		X
Truncated season for boating and lake-based recreation	Culture & Tourism	X	
Unknown human health hazards	Public Health	X	
Water quality impacts	Public Health	X	

At this stage, there is not adequate information to determine the relative priority of certain impacts. However, on the basis of the impact diversity, interpretation of the historical (Table 4) and described impacts, in addition to anecdotal discussions at workshops and meetings, the following impacts were interpreted to be of high importance to the community of Port Credit:

- **Energy (electrical supply grid):** Electricity is critical to an urban community such as Port Credit. Electrical outages have widespread impacts on almost every service area and can occur as a result of many different climate extreme conditions.
- **Port and Costal Management (shoreline and lake levels):** The Lake Ontario shoreline is a critical cultural, recreational and economic asset for Port Credit. Variability in lake levels and extremes can cause impacts to shoreline properties, municipal infrastructure, ecosystems, and recreational uses.
- **Transportation (roadways, transit and rail):** Transportation infrastructure, particularly roadways and the GO Transit rail line in Port Credit, are critical to day-to-day life. Damage to roadways can result in significant disruptions to a range of other services and can be particularly vulnerable during emergency situations.
- **Public Health (populations and public health services):** A healthy population is a critical aspect of community wellbeing. Climate impacts can affect people directly, and also the public health services designed to prevent widespread health impacts and provide coordinated responses under emergency situations.
- **Water and Wastewater (treatment and pumping facilities):** Water supply is critical to an urban community such as Port Credit. Shortages of water supply or problems processing wastewater have widespread impacts on a range of other assets and services.
- **Housing and Built Form (dwellings, businesses, and other facilities):** Damages to private housing, businesses, or public facilities have a range of short-term and long-term consequences to the local economy, in addition to posing significant health risks.
- **Environmental and Ecosystem Management (aquatic and terrestrial ecosystems):** Ecosystems are at the core of many critical functions in urban environments. Compromised ecosystem health can affect everything from water supply, provisioning of shade, recreation, and air quality regulation in an urban environment.

At the scale of a community such as Port Credit, weather and climate can be regarded as being of uniform distribution spatially. In other words, all assets and services in an area such as those described above can be expected to be exposed to the same weather and long term climate conditions. The influence of climate on the community services and assets present in Port Credit can therefore be expected to vary based on the ability of individual assets and services to withstand various climate conditions and extreme weather events. This ability can be expressed by the concept of vulnerability (defined in Section 1.6) and is a function of a given community's environment, its physical tolerances or properties, the characteristics of its populations, and the management and usage assets and services. Section 4.3 provides the results of studies describing vulnerabilities within several of the specific impacts listed above (Energy, Port and Costal Management, Transportation, Public Health, and Housing and Built Form).

4.2. Climate Trends in the Region of Peel

The following narrative pertaining to climate trends in the Region of Peel is summarized from Auld et al. (2015).

The general scientific consensus is that that climate change is very likely to result in increased temperature globally (IPCC 2013); however, the specific manner in which that trend will affect the local climate in the Region of Peel is more complex. For certain variables, specifically monthly precipitation, winds, humidity, and indices dependent on daily sequences, the specific changes are predicted within large ranges of uncertainty (Schindler et al. 2015; Deser et al. 2012). That being said, certain trends can be elucidated with higher confidence. In particular, the region will likely see increased temperatures over all seasons, and seasonal changes in precipitation distribution, along with greater probability of extreme temperature and precipitation events. More precipitation is likely to fall during the winter, with slightly greater amounts in the fall and spring. On average, the summer is likely to be drier, but punctuated by heavy rainfall events. The aforementioned trends are summarized in Table 5, and it is evident from the estimates that the uncertainty associated with climate change will make predicting seasonal climate conditions become more difficult.

Based on an analysis of past weather data and IPCC climate models applied to Peel Region, RSI forecasts with some certainty that Peel will experience increased temperatures over all seasons. It is very likely that the region will experience hotter summertime temperatures and more instances of heat waves. However, the proximity of Port Credit to Lake Ontario plays an important role in climatic conditions, as it can exert either a warming or cooling effect depending upon the season. In colder months, the lake provides a warmer moderating effect, while in summer months a cooler moderating effect due to the physical interactions of water bodies and the atmosphere. This cooling effect can help reduce the Urban Heat Island (UHI).

Table 5 Summary of baseline (1981-2010) and future (2041-2070) projected values for several climate indicators, along with interpretation of trends for the future for the RCP8.5 scenario.

Climate Condition / Event	Indicator	Season	Baseline Value	Lower Estimate	Upper Estimate	Lower Estimate Change	Upper Estimate Change	Interpretation[a]
Seasonal Temperature	Mean monthly temperature [°C]	Spring	7	9	11	2	4	Very likely warmer temperatures on average
		Summer	20	22	24	2	4	
		Autumn	10	12	14	2	4	
		Winter	-4	-1	2	2	5	
Seasonal Precipitation	Total seasonal precipitation [mm]	Spring	199	192	271	-4%	36%	Likely more precipitation overall, however more will fall as short-isolated events. Greatest increases are projected for winter and spring[b]
		Summer	219	186	261	-15%	19%	
		Autumn	221	197	272	-11%	23%	
		Winter	175	172	236	-2%	35%	
Wind Patterns	Mean seasonal surface windspeed [m s^{-1}]	Spring	3.8	3.7	4.0	-5%	5%	Uncertain with future trends showing no significant change
		Summer	5.1	4.8	5.4	-5%	7%	
		Autumn	4.8	4.6	5.0	-5%	5%	
		Winter	4.5	4.3	4.6	-3%	2%	
Extreme Winds	No local indicator data available							Uncertain - Plan for more instances
Extreme Precipitation Intensity	1-day maximum precipitation accumulation [mm]	Annual	38	36	48	-5%	27%	Likely more intense extreme precipitation events
	5-day maximum precipitation accumulation [mm]	Annual	59	56	75	-6%	27%	

Table continued on next page…

Climate Condition / Event	Indicator	Season	Baseline Value	Lower Estimate	Upper Estimate	Lower Estimate Change	Upper Estimate Change	Interpretation[a]
Extreme Precipitation Frequency	Total annual precipitation in the 95th percentile [mm]	Annual	218	213	327	-2%	50%	Likely more frequent extreme precipitation events
	Total annual precipitation in the 99th percentile [mm]	Annual	59	53	131	-10%	122%	
Extreme Heat	Mean maximum temperature [°C]	Summer	27	29	32	2	5	Very likely hotter summertime temperatures and more instances of heat waves
	Days with daily maximum temperature > 30°C	Summer	13	28	50	16	37	
Snowpack / Snowcover	No local indicators available							Likely less snow overall, by more will fall in heavy events
Drought	Moisture index (precipitation – evapotranspiration) [mm]	Growing Season (Apr-Oct)	-8	-52	13	539%	-262%	Likely overall drier season[b]
Weathering (Freeze-Thaw)	Days with maximum temperature > 0 and minimum temperature < 0	Autumn	17	4	9	-13	-8	Uncertain, as climate models may not capture these daily fluctuations well. Plan for more instances[c]
		Winter	38	29	37	-9	-1	
		Spring	28	13	22	-15	-7	

Notes: a. Interpretation is based on ensemble changes, in combination with expert opinions on the reliability of climate models in simulating the variable in question. See Auld et al. (2015) for more details.

b. Projections for Ontario suggest that precipitation during the summer months will be characterized by generally drier conditions interspersed with more frequent heavy rainfall events.

c. Although climate model ensembles suggest instances of freeze-thaw will decrease, weathering impacts are highly dependent on moisture fluctuations, which are not easy to interpret from global climate models. Additionally, freeze-thaw is a very fine temporal-scale process that is difficult to capture in global-scale models.

4.3. Storylines of Major Climate Vulnerabilities in Port Credit

The major climate vulnerabilities and impacts identified in this study are presented in the form of “Storylines”. The following impact scenarios were identified for more detailed analysis based the criteria outlined in Section 3.8 (stakeholder identification in Section 4.1, the climate trends in Region of Peel in Section 4.2, and climatological analysis in Auld et al. 2015) and mark the themes for the storylines.

Based on the application of these criteria, the following impact scenarios were identified for more detailed analysis:

- **Storyline #1: Multiple Causes of Flooding in Port Credit –** Extreme precipitation and wetter winters leading to greater likelihood of flash riverine flooding, gradual riverine flooding (wet watersheds), lake-based coastal flooding and infrastructure failures and urban flooding impacts on farm operations and crop productivity.
- **Storyline #2: A More Variable Lake Ontario Shoreline –** Extreme winds, regional-scale (Great Lakes Basin) moisture balance (P/ET) variability, and winter temperatures likely resulting in greater lake level variability, occurrence of extreme low lake levels, and storm surges leading to enhanced coastal erosion, sedimentation, flooding and asset damage.
- **Storyline #3: The Future of Power Outages in Port Credit:** Extreme winds, rainfall and heavy snow & ice storms, along with extreme heat likely increasing the frequency of power outages and reduce the longevity of overhead electrical infrastructure – a cornerstone asset in the community.
- **Storyline #4: Preparing Populations for Extreme Heat:** Instances of extreme heat are likely to get more frequent an intense, resulting in potential illness and strain on public health systems and community services.

The detailed analysis of the sources of vulnerability is characterized through the identification of “Vulnerability Factors”, “climate impact chains” and narratives called “Storylines”, presented in Sections 5.4.1 through 5.4.4. The narratives for each “storyline” are drawn from the results of the systematic review of literature completed using the P-CRAFT templates (Appendix D) and through limited consultation with local stakeholders and expert informants

4.3.1. *Storyline #1: Multiple Causes of Flooding in Port Credit Port Credit's Flood Typology*

In its 2012 report, entitled "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation", the IPCC defined flooding as:

"The overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods."

Flooding is the costliest natural hazard for Canadian municipalities (Public Safety Canada 2014), and has historically caused the greatest diversity of impacts to community assets and services in Port Credit. The consequences of flooding in an urban environment, such as Port Credit, are significant, widespread and highly diverse. They include, but not limited to disrupted transportation, electricity and water supply systems; damage to all forms of infrastructure, buildings, property, and personal belongings; risk of injury, disease and drowning; contamination to drinking water sources, surface water and groundwater bodies, and ecosystems; and associated longer-term, economic, human health and ecological impacts (Alderman et al. 2012; Kaźmierczak and Cavan 2011; Kundzewicz et al. 2013; Nastev et al. 2013). As such, flooding was identified early in this assessment as a climate-related issue of importance to stakeholders.

Port Credit is located in a complex hydrologic setting within the Region of Peel, exposing the community to possible floods driven by several different hydro-meteorological processes. These processes pose vulnerabilities to flooding independently of one another, but they can also occur simultaneously and interact. Additionally, each flooding mechanism is of greater relevance in different locations and at different times of year. Based on an inventory of historical flooding events (Appendix G), along with input from local stakeholder during the consultation process, four main classes of flood event were identified to be of relevance in Port Credit:

- **Flash riverine flooding** due to high-intensity, short duration rainfall as a result of convective or synoptic-scale precipitation events;
- **Gradual riverine flooding** due to spring freshet, elevated groundwater table, blockages (e.g., ice) in rivers, and combinations of other processes leading to overall wet watershed conditions;
- **Lake-based coastal flooding** due to storm surges and high water levels on Lake Ontario; and
- **Infrastructure failures and urban flooding** resulting from exceeded system design loads (excessive flows) and drainage system blockages (surcharged culverts and storm drains, sanitary sewer backup, etc.).

Given that there are many different hydro-meteorological processes that can lead to flooding in Port Credit, and that different assets and services may be exposed to different flood conditions, a large variety of both predictable and unpredictable impacts at the local scale are possible. This renders flood impact analysis a highly complex task; however, in order to develop strategies that build resilience against flooding in a community such as Port Credit, it is necessary to understand, as best as possible, the processes and factors that may lead to damage and disruption (Wilby and Keenan 2012). Figure 10 aims to enhance this understanding by providing an overview of the process and factors interpreted as components of a progression leading to damage of the assets or disruption of services, driven by the four major classes of flooding identified above (see Appendix H for vulnerability factor rationales). The following processes and factors were interpreted as being important influences on flood vulnerability in in Port Credit.

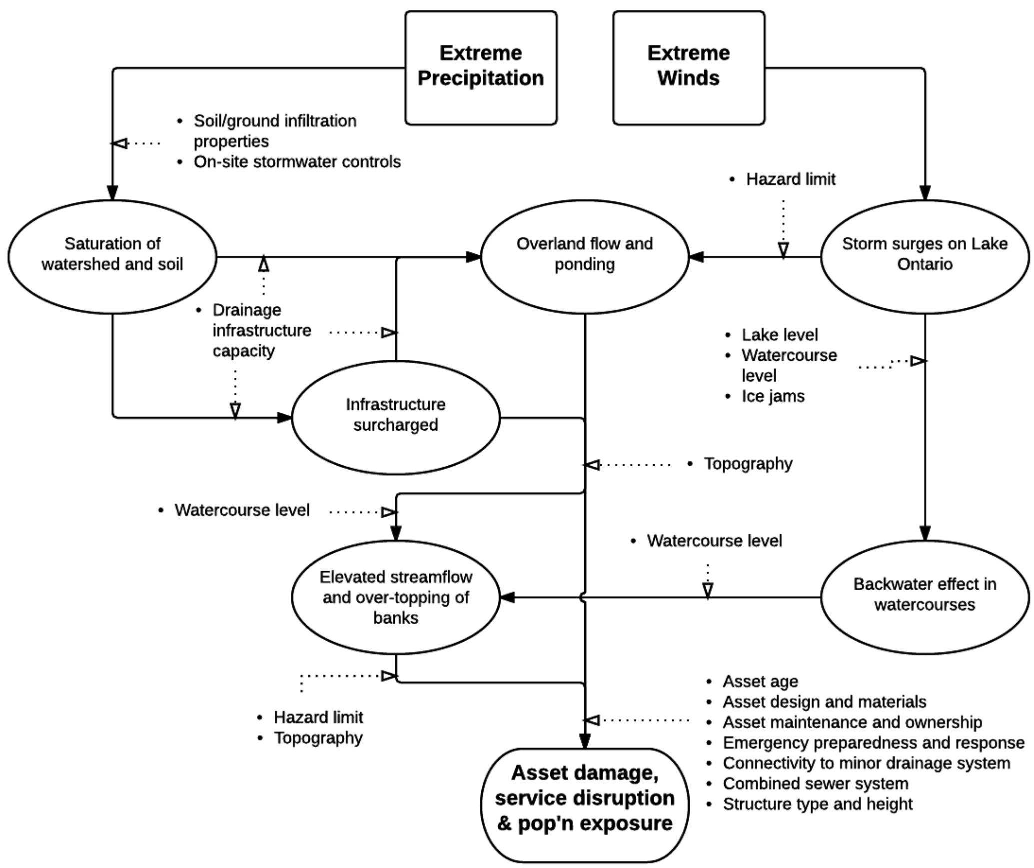

Figure 10 A conceptual diagram of the process (ellipses) and key factors (bullets) that influence the extent of flooding in Port Credit. Arrows show potential pathways leading to the ultimate outcome of asset damage, service disruption and exposed populations.

Consistent with the IPCC (2012) definition, Figure 10 illustrates that flooding begins with a hydrologic or meteorological process, which results in the accumulation of water (overland flow and ponding) due to a number of potential intermediate processes (e.g., elevated water levels, storm surges, infrastructure issues, etc.), ultimately leading to damage to an exposed asset or disruption to an exposed service.

The capacity of municipal drainage systems can be exceeded if the whole system's storage and conveyance capacities are exceeded by the intensity of a given storm, given that stormwater infrastructure is designed to handle maximum intensities that it is understood could be potentially exceeded. Also, there are key interactions between watercourses draining into Lake Ontario and the Lake itself. High water levels and storm surges on the lake can lead to backwater effects in watercourses draining to the Lake. This backwater effect could elevate water levels in upstream watercourses, increasing the likelihood of riverbanks being overtopped in the Credit River, Cooksville Creek, and Tecumseh Creek. High lake and stream water levels can also result in a lowering of the effectiveness of the drainage system to prevent overland flow, particularly if stormwater outfalls to streams and Lake Ontario become submerged or blocked by debris. Infrastructure-related flooding can also be caused if drainage infrastructure inlets become blocked by debris, which ultimately lowers the system's capacity, possibly increasing the amount of water that flows overland.

Evident from Figure 10 is the fact that there are a combination of factors pertaining to the hydrology and watershed conditions, management and maintenance of infrastructure and assets, and physical properties of the assets that mediate flood vulnerability. Variability in these factors across Port Credit means that assets and services are unevenly exposed to flooding, which is important to consider when characterizing the resiliency of built assets.

Areas within delineated floodplains and shoreline hazard zones should be regarded to be substantially more vulnerable to overland flooding from riverine or lake-based inundation, compared to other areas. Figure 11 presents a map of the regulatory riverine flood (Hurricane Hazel) and shoreline hazard (100-year extreme water levels and erosion allowances) delineations in the Port Credit study area, along with the percentage of land parcels (i.e., assessed properties) in each census dissemination area that is intersected by a hazard zone.

The fact that the land parcel is intersected by a hazard zone does not mean a structure will be flooded; however, it indicates that a property in and of itself may be vulnerable to flooding impacts. There are only three commercially-zoned parcels within the Port Credit Planning Area that are located within the riverine flood hazard zone; however, in the broader study area (1 km radius of the planning zone) there are 716. The majority of these 716 properties are in the Cooksville Creek Special Planning Area, and this area is currently undergoing significant flood remediation planning (City of Mississauga 2003). There are 70 properties within the shoreline hazard zone in the Port Credit Planning Area and another 55 in the surrounding buffer zone within the study area. For the properties intersected by flood hazard zones, key vulnerability factors pertain to whether their topography and soil conditions allow for water to flow overland or rise high enough to inundate structures and assets in the event of flooding.

Efforts are currently underway to assess each of these land parcels along with the shoreline as part of the LOISS, as such an assessment must occur at the property scale through field observation. Given the role of wave-action on coastal flooding, properties considered to be more vulnerable to impacts due to wave action are those where offshore conditions are non-depth-limiting, meaning that waves are not dissipated by gradual changes in nearshore lake bathymetry (Strum 2013).

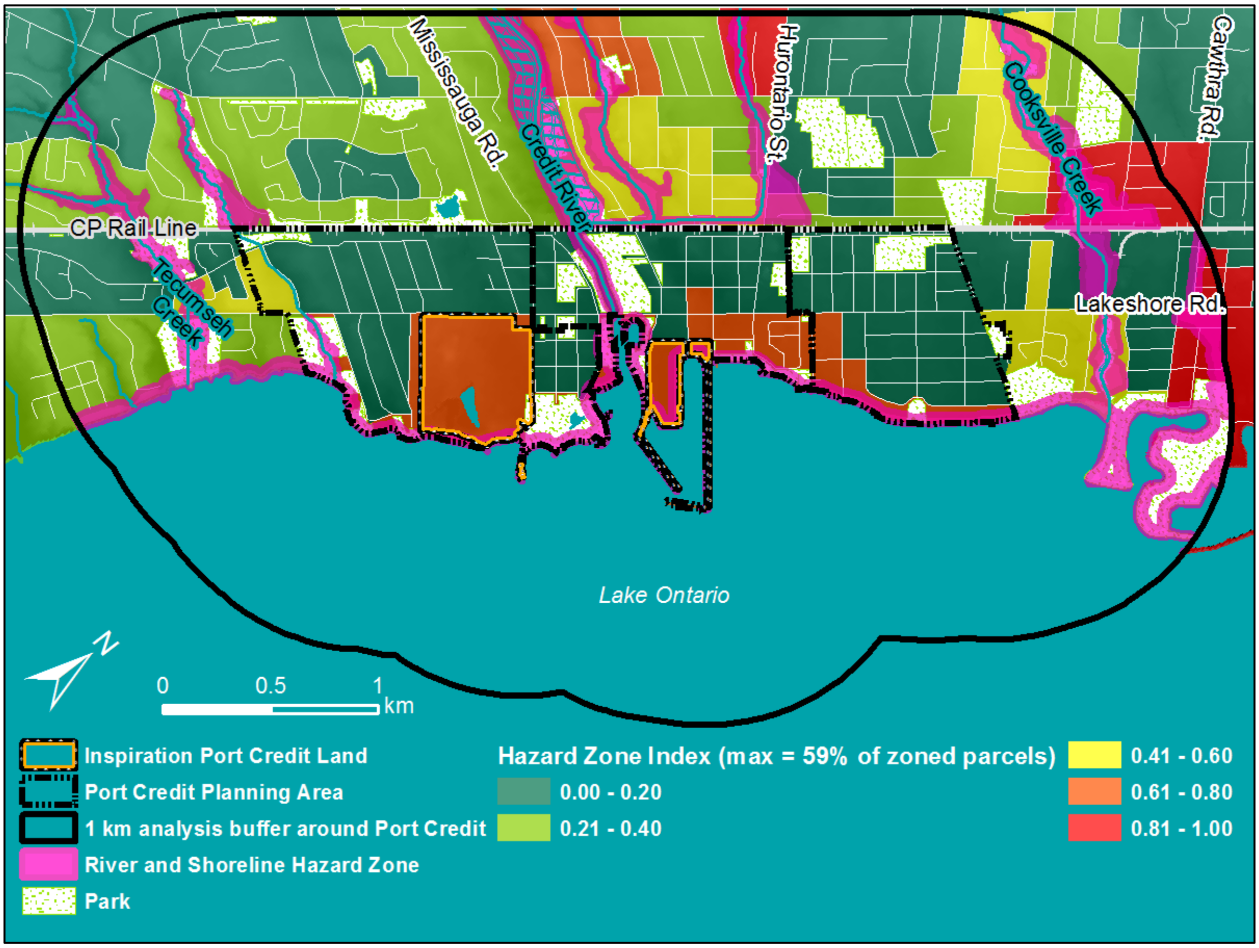

Figure 11 Map of extent of riverine and shoreline hazard zones along with the normalized index of the number of assessed property parcels intersected by a regulatory flood hazard zone within each Census Dissemination Area.

Certain classes of assets were identified as having high interest to stakeholders, and these are consistent with those considered highly vulnerable in other community-scale flood risk assessments, including FEMA (2012) and Udale-Clarke et al. (2005). These vulnerable assets are schools, emergency operation centres (i.e., fire stations and police precincts), health care facilities (including retirement homes), transportation, water and electrical infrastructure, recreational facilities and parks. Figure 12 presents a map of these facilities in Port Credit relative to hazard zones and identifies the following potentially vulnerable features that are either within or in close proximity to hazard zones:

- Roadways, water mains and wastewater mains that intersect flood hazard zones. Roads are vulnerable to being inundated by flood waters and water/wastewater mains are vulnerable to leakage (map zones # 1, 2, 3, 6, 7, 9, 10, 11)

- Water/wastewater pumping stations in close proximity to shoreline hazard zones (map zones # 4, 5, 6)
- Energy distribution transformer station (map zone #1)
- Rail crossings (map zones # 2, 3, 8, 9, 12)
- Community health care facility (clinics) and transit hub (GO Rail Station) (map zone #9)

It should be noted that this identification is purely based on mapping of existing data, while this process provides a good preliminary sense, in some cases it may require verification to precisely determine how conditions at the property-scale influence overland flow (e.g., elevation of rail crossings).

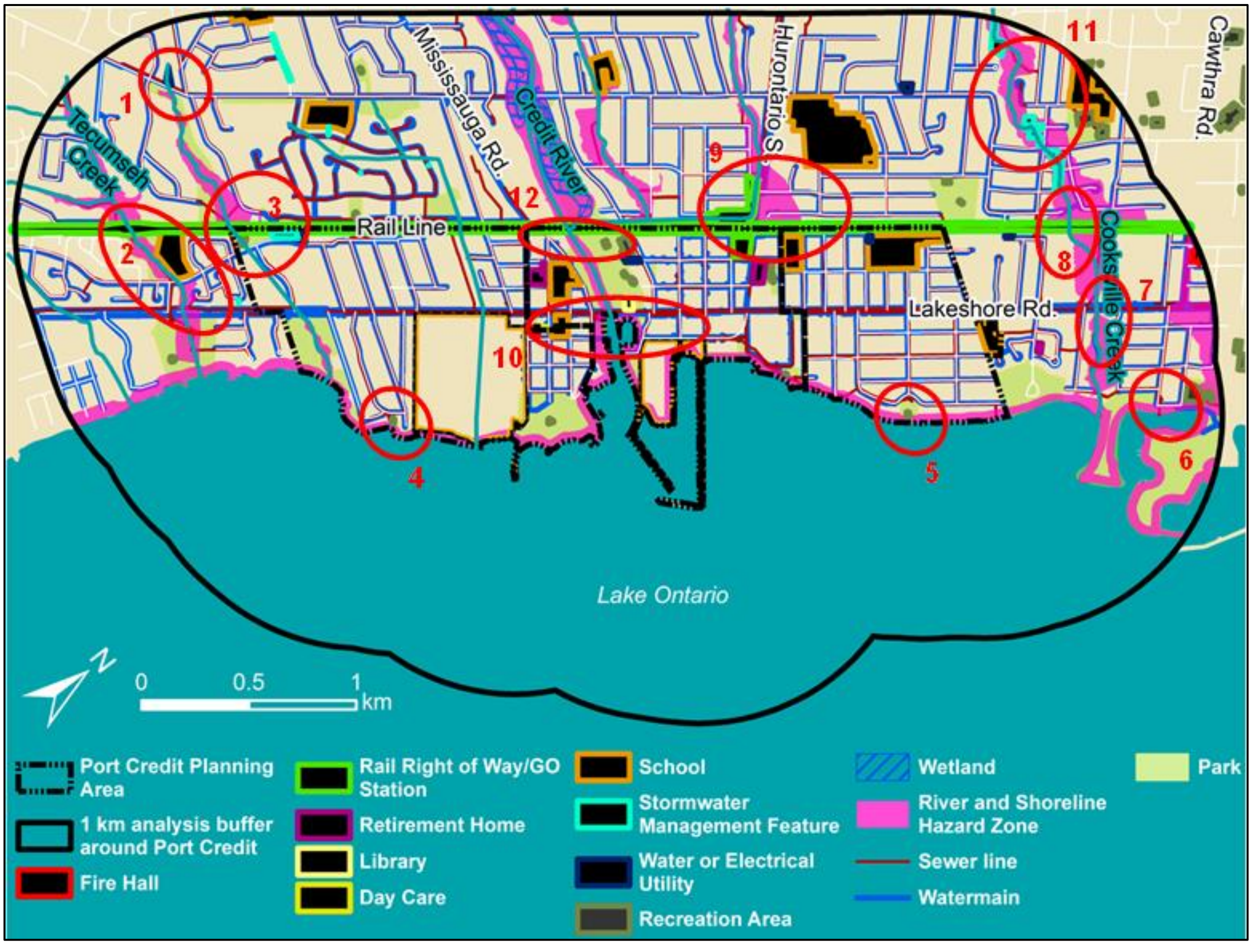

Figure 12 Map of key community assets in Port Credit with flood hazard zones and inundation-vulnerable areas overlaid. Red ellipses identify areas with potential exposure to hazards from overland flooding from surface water bodies.

Exposure to Urban Drainage Problems

From an urban drainage standpoint, Port Credit has experienced in the past: basement flooding, floor-drain backups, along with other drainage infrastructure issues resulting in flooding. This is evident based on flood complaint records from the City of Mississauga for the period of 1976 through 2009 (Figure 13). Analysis conducted following the July 8th, 2013 flooding event showed that 229 flood complaint calls were placed for Wards 1 and 2, which incorporate Port Credit. Area (City of Mississauga 2013)

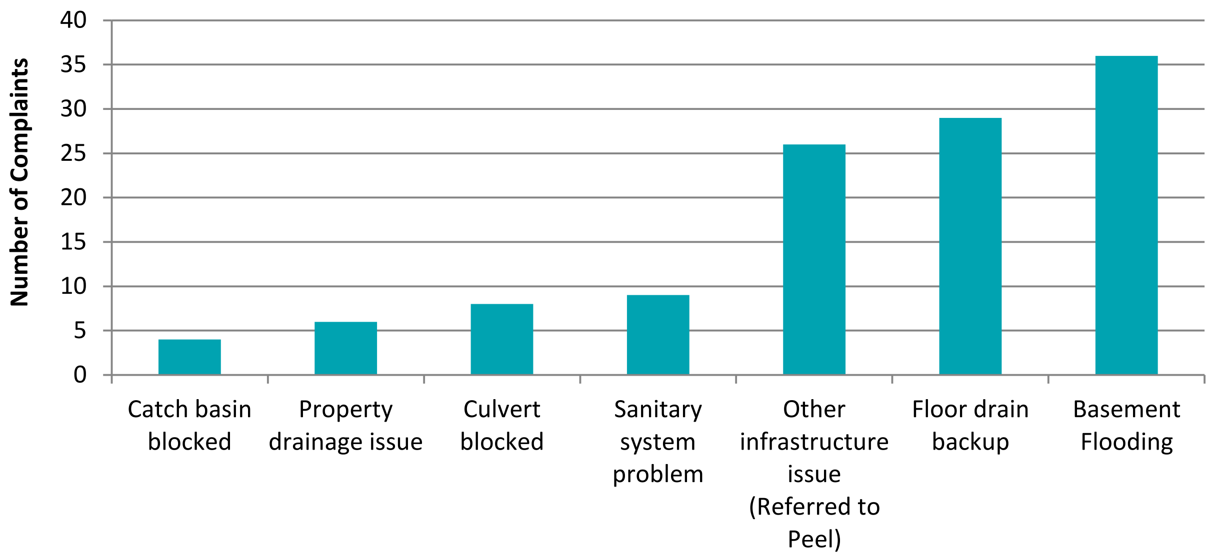

Figure 13 Summary of historical flood complains in Port Credit planning Area from 1976 through 2009 filed with the City of Mississauga

In Port Credit, there are both major and minor stormwater management systems; however, the types of drainage systems used differ across the study area. Each of these systems is theoretically designed to a capacity associated with specific storm events in accordance with design criteria based on the City of Mississauga's land development regulations. However, Port Credit is an older community and it is therefore very likely that portions of this system do not conform to current design standards. Nonetheless, in principle the City has identified the following design criteria for major and minor systems present in Port Credit:

- The minor drainage system present in most of Port Credit is comprised of storm-sewers and catch-basins designed to drain the 10-year return-period storm event;
- The minor drainage system present in the area just northern of the Port Credit Planning Area is comprised of ditches and culverts designed to drain the 10-year design storm;
- Major drainage system is present across the whole study area and comprised of major roadways and watercourses designed to convey the regulatory 100-year return-period storm (roads and small watercourses) or Hurricane Hazel (Credit River) without overtopping.

The main factors that determine exposure of assets and services to flooding caused by urban drainage issues are the infiltration properties of the soils and ground, the topography (i.e., presence of depressions), and the capacity of stormwater management infrastructure at the lot, sewershed, and roadway scales. Other factors such as lot-level stormwater controls, often referred to as low-impact development (LID) measures, could improve the resiliency of the lot to flooding and are also a form of drainage controls that are gaining prominence in urban design (CVC 2012).

Overall, Port Credit's soils are classified as well-drained (Hoffman and Richards, 1953). However, the large extent of impermeable area due to paved surfaces and built-up land may offset this landscape feature. Currently, no estimate of the precise extent of impermeable land in Port Credit was accessible for this assessment.

Figure 14 presents a map of the topography-based Flow Accumulation Index (Arge et al. 2003)[17] calculated from a 10-m digital elevation model to identify low-lying areas susceptible to ponding. This mapping demonstrates that there are 5 distinct areas outside the riverine and shoreline hazard zones that could have elevated potential for flow accumulation based purely on their topography.

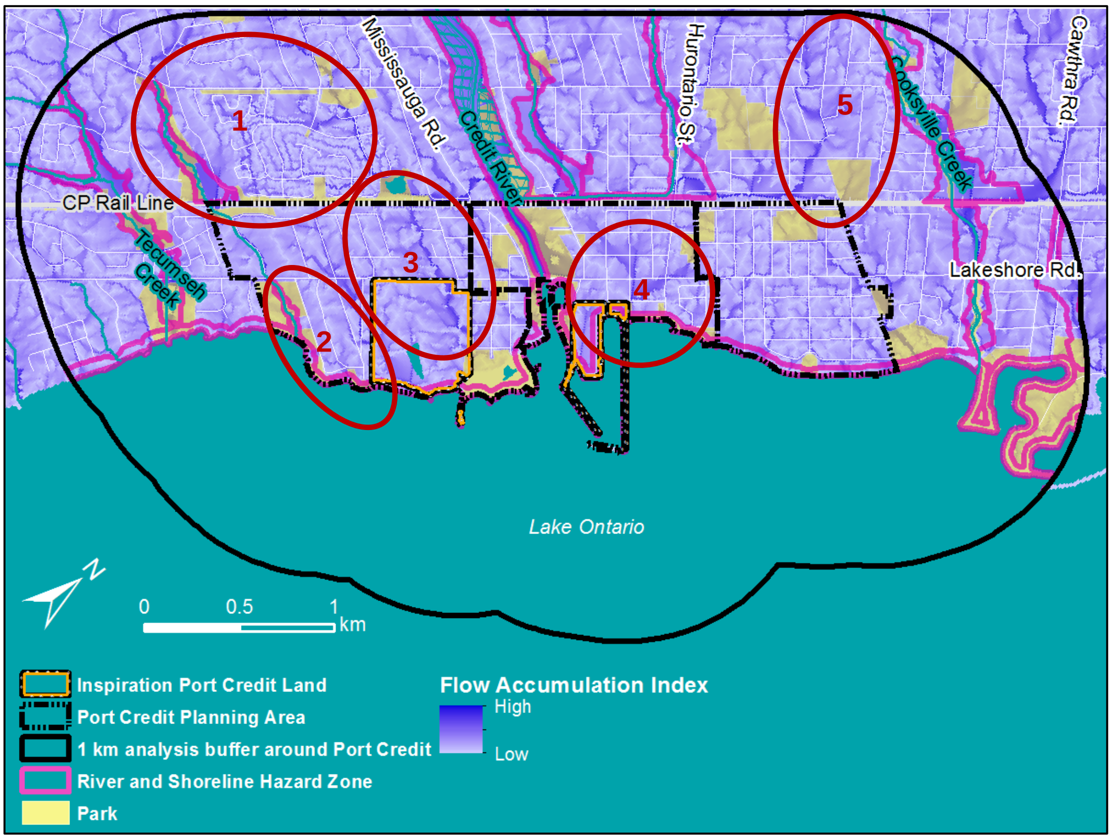

Figure 14: Map of the topography-based Flow Accumulation Index calculated from a 10 m digital elevation model using the algorithm in Arge et al. (2003) implemented in the GRASS GIS *terraflow* module. Red ellipses identify areas with potential for urban flow accumulation.

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[17] Flow Accumulation Index (FAI) is an expression of the amount of water that will accumulate at every grid cell within a raster, based on the number up-slope contributing cells (in all directions). It is a measure used to identify locations where water will accumulate on a landscape without considering other factors, such as infiltration, evapotranspiration, etc. It is simply an index of topographic vulnerability to identify depressions in the landscape. FAI is a commonly implemented GIS-based approach to identifying locations where water has the potential to accumulate. Examples can be found of its use by the USGS (http://md.water.usgs.gov/posters/flowGIS/), in the hydrologic model TOPMODEL (http://onlinelibrary.wiley.com/doi/10.1002/hyp.3360090204/abstract;jsessionid=E4DF91E6FD8F4A7DA2E9C38E0829C9AE.f04t01), and other studies. Full documentation of the approach used in this assessment can be found here: http://www.cs.duke.edu/geo*/terraflow/r.terraflow.html.

Figure 15 presents a map of the drainage infrastructure in the study area and shows that, with the exception of a few specific streets in Area 1, there is some form of either minor drainage system, either storm sewers or roadside ditches (mapped as areas with culverts) to address this potential for accumulation.

A more detailed analysis is needed to understand the conveyance capacity of the major drainage system and the actual capacity of the minor system, given potential issues with age, materials and maintenance, which can affect performance. More specifically, possible sources of vulnerability identified through consultation included:

- Blockages of outlets in creeks and Lake Ontario, with the latter being of particular concern, given the potential for lake level variability due to climate change;
- Blockages of inlets to the minor system, particularly due to leaf and debris accumulation;
- Loss of hydraulic gradients due to the age, leakages, and poorly graded properties.

Additionally, the design criteria used for analyzing urban drainage systems in Port Credit assumes that upstream areas are properly drained, inlets and outlets are not blocked, and that stormflows represent only surface runoff and not the contribution of overland flow from overtopped water bodies, or the effect of elevated groundwater tables.

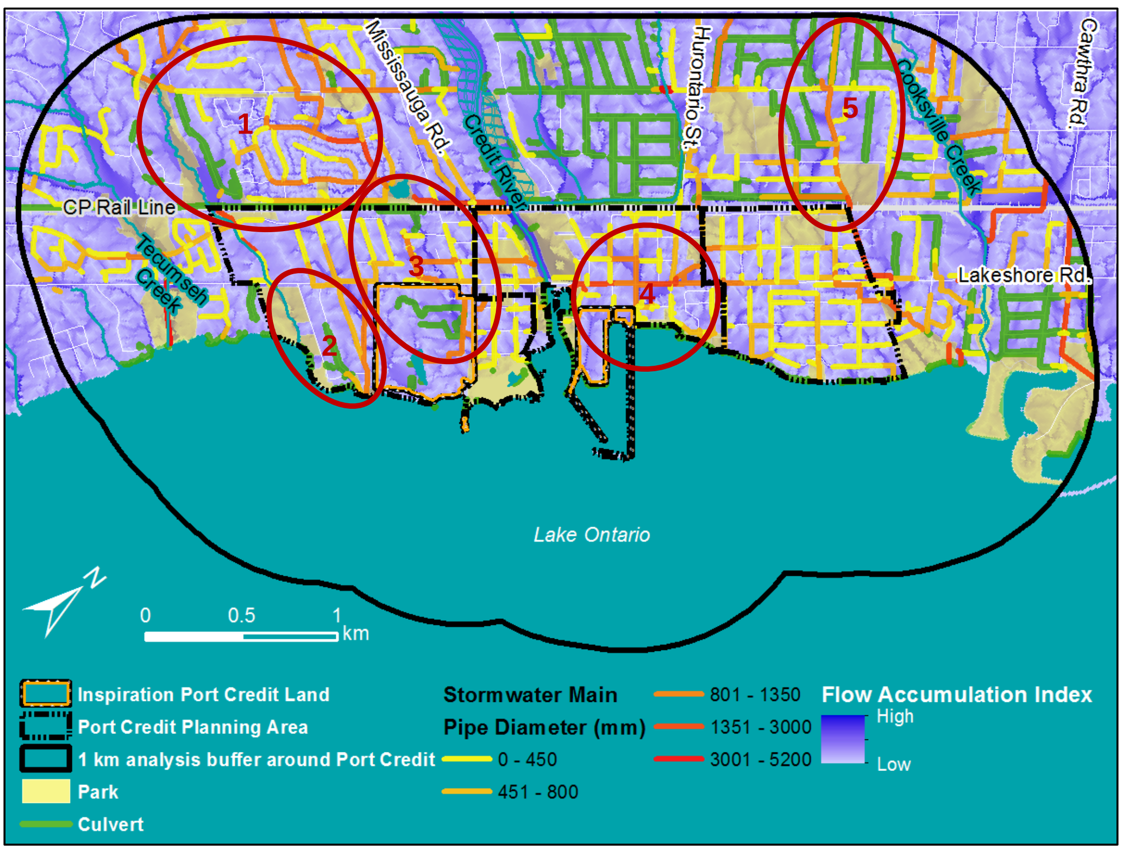

Figure 15 Overlay of drainage infrastructure on top of the flow accumulation index. Red ellipses identify areas with potential for urban flow accumulation.

Recent storm events (e.g., July 8, 2013 in Toronto), in addition to potential impacts identified by stakeholders and discussed above, suggest that these assumptions may require additional scrutiny, especially in an area such as Port Credit, where multiple different hydrologic processes (riverine, urban drainage, Lake Ontario) can interact. Port Credit is also at the most extreme downstream watershed limit, and therefore could be subject to the cumulative impact of runoff and flooding processes in the Credit River watershed. This characteristic of the community adds to the need for examining the sensitivity of Port Credit's urban drainage system and ensuring that hazard zone mapping is up-to-date and incorporates changes to upstream land use.

Flood Damage and Disruptions

The major cause of short-term and long-term disruption to services and consequences on the economy, and health in a community is physical damage hampering the functioning of assets and property (FEMA 2012). A key example of flooding impacts in Port Credit can be assessed using the recent July 8th, 2013 flooding event as a case study. During this event, urban drainage issues were the main cause of flooding in Port Credit, while riverine flooding was a major issue in many other parts of Mississauga (e.g., Cooksville Creek). For this event, no economic loss values were found specifically for Port Credit, but the estimate of insured losses due to private property was $850 million for the GTA and numerous damages to public assets were identified. In Mississauga specifically, damage to community services alone were estimated at $840,400 for direct damage repair to parks, trails, recreational facilities and community centers with an additional $41,000 in lost revenues (City of Mississauga 2013). Additionally, $1.2 million in operational and planning costs were estimated to be incurred by the Transportation and Works department (City of Mississauga 2013). Estimates of impact from the July 8th event for other services and assets in Mississauga include loss of power to approximately 50,000 Enersource customers, suspended transit service, blocked and damaged roadways (CTV, 2013).

Once a flood event occurs, damage to assets, along with the short and long-term disruptions caused by flooding are mediated by a host of factors. In other words, in the event of flooding, certain assets are more vulnerable than others. This is particularly relevant for structures within delineated flood plains. There are several physical processes which could be experienced during flooding events and that have been identified as potential causes of damage to a wide variety of buildings. These can be summarized as follows and regarded as key factors influencing the vulnerability of specific assets to damage during flood events (based on FEMA a 2012; Thieken et al. 2005; Kelman and Spence 2004; Pistrika and Jonkman 2009; Udale-Clarke et al. 2005):

- Pressure on structures due to standing water and capillary rise, including buoyance forces;
- Hydrodynamic forces resulting from the movement of water in and around structure, including erosive action;
- Debris actions from solids impacting structures;
- Chemical actions, such dissolution and mobilization of contaminants; and

- Biological actions, such as mold, bacteria growth and mobilization of microbial contaminants.

The extent of flood damage on a given asset or structure is also heavily influenced by the duration of exposure to these different processes, which is greatly influenced by hydrometeorological processes described previously (Thieken et al. 2005). However, there are several additional characteristics of buildings themselves that influence their vulnerability to damage, which can be summarized as follows (based on FEMA 2012; Thieken et al. 2005; Kelman and Spence 2004; Pistrika and Jonkman 2009; Udale-Clarke et al. 2005):

- Number of stories, with more stories providing more opportunity for safety and lower concentration of belongings at ground-level;
- Structure type, with smaller single-family homes being at greater vulnerability than larger multi-unit buildings;
- Construction and foundation type, and material (wood, brick, concrete), with wood-framed construction and unanchored foundations having higher vulnerability;
- Property ownership status (rented versus owned), with rented properties being at greater vulnerability because of a higher likelihood of deferred maintenance;
- Structure age, with older structures being more vulnerable due to loss of material and structural integrity over time.

Within the Port Credit Planning Area, information on housing foundations, height, and construction materials was not readily accessible for this assessment. However, some inferences on these factors can be made using age of construction, and building type. Approximately 80% of all assessed properties are classified as single-family homes, 60% of structures are built before 1970 (approximately 45 years old), and one third of households are classified as rentals. The percentage of rentals is slightly higher than the average for the entire Region of Peel (22%). The age and single-family home figures suggest that a high proportion of Port Credit’s housing stock may have characteristics that contribute to a higher vulnerability to impacts during flood events. However, home improvements that could have taken place in the past could have changed the vulnerability of these homes. Additional investigation is needed to update and ground-truth this information at the property-scale and to evaluate these home’s current resiliency to flooding. The identified vulnerability factors could be useful to guide such an assessment.

Climate Change Effects on Flooding

According to climate projections and interpretation presented in Section 4.2, the meteorological conditions that lead to flash flooding (extreme precipitation), lake-based flooding (high winds and high water levels) and the associated infrastructure failures are anticipated to increase in frequency and intensity under the selected future climate scenario (RCP8.5). While large spring freshets and ice blockages in rivers can be expected to become less frequent on average as winters are projected to become milder, heavy snowfall will still take place (Auld et al. 2015; ENBFLO 2010). Additionally, increased winter rainfall leads to saturated watershed conditions that could drive gradual flooding scenarios (ENBFLO 2010). The question of whether the reduced risk from freshets and ice blockages will outweigh the increased risk from milder winters and saturated conditions is currently not known. As such, a range of such scenarios should be planned for.

Given projected increases in lake level variability associated with climate change (see Storyline #2), the issue of Lake-river interactions is an increasingly important aspect of adaptive flood risk management to consider in a shoreline communities, like Port Credit (International Joint Commission 2014). As such, potential increases in the frequency of higher lake levels means that the exposure to lake-based flooding is likely to increase. While there is great uncertainty with respect to future lake level projections, there is some indication that maximum lake levels are not likely to exceed historical maxima in magnitude (See Storyline #2).

Climate change may also bring to light new vulnerabilities to flooding associated with shifts in seasonal precipitation and temperature. During the stakeholder consultation, participants identified projections of increased autumn rainfall aggravating a vulnerability to the accumulation of leaf and debris. This could lead to a scenario of increased likelihood of drainage systems being blocked at a time of year when such issues are not currently a pressing maintenance issue. Likewise, projections of increased possibility of rain-on-snow, heavy summer rainfall following drought conditions that produce hardened ground, and earlier Atlantic cyclone seasons represent important changes in the precipitation regime that impact the timing of flooding. Based these projected changes, and the policy directive for resilient and adaptive flood management strategies that address a range of potential impacts (see City of Mississauga 2013), the need for addressing all four identified types of flooding remains important going forward.

Because of the unpredictability of climate change effects, it is also important to note that a possibility for less known classes of flooding to emerge may exist in some areas. For example, basement flooding from elevated groundwater levels is a flooding scenario in many low-lying communities (e.g., see: http://www.groundwateruk.org/faq_groundwater_flooding.aspx). A key related issue is the fact that current regulatory floodplains are based on historical events and their associated accepted levels of exposure (frequency of occurrence and storm intensity). Given that climate change is likely to result in alterations to the frequency and intensity of extreme precipitation, and that storm events can be expected to change in their seasonality, there is a need to consider whether/how hazard zones may change under different hydroclimatic conditions.

Alterations to the rainfall regime as a result of climate change will also mean that the intensity-duration-frequency (IDF) statistics historically used to design urban drainage systems may not represent appropriate levels of design rainfall exposure in the future. While there is significant uncertainty in precisely calculating new IDF statistics using climate projections, there is high confidence that storm intensity and frequency is likely to increase in the future, meaning that current design criteria could underestimate the frequency and/or magnitude of extreme events (see Auld et al. 2015 for further discussion on issues associated with projecting IDF statistics topic). The implication may be that stormwater management infrastructure could be exposed to having its capacity exceeded more frequently.

4.3.2. *Storyline #2: A More Variable Lake Ontario Shoreline Significance of Port Credit's Shoreline and Coastal Management*

The Port Credit shoreline is a cultural, recreational, economic and ecological asset locally and for the City of Mississauga and Region of Peel more broadly. There are several key planning processes ongoing in the area to ensure the long-term sustainability and health of the shoreline for ecological, recreational, economic and community development purposes (Aquafor Beach Limited 2011; City of Mississauga 2012; City of Mississauga 2013; Stoss 2013). Understanding the implications of climate change on management of the shoreline and coastal assets in Port Credit is of importance locally, but it was also identified early in the this assessment as a potential case study area of interest to bi-national stakeholders involved in Great Lakes coastal governance, such as Environment Canada and the Great Lakes Integrated Sciences and Assessments Centre (GLISA). Coastal management and planning vulnerabilities to climate change are specifically referenced as topic areas of interest in the adaptive management plan for the Great Lakes (International Joint Commission 2013). The focus of this storyline is on identifying and describing which characteristics, activities, and coastal processes are sensitive to climate conditions, which are likely to change in the future, presenting vulnerabilities for coastal management.

Consistent with the definition used in the LOISS and by the Ontario Ministry of Natural Resource and Forestry (MNR 2001), the shoreline is defined as the interface between the land and the lake (Figure 16). This includes the onshore and backshore areas inland of the maximum extent wave uprush (i.e., dunes, beaches, etc.), the nearshore that includes the zone from beyond breaking waves offshore to the inland extent of wave uprush, and the offshore zone where water is deeper.

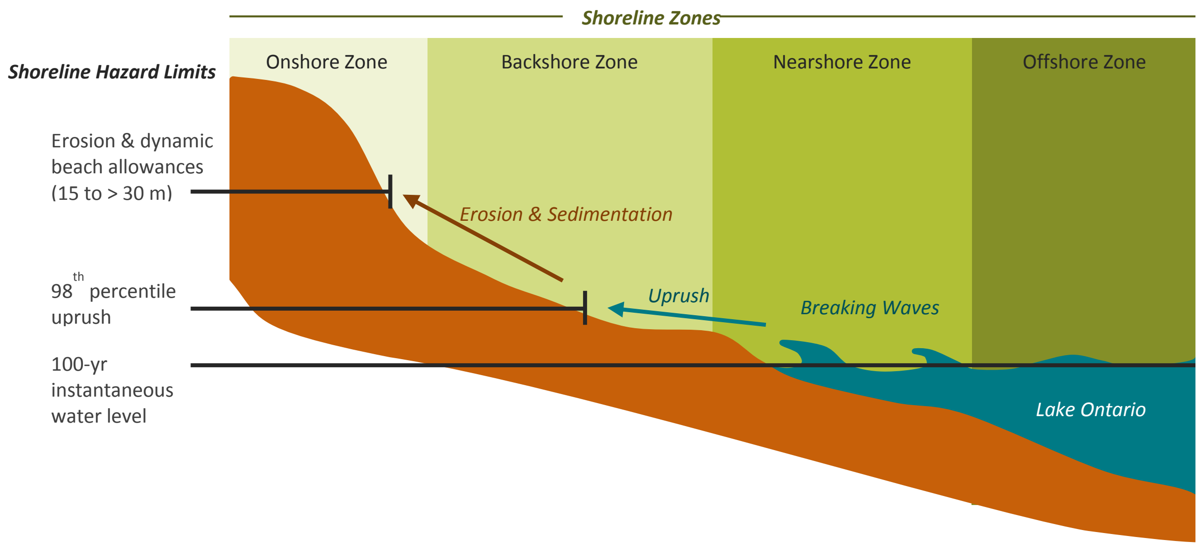

Figure 16 Schematic cross section of the shoreline area identifying (adapted from MNR 2001).

Climate Influences on the Shoreline

The climate influences shoreline in Port Credit in a complex set of ways; however, Figure 17 provides a graphical overview of the major pathways identified (see Appendix I for vulnerability factor rationales) through the literature review and consultations. Although the shoreline is a complex system, with multiple processes, understanding the factors highlighted in Figure 17 can be helpful in designing effective adaptive management strategies (IJC 2013).

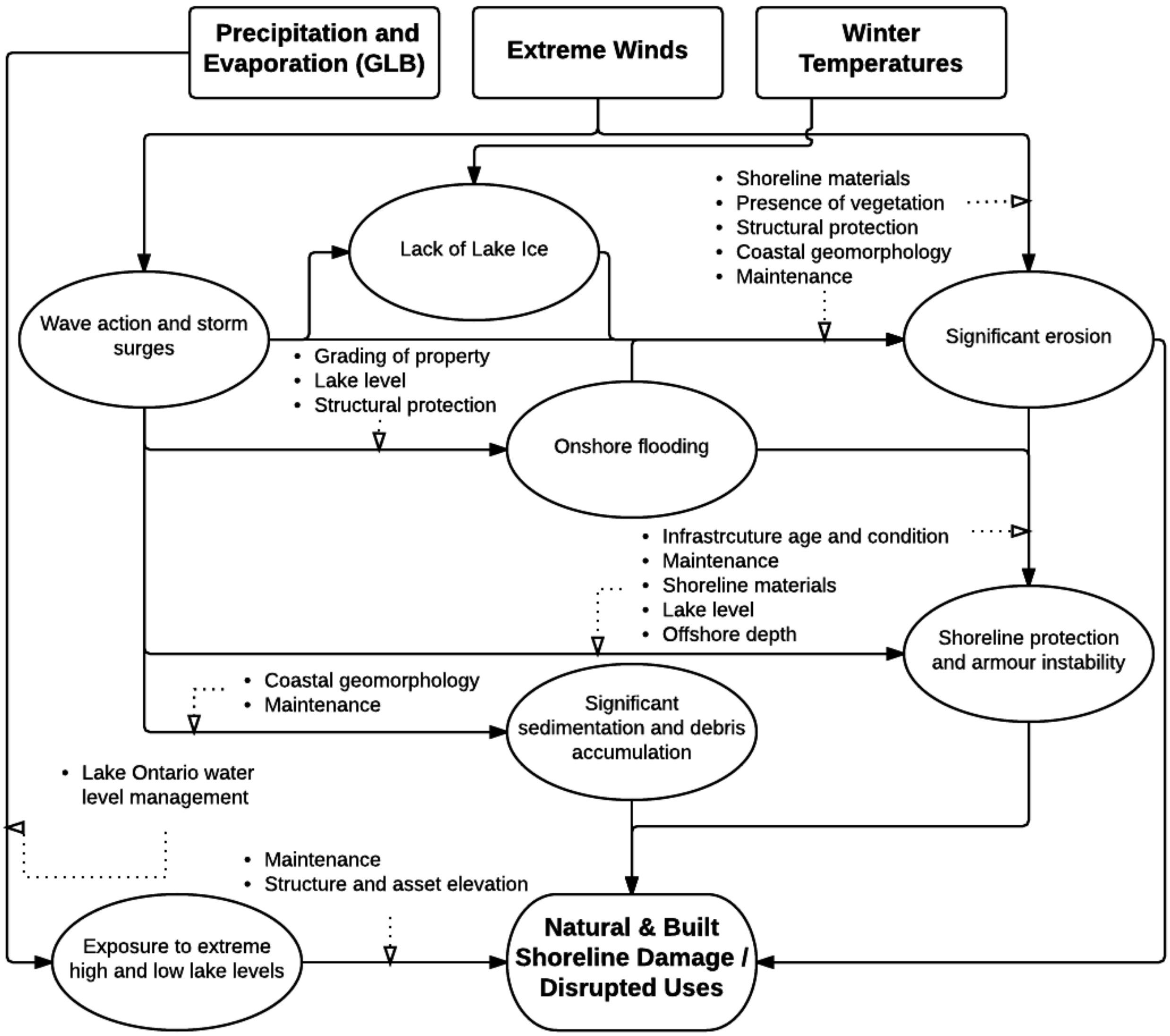

Figure 17 Conceptual diagram of the processes and factors influencing the impact of climate on the Port Credit Shoreline.

Types of relevant impacts to Port Credit shoreline, as well as definitions and parameters are defined below:

- **Coastal flooding and erosion:** Hazard zones associated with Lake Ontario are defined according to MNR (2001) as the 100-year instantaneous water level, plus an allowance for wave uprush, cited in the most recent regulation for Port Credit (O. Reg. 160/06, Sched. 1.) to be the 99th percentile annual wave height (probability of occurring once per year), plus an allowance for erosive processes and dynamic beach hazards (see Figure 16). Within this framework, wind is the main driver of wave action and can also directly cause erosion. Additionally, the 100-year water level is driven by basin-wide evaporation and precipitation, affecting Lake Ontario's water balance.
- **Onshore (inland) flooding and erosion:** This process can potentially damage shoreline assets (private properties, trails, marina buildings, docks, boats, etc.) and structural protections (breakwaters, armourstone, etc.). Such flooding was explored in storyline 1 and for Port Credit's shoreline is largely a function of urban drainage and overland flow.
- **Wave influences on costal geomorphology:** While wind-driven waves can cause erosion in some locations, costal geomorphological processes dictate that waves can also cause deposition in other areas alongshore. Both erosion and deposition are normal coastal processes, but in areas where longshore transport processes are disrupted by built structures, large amounts of deposition can be problematic. This is particularly the case in harbours and embayments in the Port Credit area, where debris and sediment build-up can impact water access and ecological processes. Coastal geomorphology is influenced by the prevailing direction of currents, which are influenced by the climate factors of lake temperature, wind-driven waves and seiches, as well as dominant wind directions.
- **Extreme low and high water levels**: Driven by basin-wide water balance that is influenced significantly by precipitation and evaporation, can lead to disrupted lake access. Exposed built shoreline structures that are designed to be submerged can be vulnerable under low-water conditions. Ecological processes and water quality can also be significantly impacted during low-water conditions.
- **Lake ice:** Under cold winter conditions nearshore water can freeze, causing ice buildup, which can lead to enhanced protection of the shoreline from wave action, but ice jams in the Credit River and other smaller watercourses draining to Lake Ontario. Ice jams are a normal hydrologic process; however, in an urban environment, they can greatly enhance flood and erosion vulnerability. Ice cover on the lake is beneficial to many ecological processes including the regulation of lake temperatures.

Table 6 helps summarize these interactions and pathways between the climate event and local impacts.

Table 6 Climate Stimulus connection to local scale impacts

Climate Stimulus	Intermediate Process	Current Threshold	Asset Class	Local Impacts
Extreme Winds	Wave action causing erosion, deposition and flooding (note, flooding is explored in Storyline 1)	1/100 year water level (75.8 m asl), plus 1/20 year wave action (5.3 m sig. wave height; corresponds to 46.8 km/hr)[18]	Private properties, marinas, piers, beaches and other natural shoreline areas.	Damage to properties and structures; loss of access for repairs; disruption to natural processes
Regional precipitation and evapotranspira tion	Lake levels	1/100-year low = 73.75 m asl 1/100-year high = 75.8 m asl	Marinas, piers, beaches and natural shoreline areas.	Loss of lake access; exposure of submerged infrastructure; water quality and ecosystem impacts
Winter Temperatures	Declines in temperature lead to reduced ice cover	Not Available	Private properties, marinas, piers, beaches and other shoreline recreational areas	Increased exposure to erosion and wave action

Variability and Changes in Lake Levels

Lake levels are a key factor mediating a number of climate-related impacts, including wave action, accessibility to the lake, hydrologic, geomorphologic and ecological processes. As such, potential alterations in the current lake level regime due to climate change are of great interest to stakeholders in the shoreline area.

Historically, during the period since regulation of water levels began in the 1950s, Lake Ontario's levels have varied at their maximum by approximately 2m, with that variability decreasing in recent decade to approximately 1.3 m (Figure 18). This variability is however, within the upper and lower limits targeted within the historical lake level regulation plan, called 1958DD. That plan managed for lake levels within approximately 2 m. The variability experienced in recent years is substantially lower, and also less than levels that existed on Lake Ontario prior to regulation or in the other Great Lakes currently (Gronewold et al. 2013). This is a significant point because the recently approved water level regulation Plan Bv7, aims for a

[18] See Appendix I for calculation of wind threshold. Location of calculation differs from Shoreplan (2005)

more natural management regime, which will see greater variability in Lake Ontario levels (Figure 18). Additionally, the IJC has shown that under significantly wet or dry conditions, lake levels can be expected to exceed the range targeted within the management plan, even though these are considered extreme scenarios (see Figure 18).

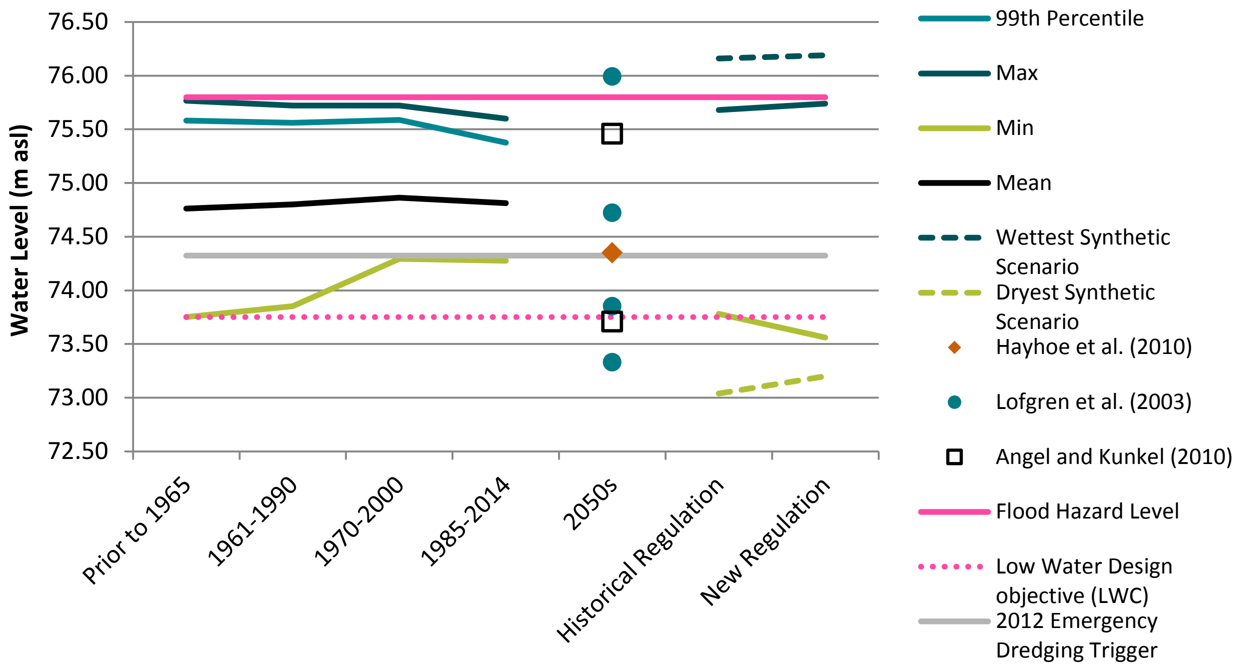

Figure 18 : Synthesis of historical, future projected and regulation plan targets for water levels on Lake Ontario. Key planning criteria for Port Credit are also shown.

In recent years, several studies have shown projections of future Lake Ontario water levels, suggesting they are, on average, anticipated to decline due to climate change (Angel and Kunkel 2010; Hayhoe et al. 2010). There are however, several critical caveats that managers need to consider when interpreting this information. Firstly, these projections represent long-term averages and are not an accurate representation of how lake levels might vary from year-to-year. Inter-annual variability will remain an ever more critical consideration in coastal management. Secondly, there is currently less confidence in these original projections than when they were originally presented (Gronewold et al. 2013; Cohen et al. 2015; MacKay and Seglenieks 2013; Music et al. 2015; Notaro et al. 2015; Music et al. 2012; Dickin et al. 2015).

New modeling that has added additional data points to the weight of evidence, and there is now a better understanding of limitations in older studies has on Lake Ontario water levels, which add uncertainty to their findings. The association for coastal managers is that effective adaptive management of water levels means being prepared to respond to instances of greater overall variability in lake levels, potentially exceeding historical conditions (Shlozberg et al. 2014; Abdel-Fattah and Krantzberg 2014; International Joint Commission 2013). This is not to say that initial low water level projections were incorrect, but rather, uncertainty in predicting climate change means that resilient strategies need to consider multiple scenarios.

4.3.3. *Storyline #3: The Future of Power Outages in Port Credit:*

Port Credit's Electrical Grid and Outages

The energy grid is a critical infrastructural asset in an urban community such as Port Credit. The grid can be vulnerable to climate impacts which may lead to failure, resulting in power outages, particularly during extreme weather events and other certain climate conditions (Chang et al. 2006; Kezunovic et al. 2008; Ward 2010). There can be serious consequences when electrical supply is lost, including short term costs of repairing equipment, electrical safety hazards to citizens and workers, impacts on businesses continuity, loss of power to households and residents, and implications for the management of other critical assets (Chang et al. 2006; Asian Development Bank 2012; Maliszewski and Perrings 2012; AECOM 2012; Karstens-Smith 2013). For instance, assets vulnerable to disruption when the power goes out include all building systems (HVAC, lighting, computer systems, etc.), transportation signals and systems, emergency services, health care equipment, water and wastewater treatment equipment, and others (Chang et al. 2006; Maliszewski and Perrings 2012). It is understood that many of these aforementioned systems may have back-up generators available; however, these power supplies may have short runtimes or only supply power to a limited number of end-points on site.

Although power outages can be disruptive to any user affected, certain classes of outages can be more impactful than others. The overall severity of an outage is typically associated with its duration, geographic extent, and the type of users affected (Maliszewski and Perrings 2012; Ward 2010; Davidson et al. 2003; Han et al. 2009; AECOM 2012). These factors are directly related to the number and location of electrical system components affected and the extent of damage requiring repair (i.e., lines, transformers, generators, affected etc.) (Davidson et al. 2003; Maliszewski and Perrings 2012). Electrical utilities customarily plan for and respond to a range of outages to avoid widespread effects; however, understanding the causes and vulnerabilities of such events, and taking steps to prevent them and reduce their impacts are critical to building a resilient energy system (Cepeda and Colome 2012).

In Port Credit and the City of Mississauga, Enersource is the private corporation licensed to distribute power to local customers. Like most local distribution companies, Enersource's electrical distribution system can be defined as a network of conductors (power lines), switches and transformers which distribute power from a high-voltage feeder stations into the lower-voltage local distribution grids and then to individual users (see Figure 19). This characterization is consistent with that used in AECOM (2012), Davidson et al. (2003), and Ward (2010). Electricity enters Enersource's network at a higher voltage than the voltage that can be used by customers, and therefore small transformers are located throughout the grid in order to step-down voltage to a useable level. In Port Credit, all conductors and transformers are located above-ground, and as such, utility poles are an important element of the system (some transformers are also located at ground-level).

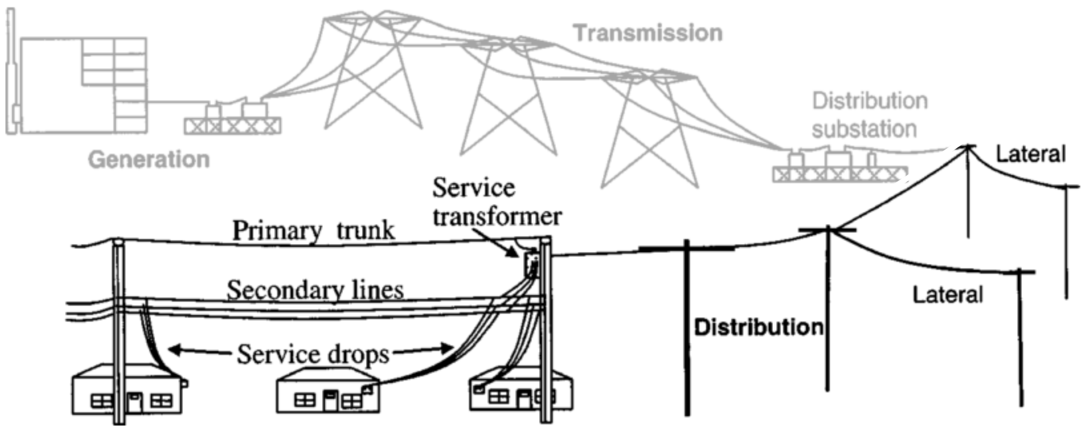

Figure 19 Schematic diagram of the electrical generation, transmission and distribution systems. Solid black components represent the Enersource grid in Port Credit (Source: Davidson et al. 2003).

Meteorological causes of electrical outages in Port Credit

The direct and indirect impacts of climate on the electricity distribution grid are typically regarded as one of the most important vulnerabilities in energy systems (Asian Development Bank 2012; Kezunovic et al. 2008). The processes by which climate cause the negative outcomes of power outages and damage, causing reduced infrastructure lifespans is shown visually in Figure 20 (see Appendix J for vulnerability factor rationalizations). Based on this interpretation, it is evident that the major processes associated with the negative outcomes are climatological loads in excess of the system's capacity. Given that Port Credit's distribution system is almost exclusively overhead, damage to trees, which can then impact poles, wires and attached equipment is an important intermediate process.

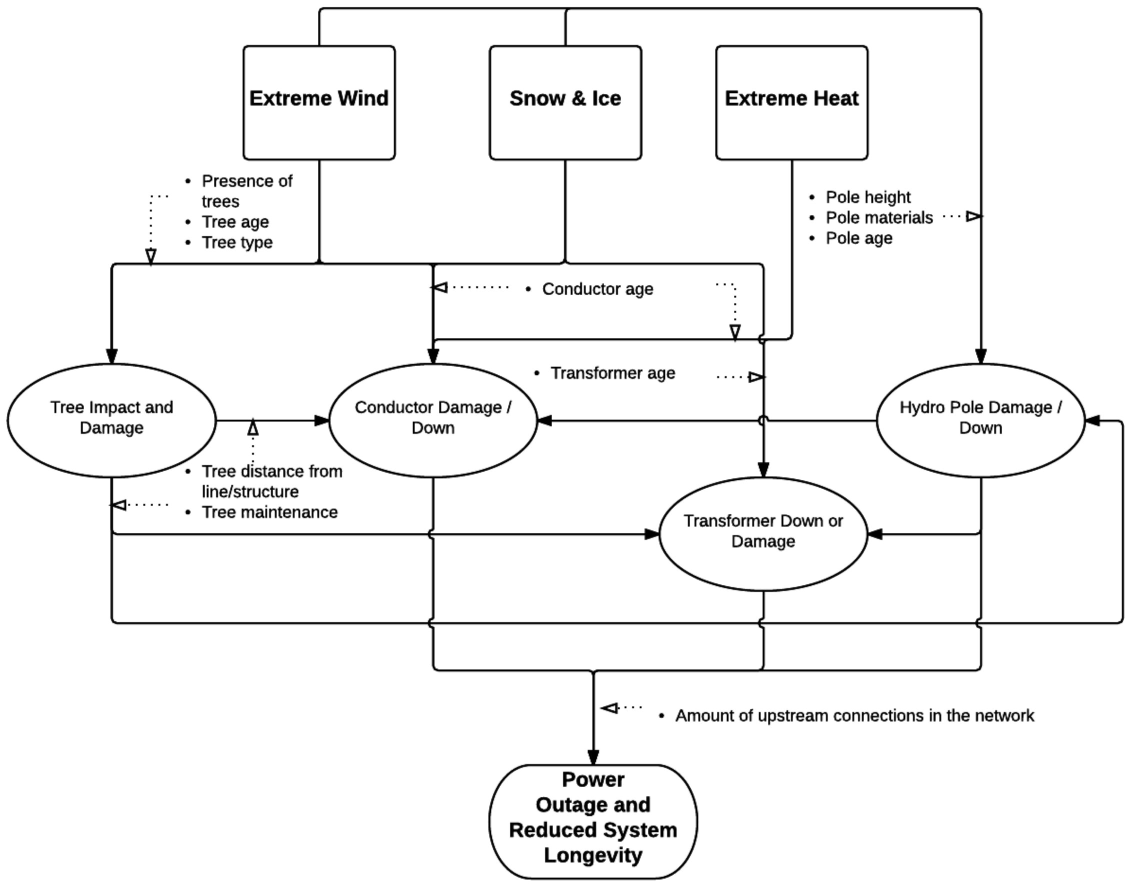

Figure 20 Diagrammatic representation of the pathways through which extreme weather leads to power outages and reduced electrical distribution system longevity..

With respect to short-term disruptions to the electrical grid, outages are the most significant climate-driven impact. Electricity outage records were available from Enersource for Port Credit for the period of July 2009 to January 2014, and based on this data an average of 54% of outages[19] were directly attributed to weather, representing the single greatest cause of outages (Figure 21). By comparison, the next highest number of outages was attributed to damage from trees, at a rate of 29%. However, tree-related outages are often associated with climate drivers, primarily heavy winds, snow and ice accumulation, and deterioration in health of equipment due to temperature and moisture stress (AECOM 2012; Maliszewski and Perrings 2012; Canham et al. 2001).

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[19] Outages are reported on the basis of the number of transformers affected

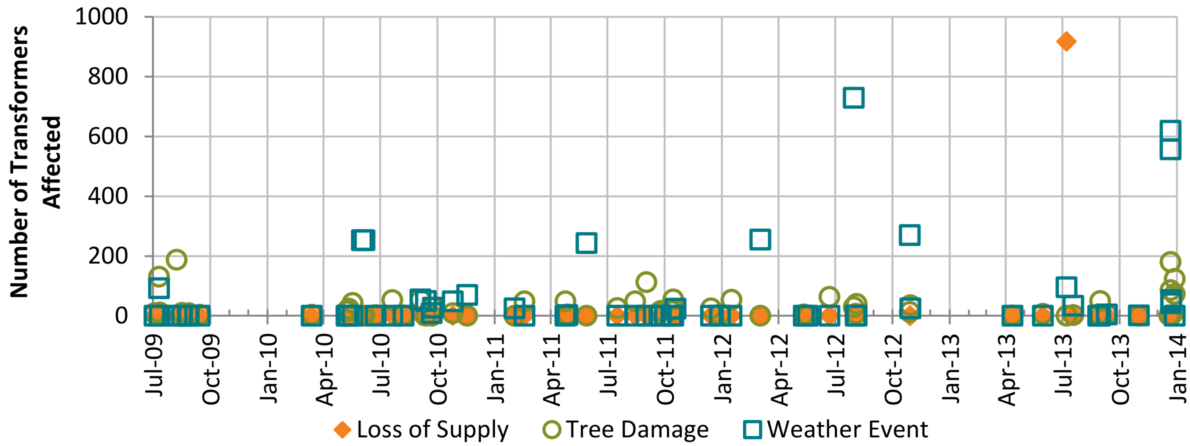

Figure 21 Extent of power outages in Port Credit shown as number of transformers affected per day.

Figure 22 provides an overview of monthly timing of outages, showing average number of days per month when outages occurred. This analysis shows that the most of weather- and tree-related outages occurred in the summer months. Major climate-related outage events that are evident in the record for Port Credit are July, 2012 and December, 2013, which are attributed to a microburst and a freezing rain storm, respectively. Outages attributed to the July 8th, 2013 flooding event were also significant, but exist coded as “loss of power” in the Enersource database. This is because the July 8th outage was the result of flooding to Hydro One transformers stations supplying Mississauga’s grid (Hydro One 2013). Other significant historical outage events identified pertain to extreme winds, and include July 11, 2009 Cawthra Microburst, and July 17, 2006 series of thunderstorms. It should also be noted that although in this data the extent of outages is greatest due to weather events (Figure 21), Figure 22 shows that tree-related damage is more frequent.

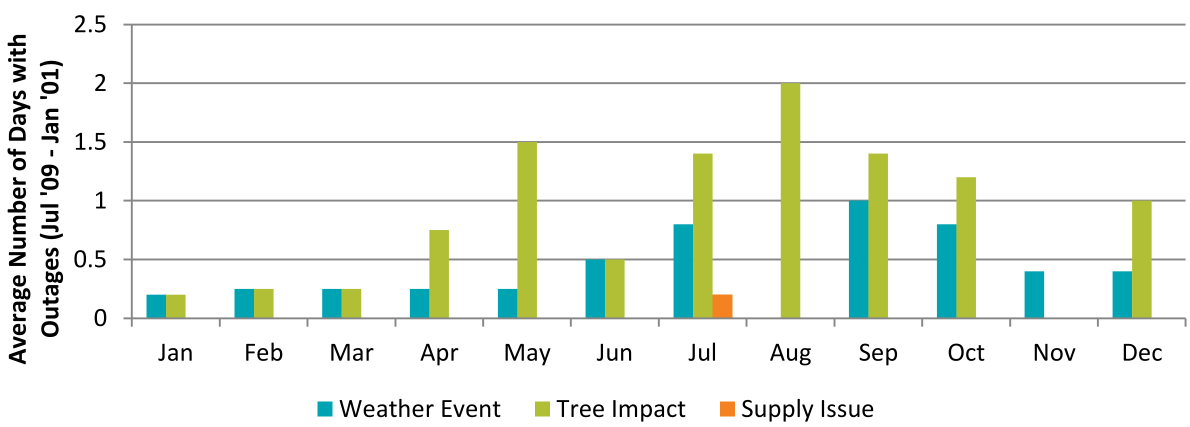

Figure 22 Extent of power outages shown as a time series (top panel) and monthly breakdown (bottom panel) for the period of 2010 through 2013 using the variable of number of transformers affected.

From a long-term standpoint, electrical distribution infrastructure is designed have a specified lifespan based on its design, which is determined in part by assumed climate conditions. As an example, the Canadian Standards Association (CSA) Overhead System design standards (CSA 22.3 No. 1-06) specifies that, for dry air temperatures of less than -20°C and greater than 25°C, corresponding windspeed design loads must be greater than 86 and 94 km/h, respectively. This is based on the 50-year return period wind gust (CSA 2010). Based on the applicable design criteria, transmission infrastructure is designed to last between 35 and 65 years, based on the specific component (AECOM 2012). Table 7 provides a summary of climate impacts relevant to the electrical distribution system in Port Credit and highlights key associated thresholds.

Table 7 Summary of climate impacts and synthesis of relevant infrastructure thresholds

Climate Variable	Distribution Grid Component	Impact Description	Threshold
Extreme Heat and Humidity	Overall Grid	Loss in performance	2°C increase in temp will cause a 0.04% decline in 64% approx. loss [1]
	Conductors	Sagging and loss of capacity	>48°C will cause line to stretch by about 6ft, and sag [1]
	Transformer	Loss of capacity, overheating due to temperature and increased grid demand	30°C [1,2,3] for 3 days or more [2]; severe outages at 38°C and humidity of 60-70% for 4-5 days [7]
Lightning	Transformer	Direct lightning strikes result in failure of transformers [2]	
Extreme Precipitation	Poles	Erosion and decay resulting in lost durability and stability of poles [8,10]	
	Transformer	Flooding of ground-surface or below-ground transformers and switches [2]	
Extreme Wind	Conductor (Line)	Damage to cables, including impact from trees and being downed winds exceeding design loads [2,3,4]	≥ 64 approx. 70 – 100 km/hr [2,3], wind gusts of 64 approx. 86 km/hr [2], in New York wind speed reached 120km/h and gusts of 160km/h severely damaging trees (>60% of trees blown down) [5]
	Poles	Loss of structural stability in poles such as bending, cracking, including extreme cases of rupturing / snapping pole	Extreme rupturing / snapping of poles at 158-228 km/hr wind gusts [6], less severe impacts at > 50 km/hr, and more severe at 70-90 km/hr [2,8], leaning of poles at 137 - 210 km/hr [6]
Freezing rain/ice	Poles and Conductors	Excessive ice build-up resulting in exceeded loads on conductors and poles causing sagging / falling lines; high potential for tree impact	25 mm [2]

References:

[1] Gupta et al. 2012
[2] AECOM 2012
[3] Canadian Standards Association 2010
[4] Maliszewski and Perrings 2012
[5] Canham, Papaik, and Latty 2001
[6] McDonald and Mehta 2006
[7] Abi-Samra, Forsten, and Entriken 2010
[8] Shafieezadeh, Onyewuchi, and Begovic 2014
[9] Hydro One 2013
[10] Nelson et al. 2010

Figure 23 provides a map of the average number of weather- and tree-related transformer outage events per census dissemination area (DA) for the period of 2009-2013 and shows that certain areas within Port Credit experienced almost double the frequency than others. The average outage per transformer for the entire study over the period examined area was approximately 5. However, it is evident from Figure 23 that the eastern DAs experienced, on average, a greater number of outages during this time period. It is important to note that within the buffer zone of the study Clarkson area to the southwest of Port Credit experienced the most transformer outages during this time. It is evident that the vulnerability of the electricity grid is variable across the study area. It is possible that the spatial variability in the frequency of outages may be associated with differences in infrastructure characteristics and management factors (Figure 23) present across the study area.

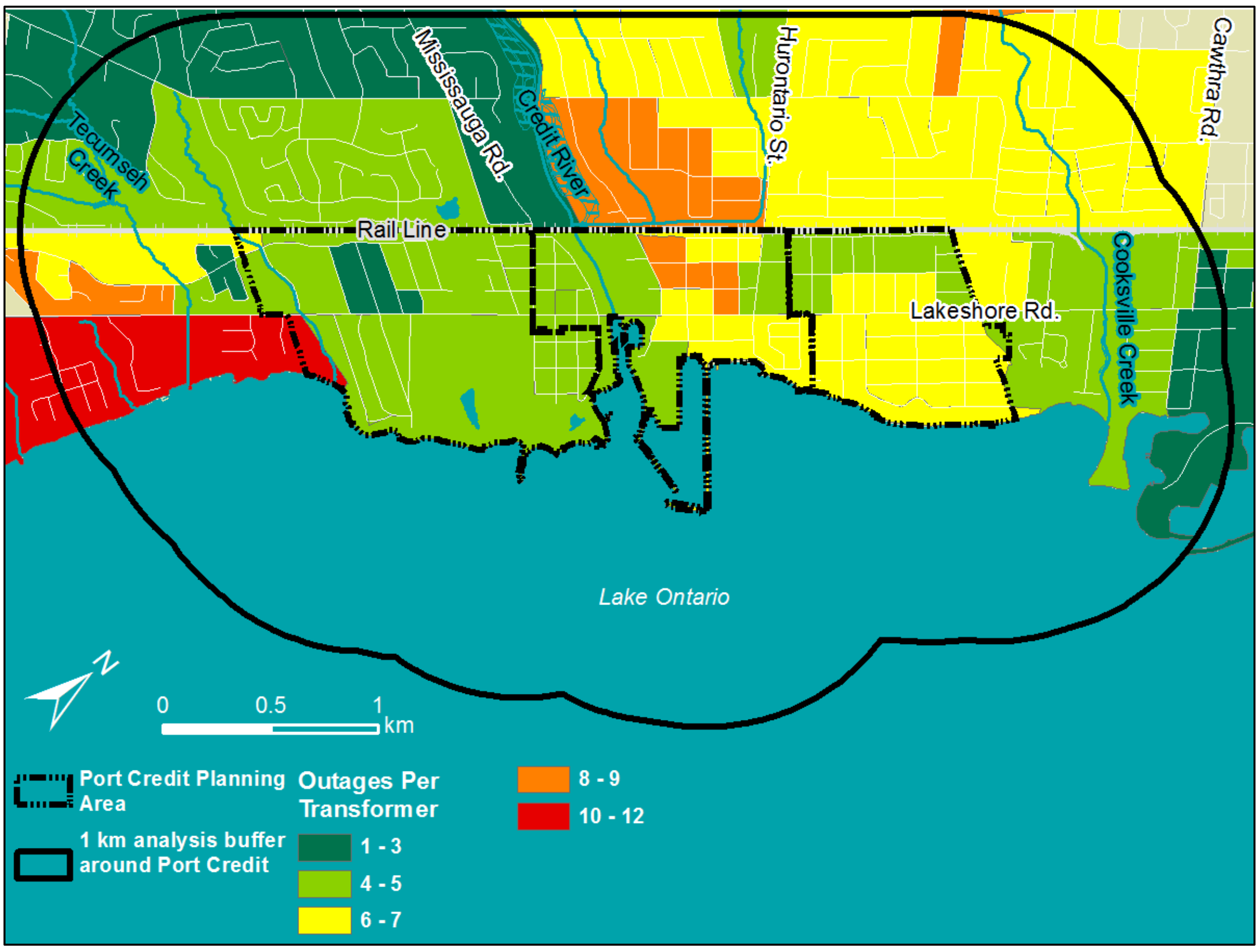

Figure 23 Map of the average number of outages per transformer located in each Census Dissemination Area for the period of 2009 through 2013.

Vulnerabilities Affecting the Occurrence of Outages and Component Damage

Appendix J provides a synthesis of key factors identified to mediate to the influence of climate on the electricity grid in terms of performance. These factors are a combination of physical system properties, design characteristics and management practices that ultimately affect the capacity of the electrical grid to absorb climate-related stress. Although the overhead electrical infrastructure in Port Credit is designed to withstand certain climatological loads, this capacity can be exceeded if weather events are outside the designed tolerance range (as described above) and if the equipment's load-bearing capacity is reduced because of material imperfections, design flaws, improper maintenance, or other hazards.

One of the most critical factors mediating the vulnerability of electrical equipment to the climate stresses identified above (extreme wind, snow/ice, heat/humidity, extreme precipitation, and lightning) is age. Over time, systems are exposed to weathering processes, normal material degradation, and possibly damaged, all of which contribute to lost capacity to resist climate impacts. Additionally, design criteria and standards change over time as new information on vulnerabilities arise. As such, older infrastructure may not be designed to the same level as newer infrastructure. In Ontario, compliance with the CSA standard is now law under O. Reg. 22/04, but past versions of the CSA or other standards may have been used for older infrastructure. Moreover, the CSA standard itself has changed over time. For example, "severe loading", defined as a combination of 19 mm ice with 400 Pa winds at -20°C, did not exist until the 2001 version of the standard was created; CSA 22.3 No.01-06. Figure 24 presents an analysis of the age of different overhead equipment in the study area, and illustrates the mean age of the grid, which is approximately 25 years. While the average age is below the design lifespan, the fact that it is an average means that there is equipment that is older than the average estimated. Figure 25 shows a map of the percentage of equipment installed or upgraded before 1970 and demonstrates that on average, secondary conductors are the oldest based on their year of installation in Port Credit (show in blue), followed by poles (green). Older equipment is considered more vulnerable to climate impacts.

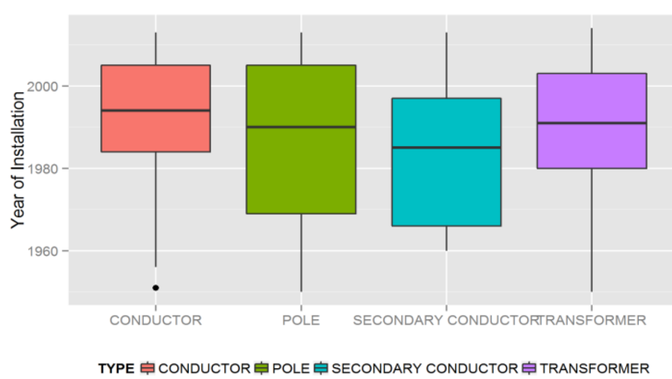

Figure 24 Boxplots showing the distribution of ages (25th, 50th, and 75th percentiles represent the boxes, while the maximum and minimum represent the whiskers) of different types of equipment in Port Credit.

Beyond the age of equipment, different materials can influence the vulnerability of the electrical grid to climate in different ways. For example, pole material and height can be a significant factor of vulnerability, especially as equipment ages (Shafieezadeh et al. 2014). Table 8 shows the variety of materials that exist for the poles in Port Credit.

Table 8 Summary of the distribution of utility poles by vulnerability characteristics in Port Credit.

Pole Characteristics	Percentage of Poles in Port Credit
Wood Poles	79
Wood Poles Installed Prior to 1971	11
Tall Wood Poles Installed Prior to 1971	3
Wood Poles within Flood Hazard Zones	3

Figure 25 provides a map of utility poles identified as possibly being more vulnerable in Port Credit; those constructed of wood, taller than 35 feet, and which were installed prior to 1970. This analysis demonstrates that very few (on average approximately 3%) have these characteristics. However, 79% of the poles in Port Credit are constructed of wood, and a slightly greater amount (11%), were also installed earlier than 1971. Given that wood is susceptible to rotting, an analysis was also completed on the percentage of wood poles within delineated hazard zones, and this also amounts to 3% of the total for Port Credit.

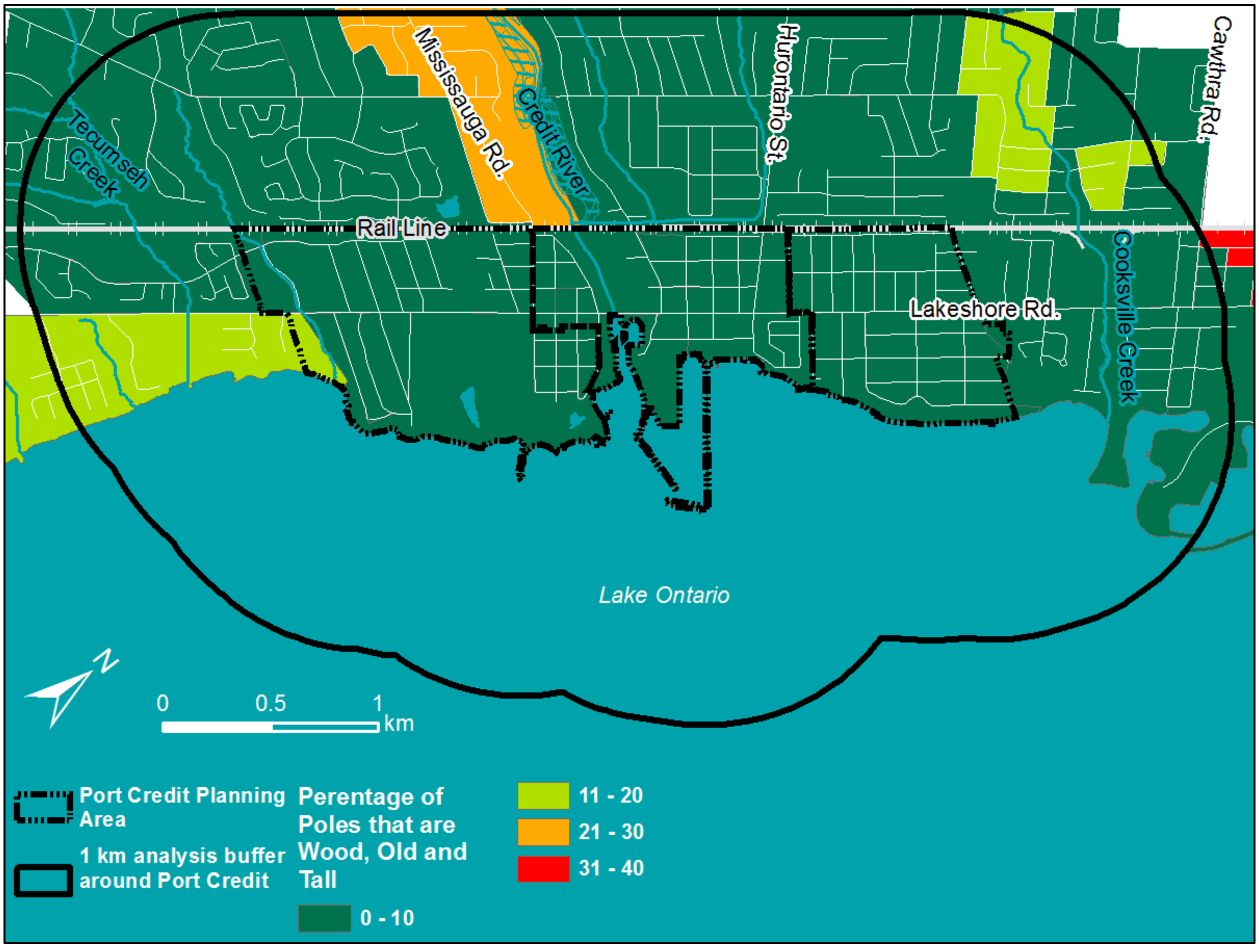

Figure 25 Map of the distribution of utility poles with characteristics (wood, prior to 1970 and taller than 35ft) that make them potentially vulnerable.

Another critical factor is associated with exposure of the grid to damage from trees. The majority of trees in Mississauga are deciduous; however, specific mapping for Port Credit was not available for this assessment. Within Mississauga, properties in Port Credit are quite old, with over 60 percent of properties constructed prior to 1961. As such, it can be expected that many of the trees are approximately that age. With respect to exposure of the electrical grid to trees in Port Credit are at least that age. Figure 26 presents a map of an index showing the relative exposure of the grid to the tree canopy along with tree-related outages by DA. This analysis demonstrates that the areas with very low outage numbers also appear to have low tree exposure index values. The correlation is less robust for areas with more outages; however, it is notable that with the exception of the DA at the extreme northwest boundary of the analysis, none of the areas with low outages have high tree exposure. This is likely a reflection of the fact that datasets outside the analysis boundary are not as complete. It should be noted that this index may need to be adjusted and that it assumes the tree canopy mapping is accurate, in addition to assuming that a 5 m buffer can explain exposure of conductors to tree limbs. While Enersouce and the City of Mississauga actively work to manage the tree canopy in the City, the age, characteristics, and density of the tree cover in Port Credit likely makes this area more vulnerable to climate-related impacts when compared to other areas in the City, and these factors are consistently deemed important in the literature.

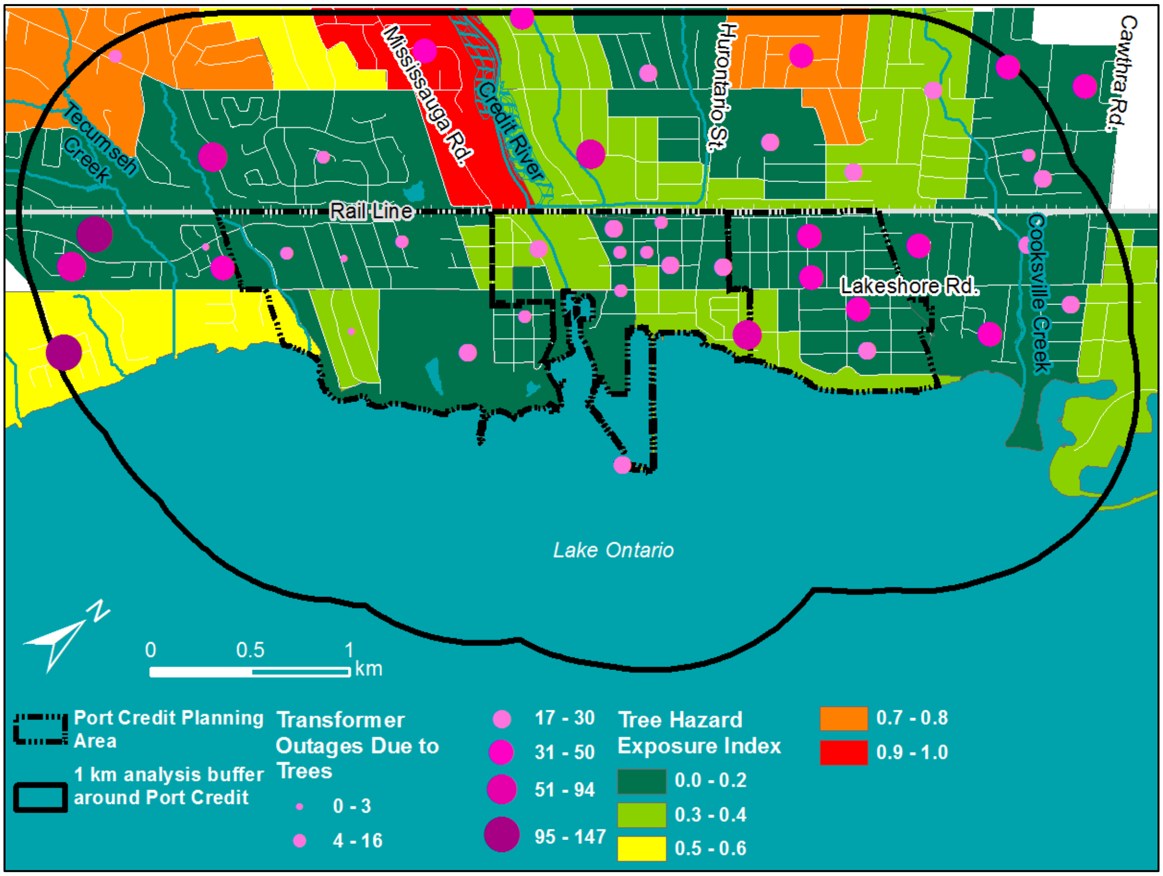

Figure 26 Map of the tree hazard exposure index along with total tree-related outages for conductors in Port Credit. The index is defined in Appendix F.

Overall, there are many factors that mediate the potential influence of climate on the electrical distribution grid in Port Credit, some of which are captured in the above analysis. It should be noted that additional work is needed to validate the findings in this section through engineering analysis and validation; however, there is high confidence that the vulnerability factors that are outlined in this report present important areas for consideration in managing climate adaptation capacity in the electrical system. These factors are of particular importance in the context of climate change, which is anticipated to result in a greater frequency of storm events and extreme weather conditions.

4.3.4. *Storyline #4: Preparing Populations for Extreme Heat*

The following section will first outline the parameters and terminology associated with extreme heat monitoring and reporting, before exploring in detail the factors which increase the human population's vulnerability to the impacts of extreme heat events.

Extreme heat is defined as the occurrence of ambient temperatures that greatly exceed a normal range over a prolonged period of time (IPCC 2012) such that hazardous effects on human health may occur. The occurrence of a heat event is a factor of temperature, humidity and wind conditions (Kovats and Hajat, 2008). Heat waves are projected to become more intense and frequent under scenarios of climate change, making them of prime interest for public health agencies (Corvalan et al. 2011). Furthermore, the consequences of extreme heat are of particular interest to stakeholders in Port Credit due to the potential for widespread health impacts during extreme heat events. These interest and impacts signal the need for a coordinated public health response in order to ensure protection and long-term provision of community assets and services, such as shaded recreational areas.

In the past heat alert and response systems, that are developed to protect health, were inconsistent across Ontario leading to confusion and inefficiencies. To address this, since 2012, Ontario public health units have been collaborating with provincial health agencies (Ministry of Health and Long-Term Care, Public Health Ontario) and federal departments (Environment Canada, Health Canada) to develop an efficient, coordinated, and evidence-based system for calling heat alerts and communicating health risks from exposure to extreme heat.

As of the summer of 2015, as part of a pilot project for the Pan Am Games, the Medical Officer of Health for Peel Public Health issues a heat warning/extreme heat warning based on weather notifications from Environment Canada. The thresholds that define the warning system were developed by Health Canada and Public Health Ontario, based on peer-reviewed science and a review of Ontario epidemiological evidence. Table 9 illustrates the heat triggers for each type of heat event. It should be noted that it is understood that consecutive days where heat warnings persist are likely to further exacerbate impacts to human health.

Table 9: Heat warning alert system triggers for Ontario established by Health Canada and Public Health Ontario (>2015).

Condition	Duration
Heat Warning	
Forecast daytime temperatures are expected to be at least 31°C and overnight temperatures are 20°C or above **OR** the Humidex is at least 40 for a duration	2 days
Extreme Heat Warning	
Forecast daytime temperatures are expected to be at least 31°C and overnight temperatures are 20°C or above **OR** Humidex is at least 40	3+ days

A regional climate analysis conducted by Auld et al. (2015), indicates that areas in Peel that are further from the lake and areas in which the urban heat island effect is more intense, can be expected to experience more extreme conditions during a heat wave. As such, communities like Port Credit, which have a large amount of shaded and shoreline recreation space may become popular destinations for those seeking relief from extreme heat. Within Port Credit itself, vulnerability to the impacts of extreme heat are associated with factors related to the population characteristics, and assets and services that assist with coping.

Figure 27 provides a conceptual diagram of the impact pathways associated with extreme heat that have the potential to disrupt the management of community services and assets (see Appendix L for vulnerability factor rationalizations). This diagram is informed by the results of an extensive review of health-related vulnerabilities in Peel conducted by Buse et al. (2014), as well as a broad review of other relevant literature (see P-CRAFT in Appendix D).

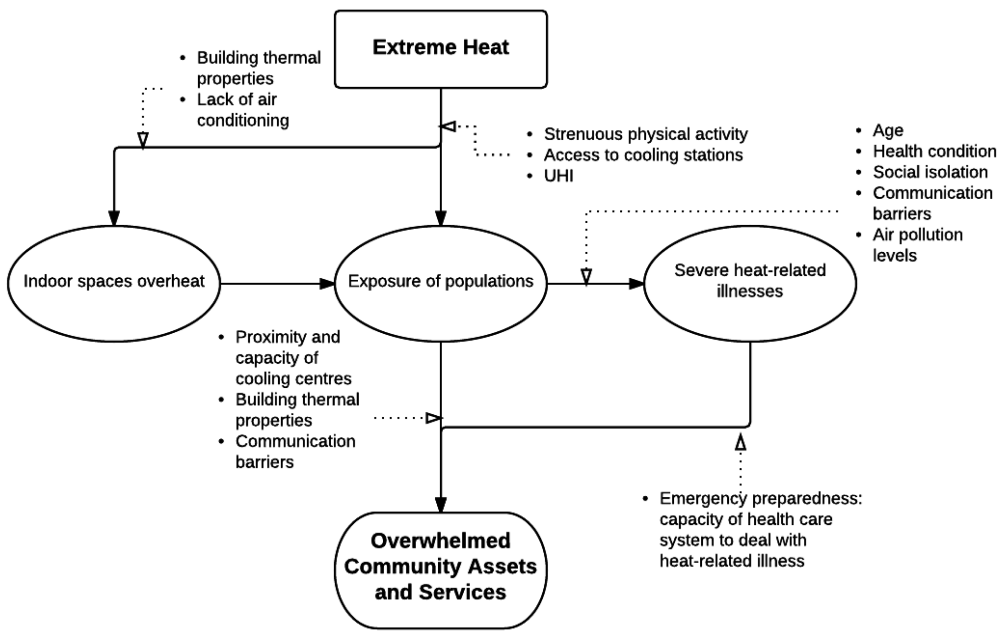

Figure 27 Conceptual diagram of the impact of extreme heat events (heat waves) on community services and assets in Port Credit.

Vulnerability to heat impacts is a function of many factors that are explored in more detail throughout this section. For instance, extreme heat becomes a health issue at the community scale when large populations are exposed to conditions that produce physiological responses which lead to illness and require a coordinated public intervention. Exposure to extreme heat conditions can occur directly where large populations are outdoors or more indirectly if indoor areas are prone to poor thermal regulation.

During instances of extreme heat, related illnesses can manifest in many forms, most commonly as heat cramps, fainting, heat exhaustion, heat stroke, and in some instances mortality (Corvalan et al. 2011). Heat exhaustion is considered the most common heat-related illness (Luber and Mcgeehin 2008). Heat-related illness can be exasperated by numerous environmental and physiological factors that may affect large segments of the population, which are summarized in Appendix L; their associated pathways are shown above in Figure 27.

Physiological Factors and Social Situation

Individuals with pre-existing health conditions such as cerebrovascular or cardiovascular disease, mental illness, diabetes, obesity, and/or respiratory conditions are considered more vulnerable to extreme heat, as they often have weakened or suppressed immune systems or may have impaired senses (Ebi et al. 2006; Luber and McGeehin 2008). Chronic conditions can be exacerbated by heat, and individuals on certain types of medication or who abuse drugs or alcohol are also vulnerable to heat morbidity and mortality (Luber and McGeehin 2008; O'Neil et al. 2005). At this time, no reliable data exists to capture the number of residents in Port Credit with pre-existing health conditions or who use medications or substances that may increase vulnerability to extreme heat. Roughly 47% of Peel residents do, however, report having at least one chronic condition (Peel Region Public Health 2008).

Age can also be an important factor influencing vulnerability during extreme heat events. Both contextual (such as living situations and daily activities) and physiological factors make younger and older populations more susceptible to heat-related illness. The ability to maintain normal body core temperature decreases with age and as physiological changes occur, the body's ability to cope with extreme heat is reduced. Similarly, children have a reduced capacity to regulate their body temperature. Infants are particularly vulnerable, as they rely on others to help regulate their response to their environment (by increasing fluids, dressing for the weather, being in a cooler environment, etc.) and may not be able to communicate when they are uncomfortable or heat stressed (Health Canada 2011). In Port Credit, roughly 16% of the population is greater than 65 years old, and 4% is under 4 years old (Environics DemoStats 2014). This percent of the population over 65 years old is slightly higher than the average for the entire Region of Peel, which is 10%. However, the percent of the population under 4 years old is roughly the same for Peel (6%).

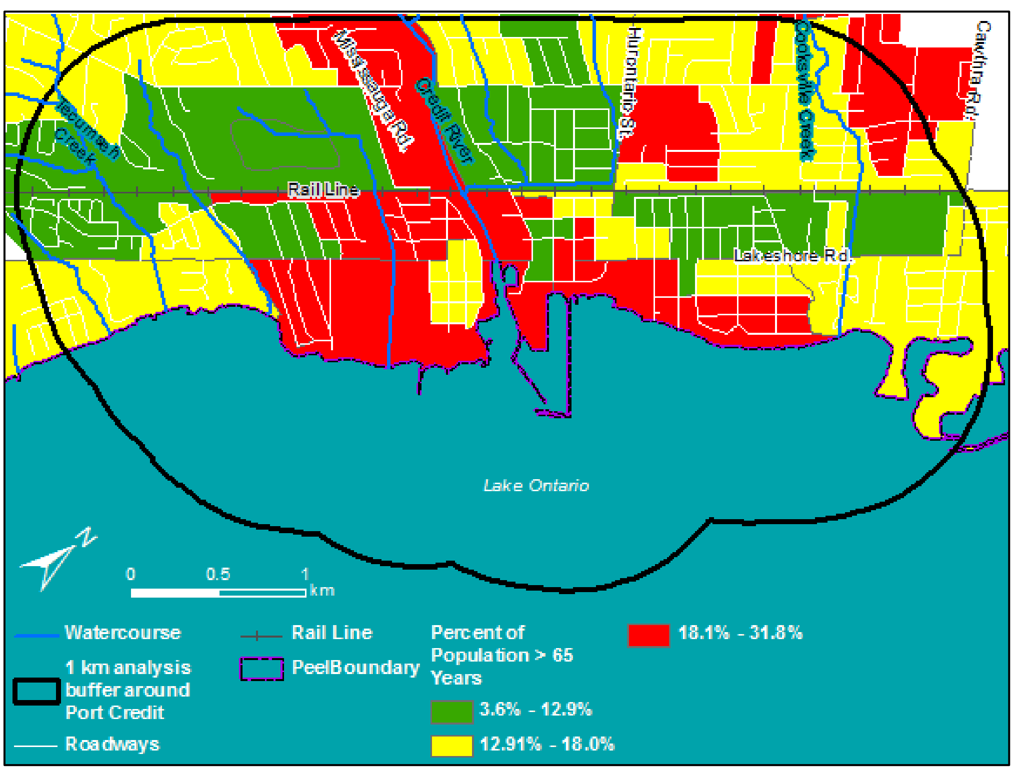

Figure 28 Percent of the population greater than 65 years and older in Port Credit summarized by Census Dissemination Area (Environics DemoStats 2014).

Figure 28 illustrates the location of older populations (65 years and greater) summarized by Census Dissemination Area. It appears that there is a particular concentration of these populations along the water front, with the least of these populations residing in the northeastern portion of Port Credit. A nearly opposite pattern can be seen in Figure 29 for populations less than 4 years old, with greater concentrations residing in the northern and eastern areas of Port Credit.

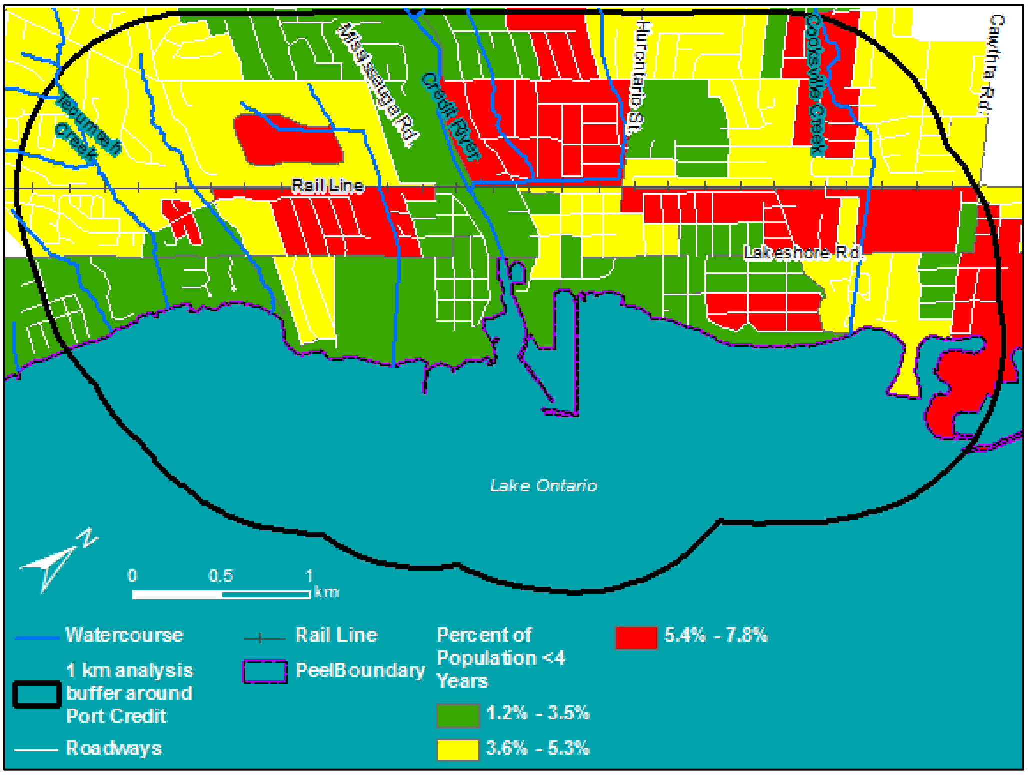

Figure 29 Percent of the population less than 4 years old in Port Credit summarized by Census Dissemination Area (Environics DemoStats 2014).

Other physical characteristics and lifestyle choices of the population within a community can also dictate extent of vulnerability during an extreme heat event. For example, those individuals who are directly exposed to extreme heat conditions due to their employment, or those who partake in activities that involve vigorous physical exertion (e.g. playing sports or running outside) are also considered to be more vulnerable (Health Canada, 2011). At present, there is no data to accurately represent these populations in Port Credit.

Additionally, and independent of age, language barriers, or a lack of understanding of what to do in the event of an extreme heat warning (e.g. comprehending health messages and taking preventative measures) can leave people vulnerable to heat related illness (Health Canada 2011). Table 11 represents the knowledge of official languages in Peel and Region; this table is broken down further to the municipal region of Mississauga where Port Credit is located. In Port Credit specifically, 28% of the population speaks a non-official language at home (Environics DemoStats 2014); however, this does not mean that these individuals cannot also speak one of the official languages. Table 11 below shows that a high majority of the population of Peel understands at least one official language.

Table 10 Knowledge of Official Languages in Peel and the Municipal Region of Mississauga

	Peel		Mississauga	
Language	**Number**	**Percent**	**Number**	**Percent**
English only	1,162,125	90.0	635,660	89.5
French only	965	0.1	575	0.1
English and French	78,415	6.9	49,125	6.9
Neither English nor French	49,865	3.9	25,115	3.5
Total Population	1,291,370	100	710,475	100

Source: Statistics Canada, 2011 Census (Peel data centre)

Individuals who experience communication barriers may be socially isolated and therefore vulnerable, as evidence suggests that the extent of an individual’s community integration and social network involvement is related to an individual's health status. Those offering interventions and support often have difficulty reaching socially-isolated individuals due to their limited community integration and social networks (Health Canada 2011). Within Port Credit, 5% of the population has no internet at home, and 44% of individuals do not have cell phones (Environics DemoStats 2014). These characteristics may increase an individuals’ level of isolation, contributing to greater vulnerability during heat events. However, 42% of the Port Credit population is part of some form of a social network (Environics DemoStats 2014), which can reduce vulnerability, as information on heat events can be shared through social networks. In Port Credit, roughly 11% of the population 70 years old and up live alone (Environics DemoStats 2014). Social isolation, as related to living alone and age, is a known vulnerability factor.

Influence of the Built Environment

In addition to living situation, housing type (i.e. apartment building, detached home etc.) can increase the vulnerability of individuals to the impacts of extreme heat events. For example, living on the top floor of an apartment building without air conditioning may increase the individual’s vulnerability because the top floor can be much hotter than the ground level. Table 12 shows the number and percent of the population living in various housing types.

Table 11 Housing Type in Peel and Mississauga

Housing Type	Peel	
	Number	**Percent**
Single-detached house	186,945	46.4
Semi-detached house	47,725	11.8
Row house	51,170	12.7
Apartment, duplex	16,830	4.2
Apartment, building that has 5 or more storeys	75,865	18.8
Apartment, building that has fewer than 5 storeys	23,895	5.9
Other single-attached house	130	0.0
Movable dwelling	345	0.1
Total	40,940	100

*Source: 2011 Census, Statistics Canada

Within Port Credit, roughly 28% of the population lives in an apartment/building that has 5 or more stories (Environics DemoStats 2014); this is higher than the average for Peel, which is nearly 19% (Statistics Canada 2011). However, no data was found on which of these buildings have air conditioning. Individuals who live in households that are not well thermally regulated are more sensitive to extreme heat. When this phenomenon is scaled up to the community scale, areas with these socio-economic characteristics would collectively require a bigger public health response or resources during instances of heat events. Ultimately a community characterized by low-income households (often correlated to not well thermally regulated houses) and isolated individuals is more vulnerable to morbidity and/or mortality as a result of extreme heat.

Certain characteristics of the built environment can also exacerbate the impacts of extreme heat events. In terms of geography, heavily urbanized areas are often associated with an intensification of ambient heat due to the urban heat island (UHI) effect, which has been shown to increased temperatures of cities compared to surrounding rural or less developed areas (Region of Peel Air Quality 2007). Average temperatures in UHIs can be up to 5 degrees warmer than surrounding areas (Frumkin 2002), depending on the degree of urbanization and heat storing capacity of the built environment (albedo). Areas covered by impervious surfaces such as roadways, buildings, and parking lots retain more heat than natural areas such as forests and greenspace. Additionally, greenspace can provide a cooling effect as a consequence of the shading effect of trees and the vegetative process of evapotranspiration, which result in ambient temperatures that are typically several degrees cooler than those found in the built environment (O’Neill and Ebi 2009). Figures 30 and 31 illustrate the urban heat island effect in Peel and Port Credit (TRCA 2015). These figures indicate that ground surface temperatures in Port Credit (particularly along the waterfront) are lower than temperatures found in the central portion of Peel Region.

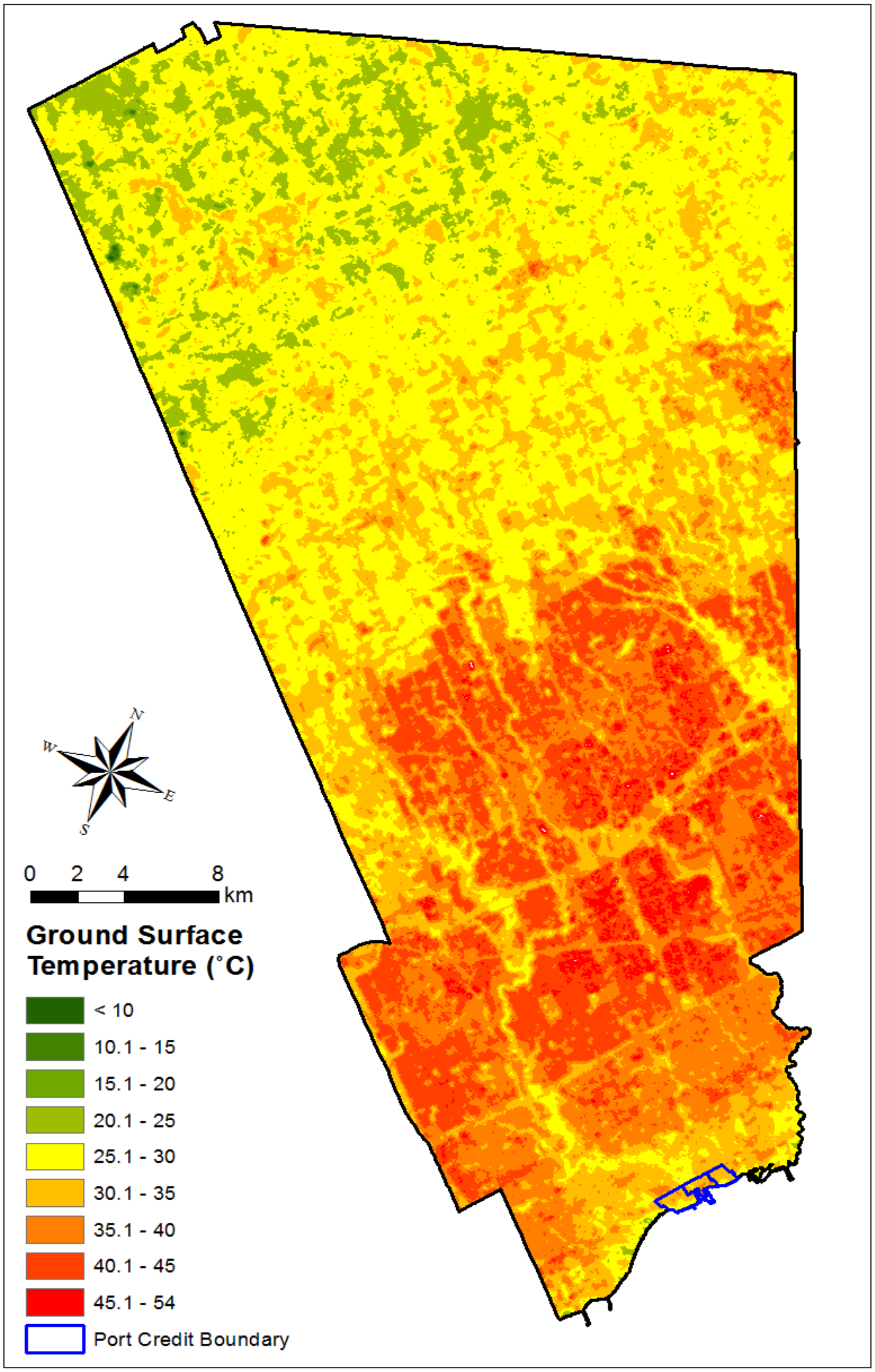

Figure 30 Ground Surface Temperature in Peel Region (LANDSAT8 image taken June 18, 2015) (TRCA 2015).

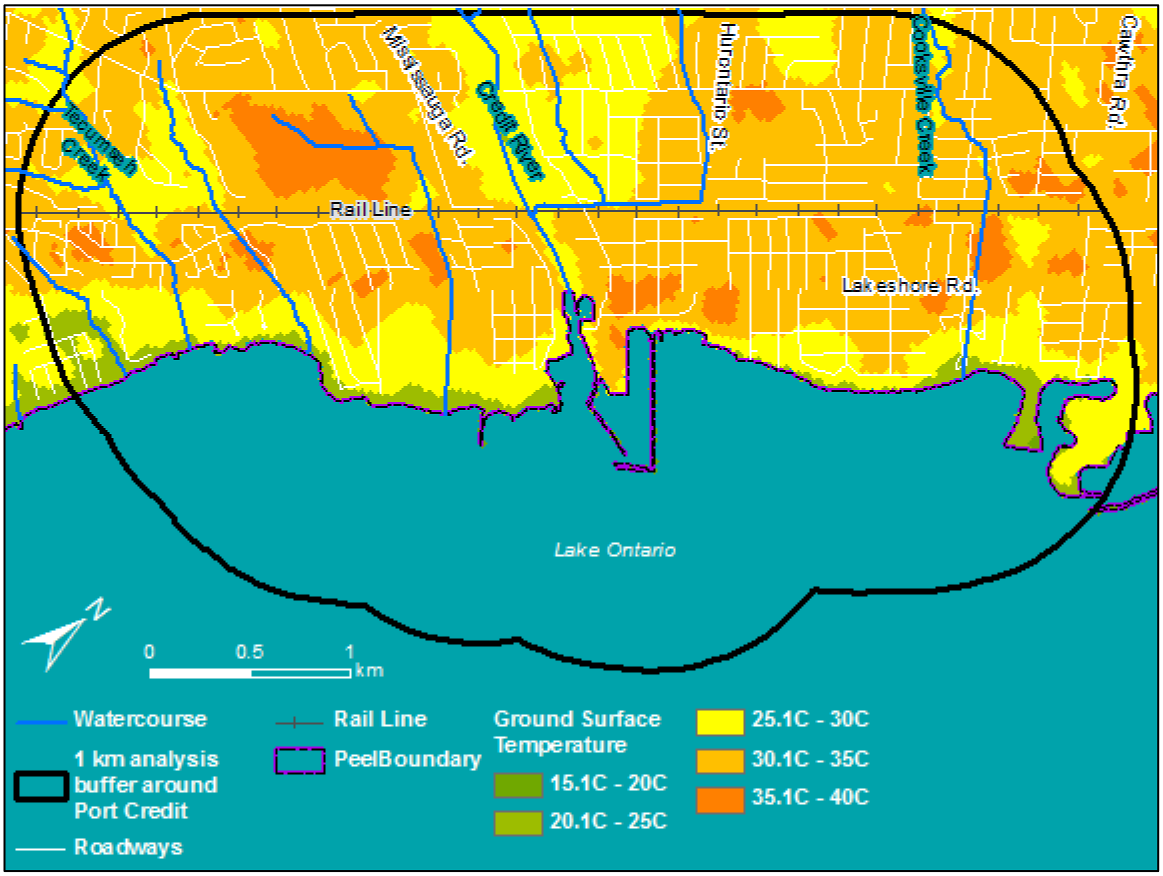

Figure 31 Close up of ground surface temperature, Port Credit boundary (LANDSAT8 image taken June 18, 2015) (TRCA 2015).

Tree canopy cover helps to moderate the UHI by providing shade. Figure 32 shows that within Port Credit the eastern portions of the community support a much higher percentage of canopy cover than the central and western portions. Areas that lack canopy cover are more vulnerable to heat events that exacerbate UHI. In these areas where canopy cover is low, the cooling effect of Lake Ontario helps to mitigate the UHI by reducing ground surface temperatures.

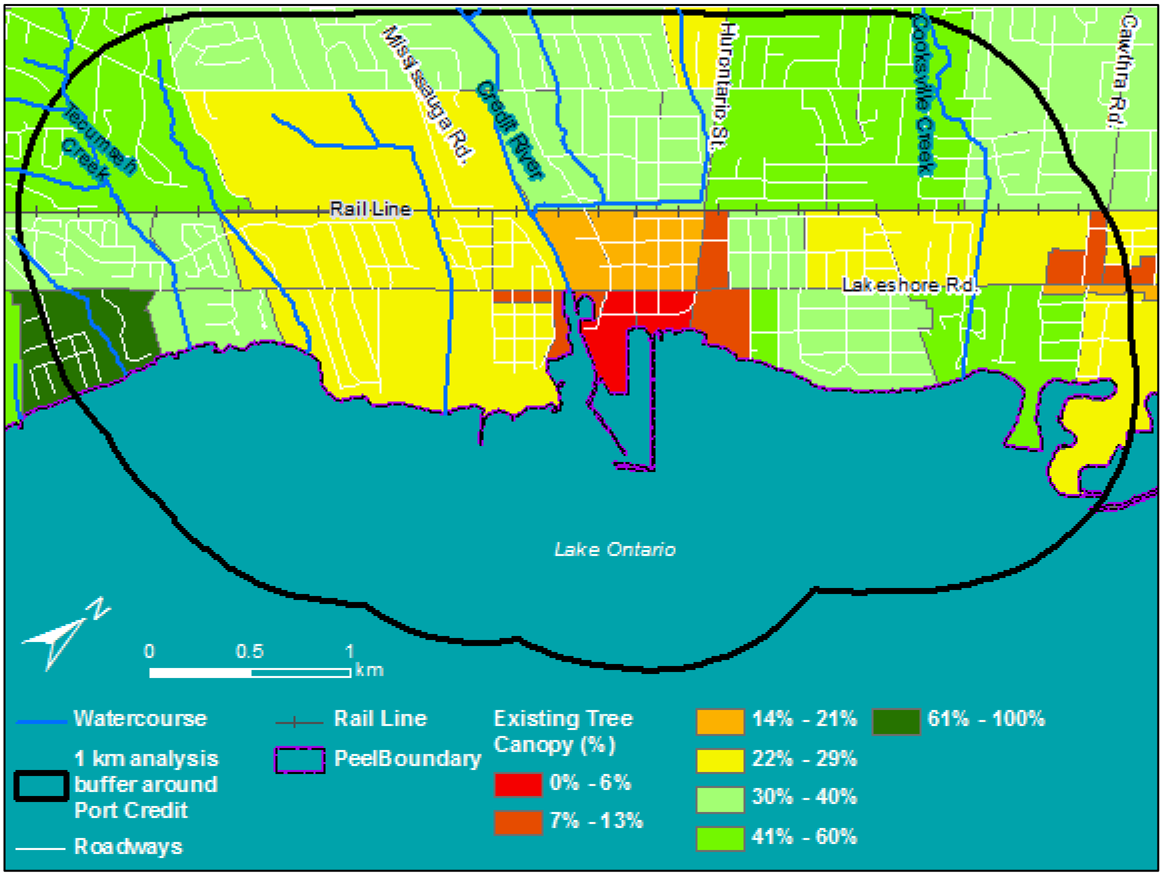

Figure 32 Urban canopy percent cover in Port Credit (TRCA 2011)

Urbanized areas are often associated with poorer air quality and higher air pollution levels. High ambient heat has an effect on air pollution. Extreme heat can exacerbate existing air quality issues (Kinney 2008), as increasing temperatures contribute to the development of ground level ozone, greater pollen production, and the spread of particulate matter (Kovats et al. 2010; Myers and Bernstein 2011; Sheffield and Galvez 2009). According to an Air Quality Discussion Paper produced by the Region of Peel in 2007, the Windsor-Quebec corridor, of which Peel Region is a part of, experiences the most smog episodes in Ontario.

Overall, air quality is considered a public health issue in the Region of Peel for a number of reasons. Some of the busiest highways in the country run through the region, including the 400 series highway and Pearson International Airport. The human health implications associated with ozone and particulate matter (PM) include, but are not limited to, respiratory illness, reduced cardiovascular function, and the exacerbation of pre-existing illness, especially respiratory related illnesses.

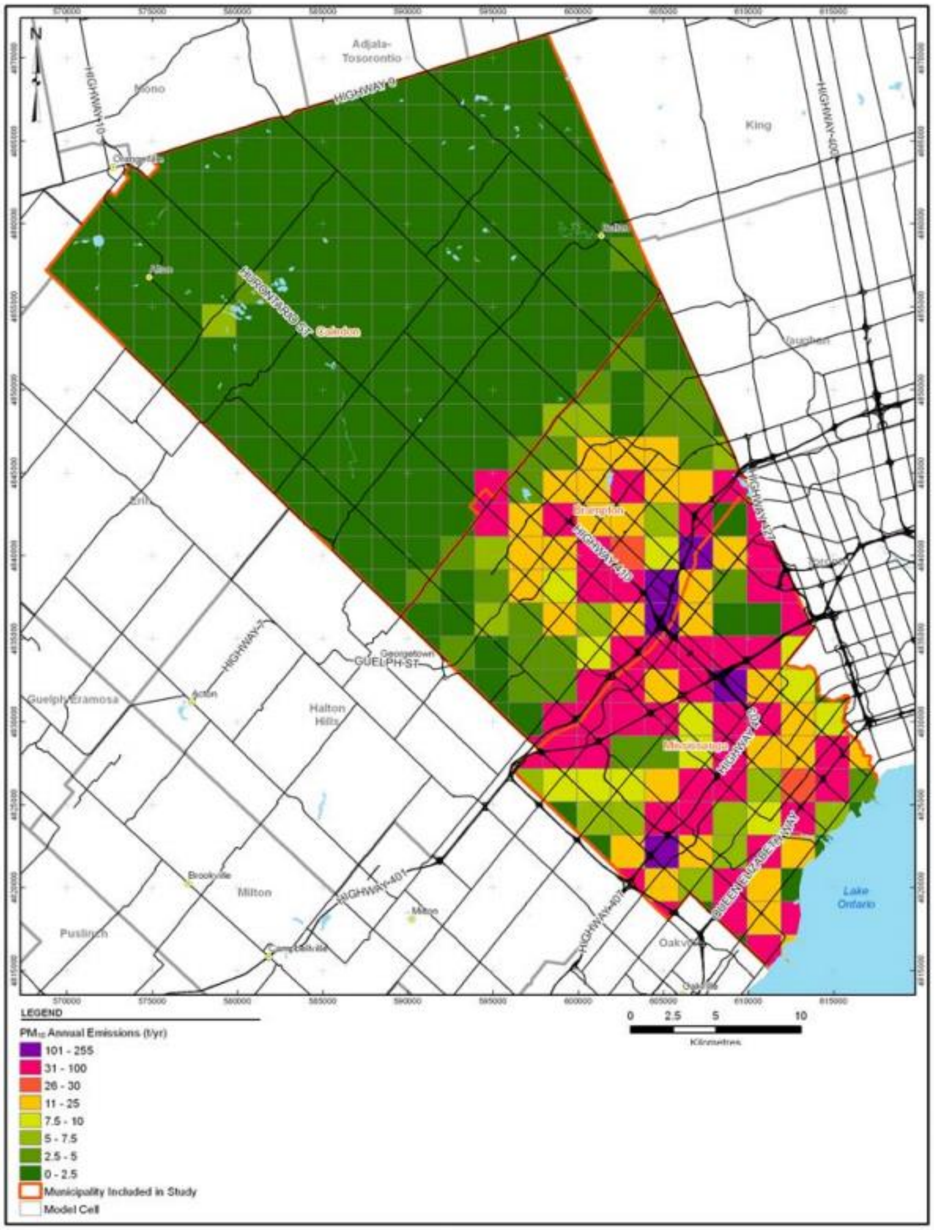

Figure 33 PM10 annual emissions from industrial, residential, traffic and airport in Peel Region. Particulate matter is made up of particles of sulphates, nitrates, organic compounds, metals and soil dust and are generated as wind-blown dust from roads, construction sites and agricutlraul areas, emisssions from vehicles and industry, etc. PM10 describes particulate matter smaller than 10 microns in diameter (Region of Peel 2007).

As part of a survey conducted in 2010, residents from Peel Region were asked how they would describe the outdoor air quality in Peel from very good to poor (Table 13). The majority of the sampled population believed that the outdoor air quality was good during the winter, spring and fall months and fair or poor during the summer months.

Table 12 Perception of Outdoor Air Quality in Peel by Season (2010)

	Winter (%)	Spring (%)	Summer (%)	Fall (%)
Very good/good	81.3	77.1	46.7	77.6
Fair	12.0	16.3	30.1	16.6
Poor/very poor	3.7	4.4	20.9	3.9
Don't know/refused	3.0	2.2	2.3	2.0

Source: Rapid Risk Factor Surveillance System, 2010, Peel Public Health (Peel Public Health 2012)

Air quality monitoring network data is used by the Ministry of Environment and Climate Change to calculate air quality index (AQI). AQI is connected to a scale ranging from 0 to over 100, with the lower numbers equating to better air quality. A smog *watch* is issued when there is a ≥ 50% chance that the AQI number will reach or exceed a score of 50 within the next 3 days. Smog *advisories* are issued when there is a high chance that the AQI will reach or exceed a value of 50 within 24 hours (Region of Peel Air Quality 2007). Figure 34 represents the number, and duration, of smog advisories issued for Peel Region between 2003 and 2013 (issued by the Ontario Ministry of the Environment and Climate Change). The figure shows that certain years, 2005, 2007 and 2012, experienced a greater number and duration of smog advisories. While several climate factors can affect smog (precipitation and wind), extreme temperatures has been identified to exacerbate the generation of smog pollution over urban areas; therefore, there is a strong correlation between smog and heat advisories, and one can speculate that as the number of extreme heat days increases so too will smog advisories. Precipitation also interacts with smog affecting the number of smog days, it is understood that some precipitation can reduce particulate matter from the air, reducing the number of smog days; however, this can result in acid rain and smog can.

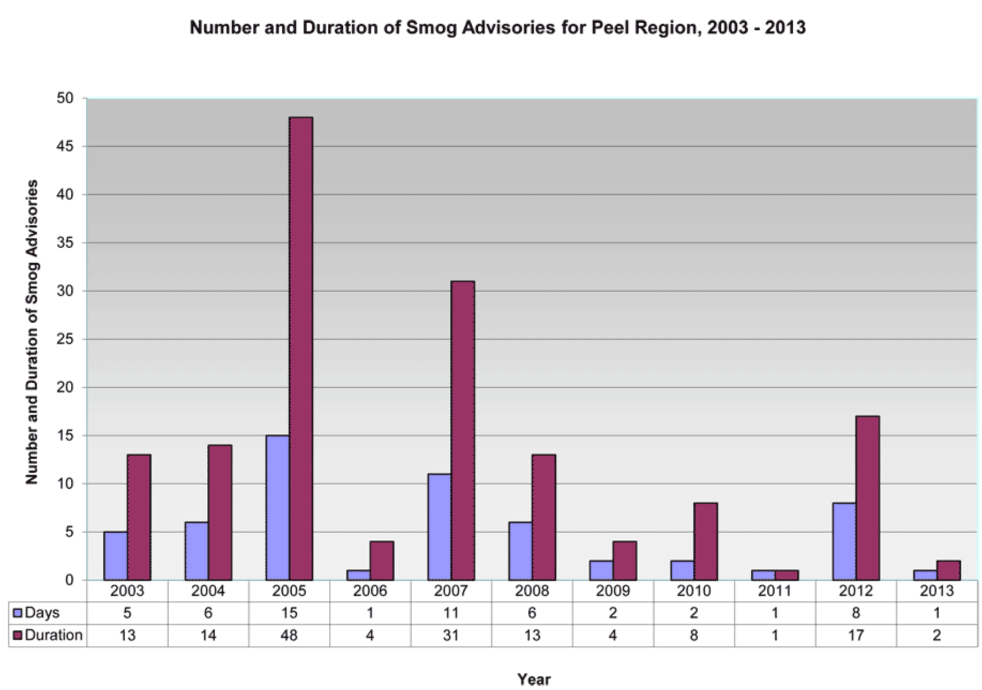

Figure 34 Number and duration of smog advisories for Peel Region (2003-2013) (Region of Peel 2015.

5. EXISTING ADAPTIVE CAPACITY IN PORT CREDIT

It is often recognized in climate change adaptation guidance that vulnerabilities can be addressed by increasing the adaptive capacity of a given system. By understanding the anticipated implications of climate change on community assets and services, decision makers can identify and prioritize alternative responses that represent viable adaptations. Such adaptation measures can be implemented through adjustments to operational practices, design of new systems, administration of broader policies and programs, and by building adaptive capacity within the range of stakeholders that comprise the community of Port Credit. Ultimately, the aim of all adaptation initiatives is to foster more resilient communities.

There are fundamental principles in adaptation that have emerged over several decades of research in this area and, if applied, present a promising pathway for addressing the effects of climate change in Port Credit. Table 14 provides an overview of specific examples that contribute to adaptive capacity resources and programs in Port Credit. One key strategy that holds great promise is bolstering the resources available for advancing adaptive capacity in the community following 5 categories: policy and regulations, human and social capital, information and knowledge, physical resources and financial resources. Adaptive strategies should be targeted at these various categories and at multiples, as follows:

- **Policies and regulatory frameworks** shape the community and the goods and services that multiple assets provide, with numerous levels of government influencing the programs, services and policies. These policies and frameworks must be flexible enough to deal with the great level of uncertainty that comes along with managing and adapting to climate change.
- **Human and social capital resources** are the primary asset for enhancing the resilience of community assets. The changing climate presents a new set of conditions that may preclude strategies (i.e. emergency response strategies) that were effective historically. Adaptive measures need to be targeted to support the operators and by extension the community in order to build community capacity by means of social networks and sharing resources as new conditions emerge.
- **Knowledge and information** is at the root of adaptive decision making, as a populations’ experience with and preparedness towards disruptions to community assets, goods and services are an integral part of learning. Providing the community with new information and extension services to assist in decision making, especially under a changing climate that brings with it a great level of uncertainty is key to adaptive management and planning.
- **The physical supporting resources** play an important role in how a community can adapt. The natural supporting services and ecosystem services, (such as flood attenuation, maintenance of habitat diversity, primary production, etc.) are equally as important as the built infrastructure and technology that shape a community. Extreme weather and a changing climate will challenge both the natural and built resources

needed for resilient communities. Adaptive strategies and infrastructure will need to be able to cope with a certain degree of uncertainty and extreme weather, while ensuring supporting systems are as equally capable of adaptation.

- **Financial resource** strongly constrains how a community will be able to adapt to changing conditions. Sufficient and stable financial resources can ensure there is a capability to invest in innovation, which could include testing new strategies and implement new technologies.

Table 13 Overview of specific examples that contribute to adaptive capacity in Port Credit

Resource Category	Resources in Peel
Policy and Regulatory Resources	• Emergency Preparedness Guide (City of Mississauga) • 72 Hour Emergency Guide (Government of Canada) • Emergency guides for severe storms, power outages and floods • Strategic Plan Report (City of Mississauga) • Older Adult Report (City of Mississauga) • Living Green Master Plan (City of Mississauga) • Watercourse Monitoring and Pond Maintenance (City of Mississauga) • Rainfall Monitoring (City of Mississauga) • Credit Valley Conservation's Lake Ontario Integrated *Shoreline Strategy* (*LOISS*) (City of Mississauga) • Stormwater Charge (City of Mississauga) • Official Policy Master Plan (Port Credit) • TRCA Flood Management: Flood Contingency Plan
Human and Social Resources	• Social media feeds (Port Credit, City of Mississauga, CVC, TRCA) • Networks, associations and resource sharing
Knowledge and Information Resources	• CVC Low Impact Development • CVC Grey to Green Residential Retrofit Guide • CVC Living by the Lake Newsletter
Physical Resources	• Low Impact Development Stormwater Management Planning and Design Guide (City of Mississauga)
Financial Resources	• Home insurance

Human and social capital and information and knowledge resources within a community are fundamental and an important platform for building adaptive capacity, as access to new information, skills and technology can help individuals and communities prepare for a changing climate and strengthen community resilience. Informed communities can better prepare themselves for climate change impacts and uncertainty. Based on survey data for Port Credit, 54% of the population said they discussed problems in their neighbourhood or municipality with people often. In terms of technological use and information, 56% of the population agreed that they always keep informed about the latest technologies, and 84% said they are excited about possibilities presented by new technologies. Additionally, more than half of the sampled population, 65% agreed that they are prepared to pay more for an environmentally friendly product. These social and decision making statistics help provide a better understanding of the populations' interests, wants and needs (Environics DemoStats 2014).

6. CONCLUSIONS AND CONSIDERATIONS FOR THE IDENTIFICATION OF ADAPTATION ALTERNATIVES

There are currently numerous ongoing strategic policy and land redevelopment projects taking place in and adjacent to Port Credit. Given the long-term nature of these projects, they present an important opportunity to build resilience into the local system now. Each initiative has a slightly different focus and thus unique way of addressing climate change vulnerabilities. As such, it is essential that they are coordinated, all use the same assumptions about climate and work toward a strategy that is integrative and promotes resilience across systems, not just for the one in question within each plan.

Within the Region of Peel, the average temperature is projected to increase over all seasons, with the greatest increases projected for the winter months. As the overall temperature increases locally, it is expected with confidence that the frequency and intensity of extreme high temperature events will also increase, while extreme cold events will decrease. Precipitation trends are much more variable than temperature. Looking ahead, the total mean annual precipitation for Peel is projected to increase from the current baseline average. Seasonally, winter and spring precipitation amounts are projected to increase, while summer and autumn precipitation are projected to either remain steady or slightly decrease. The frequency of extreme rainfall events is also projected to increase, resulting in shortened return periods associated with current storm intensities. In other words, heavy precipitation events will not only be more intense, but will occur more frequently. As noted above, precipitation patterns will either remain the same or slight decrease during the summer and autumn months.

As the climate changes, current vulnerabilities to climate and the exposure to extreme weather events can be exacerbated if they are not addressed through strategies that target root causes and promote flexible adaptive decision-making. This assessment characterized current, and identified potential future, climate vulnerabilities on multiple classes of community assets and services in Port Credit, in addition to possible benefits.

Despite the abundance of information on climate trends and potential impacts, there is substantial uncertainty regarding the precise extent and nature of the effects climate change will have on community assets and the disruption those impacts may have to public goods and services. It is recognized that current understandings about both climate and its interactions with community assets need to be constantly improved. As such, ongoing monitoring of the climate and the effectiveness of any measures aimed at reducing vulnerability is a cornerstone of the adaptive management cycle.

Efforts should be made to improve the amount and quality of information related to weather, and therefore climate observations, along with tracking of impacts. This should include the relationship between the specific opportunities and vulnerabilities identified in this report. A crucial element of effective adaptation monitoring and evaluation will be augmenting the quality and coverage of the climatological and hydrometric networks in Peel. Adaptation needs to be integrated across multiple scales with the right policies and economic market environments. Given that there is an array of potential strategies for building adaptive capacity, it is necessary to have a process for assessing these alternatives and prioritizing them.

Currently, this report does not rank the relative significance or importance of different climate change effects. This is because such a prioritization requires further stakeholder input, and in the context of Peel and Port Credit's broader adaptation planning process, needs to incorporate findings from the other assessment themes and supporting systems, assess trade-offs among impacts, and consider cumulative effects. Therefore, a risk assessment is the next logical step for identifying and developing adaptation priorities using the impacts, associated sources of vulnerability, and consequences to the community.

6.1. Building Flood Resilience and Adaptive Capacity

Given its unique hydrologic setting at the confluence of the Credit River and Lake Ontario, and the age of physical assets in Port Credit, this community has a complex set of natural and infrastructural factors that influence its vulnerability flooding. Interactions between these factors and the numerous processes that mediate flooding, in combination with uncertainty about future climate and watershed conditions, means that it is not possible to precisely identify future flood vulnerabilities with the same certainty as in retrospective assessments. As such, flood management needs to be based on principles of adaptive management and resilience, which assume that climate exposure will change and new risks emerge over time. Resiliency-based decision-making also means understanding and leveraging the entire stormwater management system and context (i.e., infrastructure, natural features, capacity of private properties, etc.) to address overall vulnerability rather than isolating and managing individual components independently, such as only upgrading the size of storm sewer pipes without considering the potential of lot-level storage. As this relates to Port Credit specifically, the following considerations are important:

- **Mitigating flood waters:** Urban flood management needs to focus on enhancing water storage and conveyance capacity throughout the entire local area rather than relying on a single urban drainage system (i.e., pipes). This could mean promoting widespread uptake of LID systems on public and private properties, and looking for unconventional opportunities to store and convey water.

- **Preparing for safe flood failure:** In the event of flooding, it is impossible that all impacts will be avoided, particularly in an era of climatic change where unanticipated scenarios are likely to arise. As such, it is critical that asset and service managers in the community of Port Credit to prepare to the possibility of being impacted by weather events, and identify strategies to ensure the systems can easily recover from these impacts. This means ensuring contingency plans are in place, known which historical impacts can be anticipated, identified vulnerabilities and ensure that emergency supplies are at the ready.
- **Learning and adapting to changing flood risks:** Flood events provide an opportunity to identify new vulnerabilities and learn more about the causes and effects of flooding. As such systems should be in place to monitor and evaluate flood impacts and responses. Additionally, the vulnerabilities identified in this storyline represent existing known or potentially important effects that, if managed, will build resilience to flooding. A key opportunity for doing so is ensuring that urban (drainage issues), lake-based and riverine flooding are anticipated in designs for new land development projects, in addition to assessing the veracity of existing hazard delineations.

Fortunately, there are many ongoing planning processes Port Credit that are already addressing the aforementioned considerations. Key ones include the Cooksville Creek SPA planning process, efforts by CVC and the City of Mississauga to promote the use of LID on private properties and right of ways, a recently introduced stormwater management fee that will enhance revenues for stormwater infrastructure repairs, and the LOISS planning initiative to strengthen natural systems. Beyond the current policies and planning processes in place, there are a number of other efforts that can be undertaken to enhance flood resilience in Port Credit. In a recent assessment of flood resilience in 15 Canadian cities that included the City of Mississauga, Feltmate and Moudrak (2015) assessed a range of practical management themes. Results are summarized in Table 15 and demonstrate that key areas of opportunity for enhancing flood resilience:

- Encouraging businesses and residents to assess and mitigate property-level flood vulnerabilities;
- Enhanced clearing of debris and maintenance of stormwater systems;
- Addressing threats to transportation networks – in Port Credit this pertains to the GO Transit station and main thoroughfares
- Addressing threats to water/wastewater utilities – in Port Credit this pertains to pumping stations and the water supply network (i.e., leakage)
- Addressing threats to critical community and emergency services, including health care, food supply, and financial services – in Port Credit one emergency health care clinic was identified to be in a flood hazard zone, and additional work is needed to assess the reliability for food supplies and financial services. Additionally, there is a fire station in downtown Port Credit that is not currently identified as exposed, but a more site-specific assessment should be considered for this asset.

Table 14 Summary of responses on flood management for the City of Mississauga. Overall score for Mississauga was a C+, placing it 7th out of all municipalities surveyed (from Feltmate and Moudrak et al, 2015)

Management Areas	Score	Description
Flood Plain Mapping	A	Flood plain maps for your city have been updated within the past 5 years, and they are forward projected (e.g., 15-25 years) to model future flood plains
Land Use Planning	B	Flooding in an area over the period of the past 50 years would negate siting structures, or infrastructure would be established to limit the potential for 50 year floods
Urban Drainage Maintenance	C	Water courses are cleared of debris during times of year when the potential for flooding is high
Home Adaptation Audit	C	Our city provides on-line information to help homeowners self-assess their property relative to basement flood potential
Commercial Real Estate Adaptation Audit	E	Our city has no program to encourage commercial real estate property owners/managers to limit flooding
Backwater Valve Installation (new house construction)	A	Our city mandates the installation of backwater valves during new house construction
Backwater Valve Installation (house retrofits)	A	Our city offers a subsidy to all home owners to install a backwater valve
Electricity Supply	A	Relative to electricity generation, transmission and distribution, our city has identified flood-related vulnerabilities, budgeted for and instituted adaptation practices, and maintains a system of continuous improvement
Petroleum Supply	A	Relative to petroleum supply, our city has identified flood-related vulnerabilities, budgeted for and instituted adaptation practices, and maintains a system of continuous improvement
Transportation Systems	C-D	Relative to transportation, our city has identified flood-related vulnerabilities but has identified, and budgeted for flood-related adaptation practices.
Telecommunication Systems	A	Relative to telecommunications, our city has identified flood-related vulnerabilities, budgeted for and instituted adaptation practices, and maintains a system of continuous improvement
Retail Food Supply	D	Relative to retails food supply, our city has identified flood-related vulnerabilities
Banking/Financial Services	D	Relative to financial services, our city has identified flood-related vulnerabilities
Water Supply and Raw Waste Management	D	Relative to water supply and raw waste management, our city has identified flood-related vulnerabilities
Human Health & Safety	D	Relative to ensuring the health and safety of its most vulnerable citizens, our city has identified flood-related vulnerabilities
Emergency Responders	D	Relative to emergency responders, our city has identified flood-related vulnerabilities

6.2. Addressing Vulnerabilities to Extreme High and Low Water Levels

In Port Credit more specifically, lake level variability means addressing impacts pertaining to all classes of assets on the shoreline, including recreational and cultural facilities, primarily marinas, water quality and ecosystem management. High water level scenarios are primarily a concern because of flooding, which are explored in Storylines 4.3.1 and 4.3.2. However, given the projected range of variability in Lake Ontario water levels, there is a need to scrutinize planning and design assumptions based on historical water levels to ensure they reflect desired levels of likelihood of exceedance. Based on Figure 18, this appears to be less of an issue for high water levels, compared to lower water levels. The historical annual high 100-year instantaneous water level typically used in design applications and the current hazard delineations is 75.8 m asl, and this value is already at the top of the range for both available climate projections and the Bv7 regulation plan (Figure 18). There is a need to consider the implications of experiencing this water level more frequently at an infrastructure and property-specific level, particularly in design and planning for Inspiration Port Credit, the Waterfront Parks Strategy, and management plans that emerge from LOISS.

With respect to low water extremes, recent instances of low water levels have already had significant impacts to water access, water quality protection, and highlighted vulnerabilities of infrastructure. For the first time in Port Credit's history, an emergency dredging project was required in 2013 at a cost of over $500,000 to address the combined effect of low water levels and siltation in Port Credit harbour due to enhanced runoff in Credit River (City of Mississauga 2013a). Low water levels on Lake Ontario in 2013 also caused lack of accessibility to the water for recreational uses in private marinas (per interview with D. Looyen). The relatively low water levels experienced the summer prior represent a key trigger for this dredging, and as shown in Figure 18, while this water level approached minimums experienced in recent decades, low levels can be expected to be much lower under drier scenarios expected with climate change and under regulation plan Bv7. Additionally, the combination of high streamflows followed by lower water levels is an important climate driver that can be more likely to occur under climate change. In Storyline 4.3.1 interactions between high water levels and streamflow were associated with enhanced upstream flood vulnerability, but increased vulnerability to sediment deposition are associated with the interaction of high streamflow and low lake levels.

In addition to marinas, low variability in water levels can affect the performance of shoreline protection infrastructure. The durability and lifespan of shoreline protection infrastructure, such as armour stones, is much greater in deeper water (Strum 2013). This is because it is designed to remain submerged and if exposed, can be subject to erosive forces, such as waves. Although most armour stone and rebutements are heavily reinforced, those older in age are more vulnerable to wave action. Detailed mapping and assessment of shoreline infrastructure risks is available through the LOISS assessment.

From an ecosystem standpoint, key vulnerabilities pertain to the connectivity of aquatic ecosystems within tributaries to Lake Ontario and the Lake itself, in addition to water quality degradation in the nearshore zone. Substantial work has been ongoing through the LOISS assessment to address these issues; however, resultant strategies will need to consider the higher probability of low water conditions on ecology, such as habitat connectivity, water quality parameters (e.g., shallow water is more vulnerable to heating and lower assimilation of nutrients and contaminants). Aquatic habitat issues are particularly relevant in Port Credit, given the importance of the Credit River and the upstream wetlands as ecologically sensitive areas.

6.3. Enhancing Resilience in the Energy System in the Context of Climate Change

Changes in climate will result in alterations to the frequency at which the electrical grid in Port Credit is exposed to adverse weather. This may have implications for many assets and services in Port Credit, and highlights the importance that electrical supply contingency emergency and plans have, as strategies for addressing the potential for increased frequency of outages.

The longevity of existing infrastructure and the design criteria for new assets, along with maintenance regimes, will require additional study in the context of shifting climate exposure for the electrical grid, to determine the extent to which equipment lifespans will be altered. Another important consideration is associated with the management of the urban tree canopy and its influence on mediating extreme weather impacts to the electrical grid. Climate variability is expected to have significant impacts on the health of ecosystems and vegetation niches, which can have important implications for line maintenance practices, frequency and right-of-way management (Zizzo et al. 2014).

Given that Port Credit’s electrical supply vulnerabilities also exist in the transmission and generation systems, it is important that end-users and planners begin to identify opportunities for enhanced alternative, and preferably low-carbon, supplies. Distributed generation using solar, wind and other renewable energy sources presents an important opportunity for enhanced resilience of the electricity grid (Meier 2002; Asian Development Bank 2012; U.S. Department of Energy 2013).

6.4. Responding to Extreme Heat Events

The vulnerability of a region/population to extreme heat events depends on many factors including biophysical conditions as discussed above (e.g. age and pre-existing health condition), as well as the built environment and access resources, which can either exacerbate or mitigate impacts. Building resilience around extreme heat impacts largely involves public awareness and communication. Heat-related illnesses are largely preventable through adaptation in human behavior, such as staying hydrated, staying indoors, and reducing physical activities during high heat (Health Canada 2011). Effectively and appropriately communicating human health and heat risks to the population is essential, which may include tailoring messages to a diversified range of audiences (Health Canada 2011).

During public emergencies, public health agencies and officials assist with organizing and monitoring community response. These roles often include coordinating and distributing heat information as well coordinating response and help once heat warnings have been triggered. During extreme heat events, Public Health can use a heat advisory system to assist in communicating the increasing risk to human health during these events. Best practices to help increase public awareness and adaptive capacity include distributing informative and educational material to the population on what to do during a heat event, how to stay cool, and how to identify early stages of heat-induced illness. Additionally, it is important to provide the population with information on the appropriate actions to take in the event of heat-related illnesses, such as how to treat the event at home and when to seek medical attention (Health Canada 2011).

One key strategy for reducing heat related illness is access to cooling in a home and/or community, which can greatly help to reduce symptoms (i.e. thirst, exhaustion, etc.) during extreme heat events. In Peel Region, there are four community centres open with extended hours during extreme heat events in Brampton. Additionally, the City of Mississauga has agreements with air conditioned commercial centres, such as shopping malls, to stay open during these events, as well as public swimming pools and splash pads. It should be noted that little information currently exists to identify how many individuals use cooling spaces, shelters or social services during extreme heat events (Region of Peel 2015).

Emergency preparedness requires the coordination of a response plan that is intersectoral and interdisciplinary. In order to effectively manage response, coordination among multiple players, such as health care workers, front-of-line personal such as emergency responders and police officers, and public health agencies is essential in order to outline key roles and responsibilities during an extreme event (Health Canada 2011).

7. ADDITIONAL ANALYSIS AND RESEARCH

Given the large number of community assets and services in Port Credit, it was not possible to assess all potential impacts at the highest level of detail. Only the impacts deemed to be the most critical were assessed in greater detail. It should be recognized that these detailed analyses were based on stakeholder identification as being important. As such, additional work is needed to assess other impacts that may not have been currently prioritized by stakeholders, but may emerge as priorities during the synthesis process.

This analysis could be expanded to other communities, asset classes, or services in Peel. Through this report and the research process undertaken, a number of key questions remain to be addressed. Addressing the following research question would enable continued progress on building adaptive capacity in Port Credit by enhancing the information and knowledge and providing opportunities to continually engage with stakeholders:

What other systems and contextual factors contribute to the effects of climate change on community services and assets beyond the systems themselves, such as community socio-economic and cultural factors, economic and political constraints, ecosystem health, among many others?

What specific management factors are in place within the higher vulnerability areas identified, and which other management factors applied already in this area could have significant effects in reducing the vulnerability of the system?

What existing programs or systems can be leveraged for the ongoing monitoring the effectiveness of measures aimed at reducing vulnerability of the system to feed into the adaptive management cycle?

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APPENDIX A: ICLEI MILESTONES PURPOSE AND OUTCOMES (ICLEI, 2012)

Milestone & Purpose	Outcomes
Milestone 1. To initiate your climate change adaptation planning process and build political as well as community support for the process.	• List of possible stakeholders • A climate change adaptation team • A climate change adaptation champion • A first look at how climate change will affect your community • List of existing municipal actions that improve adaptive capacity • Identification of municipal plans and activities that could include adaptation components • Council resolution which entrenches your communities'
Milestone 2. To research the climatic changes and impacts for your region and identify the main service areas that will be impacted by those changes.	• A list of impact statements and the service areas that will be directly or indirectly affected • A vulnerability assessment • A risk assessment • A prioritized list of impacts – based on vulnerability and risk assessment
Milestone 3. To establish your short and long terms adaptation actions and finalize your climate change adaptation plan.	• Vision • Goals and Objectives • List of Adaptation Actions • Financial implications of your plan
Milestone 4. Secure the support of Council and the community and implement the actions identified in your adaptation plan.	• Support and Approval from Council • Implementation Tools • Community Engagement and Partnerships
Milestone 5. Assess progress towards the goals and objectives that were set out in Milestone Three and to reassess the scientific information upon which vulnerability and risk were evaluated.	• Review of scientific information • Progress on implementation • Effectiveness of actions • Updated action plan • Communication of accomplishments

APPENDIX B: INVENTORY OF HISTORICAL CLIMATE EVENTS IN PORT CREDIT

Climate Event	Year	Season	Description
Blizzard (Synoptic Storm)	1978	Jan	16 cm at Toronto City, winds 90 gusting to 126 km/hr at Toronto Island, near zero vis, 941.5 hPa lowest pressure on record for station (as of 1990, need verify), road closures, over 400 injuries associated w/ storm, 1 death exposure near Pearson Intl., total costs damage, closures, etc., est. $41 million
Dry Spell	2007	Jul-Aug	Toronto Pearson experienced driest summer in nearly 50 years with 95 consecutive days without significant rainfall. Lake Ontario water levels down 0.25 metre from long-term average
	2001	Jul-Aug	Driest summer in 54 years of records (Pearson)
	1876	Jul-Aug	34 days; Longest on record for City of Toronto
Extreme Precipitation	2013*	Jul	On July 8th rainfall of over 120 mm fell in less than 6 hours with addition rainfall on the days preceding and after, resulting in extensive flash-flooding
	2012	Oct	Intense rainfall and storm drains clogged with leaves resulted in localized flooding in several low-lying areas
	2012	Sep-Oct	Remnants of Hurricane Sandy led to several days of heavy rainfall leading to localized flooding and isolated power outages throughout Mississauga.
	2011	Oct	Intense rainfall and storm drains clogged with leaves resulted in localized flooding in several low-lying areas
	2009	Aug	One hour rainfall from a Mississauga gauge exceeded 1 in 100 year event, with flooding damage to private properties, municipal and regional infrastructure
	1980	Jul	High-intensity, short duration rainfall resulted in localized flooding
Fog	1962	Dec	"fog bowl" Grey Cup delayed, play extended for 2 days
Hail Storm	1981	Aug	Week of storms ending on Aug 19th, tennis ball sized hail reported N of Toronto
Heat Wave	2012	Jul	Several days of temperatures well above 30°C posed elevated health risks
	2011	Jul	Toronto Pearson Humidex exceeds 48
	1995	Jul	Extreme temperature and humidity caused the humidex to reach 50.3
	1988	Jul	5 day heat wave, temps to 35°C at Pearson Intl., and the most number of extreme heat days from 1971 through 2000
	1953	Aug-	10 days Late Aug-Early Sept 1953, a "few" fatalities

Climate Event	Year	Season	Description
		Sep	
Ice Storm	2013*	Dec	More than 250,000 customers were out of power for between 1-4 days as a result of a flash ice storm
	2003	Apr	Over 48 hours of freezing, drizzle or ice pellets reported at Pearson travel (hazardous roads, flight delays) leading to ice loading on wires, cables and trees; maintenance & timing (occurred late season, snow removal contracts expired April 1)
	1986	Dec	Toronto, rapid drop in temperature following 11 mm of rain, "hundreds" of accidents, "scores" of injuries and two fatalities
	1959	Dec	NW of Toronto 30 mm accumulations, lasted over 32 hours
Post-Tropical Storm	2003	Sep	Remnants of Hurricane Isabel; winds measured gusting 70-80 km/hr at multiple locations, waves to 4 m west end of Lake Ontario
	1954	Oct	Remnants of Hurricane Hazel dumped ~200 mm of rain causing flooding, 80 dead and $24 million in damage (worst Humber Valley, Toronto); winds (gusts?) 90 up to 115 km/hr reported, prompted significant flood plain management improvements; Port Credit Climate Station reported 128.3 mm Oct 15th, total of 161.3 mm Oct 14-16; est. $20 million along Credit River Valley, $30 K damage Credit Valley Gold & Country Club
Rapid Spring Melt	2009	Feb	Rapid warming caused ice jams and rapid rises in water levels on the Credit River and overtopping of banks in some Mississauga locations
Snowfall	2001	Jan-Apr	104 day stretch with snow on the ground; longest snowcover period in record (dating to 1840)
	1999	Jan	Snowiest two-week period since 1846
Thunderstorm	2009	Jul	Heavy winds and rain resulted in downed hydro poles and damage to properties in Mississauga
	2005	Aug	Trees down, quarter sized hail in severe thunderstorm; Air France Crash Pearson Airport associated
	2000	May	Near midnight, boats blown over at Port Credit Yacht Club during severe thunderstorms causing "extensive boat damage", gusts over 70 km/hr at Toronto Island during same event, hydro poles snapped and trees down in Brampton causing power outages, trees down in Mississauga as well, pieces of trees and shingles floating in lake to west in Bronte Harbour (Oakville)
	1976	Aug	$2 million severe t-storm damage E Toronto
	1956	Jul	134 km/hr gust @ Pearson Intl.; highest gust on record for station (as of 1990, need verify)
Tornado	2009	Aug	A tornado outbreak resulted in > 18 tornadoes across the GTA, with Tornados in Vaughan causing > $10M in

Climate Event	Year	Season	Description
			damages; largest single-day tornado outbreak in Canadian history
	1986	Jul	Mississauga (morning)
	1985	Jul	10 injuries, $400 K property damage Mississauga, torrential rains further south delayed Canadian Open (Glen Abbey, Oakville), ponding in fields; F1 tornado, 40-50 m wide, ~1.5 km track located just south of Creditview and 401, ~1:30 PM
	1980	May	F1 tornado, 26 kmX250m track (max 485 m wide) NW of Georgetown through N end Bramalea to , est. $0.9 million in damage (1980 dollars, replacement only), mostly rural damage, lasted over 1/2 hour total
	1979	Jun	Brampton industrial park and adjacent residential areas
Tornado & Severe Thunderstorms	1923	Jun	3-4 dead, hundreds of barns destroyed, possible tornado or severe thunderstorm wind present day southern Mississauga, track from Guelf to Long Branch
Unseasonal Heat	2012	Mar	Toronto Pearson high temperature reaches 26.0°C; warmest March on record for many stations (Toronto Pearson & City)
	2010	Jan	warmest in Canada since nationwide records began in 1948 - 4.0°C above normal; Lake Ontario temperatures peak at 24°C
Wet Year	2008	Jan-Dec	Winter snowfall at Pearson reached a total of 194 cm, 13 cm shy of the historical record. Summer saw the wettest June, July and August on record (396 mm).
Winds	2013	May	Property damage resulting from a tornado or microburst in Brampton
	1964	May	121 km/hr average wind at Toronto Island due to a synoptic storm event

* Denotes an event that occurred following the first stakeholder workshop

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Climate Event	Year	Season	Description
http://www.mississauga.com/news-story/3127081-heat-wave-continues-to-bake-mississauga/ http://www.mississauga.com/news-story/3129475-flooding-creates-traffic-chaos/ http://www.mississauga.com/news-story/3241255-update-environment-canada-looks-at-possible-brampton-twister/ Region of Peel Emergency Management (http://www.peelregion.ca/prep/resources/past-events.htm); AMEC 2014 Region of Peel Emergency Management (http://www.peelregion.ca/prep/resources/past-events.htm)			

APPENDIX C: WORKSHOP 1 MATERIALS

Equipment Needed: Notepads, Pens, White Board, Post-it Notes

Purpose: To begin the process of defining weather related impacts in the Port Credit area, specifically the impacts of flooding and consequently the key manner in which flooding impacts the area; To understand the different ways in which the same impact affects different stakeholders within the Port Credit area; and To collectively prioritize the key elements of how flooding impacts Port Credit in short and long term.

Instructions, Part 1: Defining a flood impact criteria

- On a piece of paper around 7 – 10 things that make a flood impactful in the Port Credit area;
- Individual stakeholders should share their lists of impacts with other participants at their table and consequently prioritize the top 5 elements of what makes a flood impactful in the Port Credit area;
- Each group (i.e. table) of stakeholders is to take turns identifying top priorities.
- Group by group stakeholders will identify the top 5 priorities until all 5 impacts are identified for the group as a whole
- As an overall group stakeholders are encouraged to begin grouping impacts and consequently categorizing them.

Purpose: To consider the relative levels of risk associated with different types of flood hazards in the Port Credit area in both the short and long-term; To prioritize the risks associated with key flooding hazards in order to consider the influence of additional non-flood hazards; To develop a process for identifying area level hazards and risk associated with extreme weather and a changing climate; and To inform a process aimed at developing adaptation responses required to mitigate said risks.

Instructions, Part 2: PairWise Ranking

- Using the pairwise matrix provided identify the relative risks associated with the 5 flood hazards in both the short-term (<10 years) and long-term (>10 years).

Short-term (<10 years)

- Using the pairwise matrix provided consider the various hazards identified and consequently decide which of the two hazards in a pair poses a greater risk.
- The hazard which poses a greater risk will be placed in the box.
- Once the table is complete, each group will identify how many times each hazard was identified. This list will show which hazard presents the greatest threat for each group.

Long-Term (>10 years)

- Repeat the exercise stated above while taking into consideration which hazards pose long-term risks.

Working Session 2 | Beginning the Multi-Hazard Risk Analysis Process

Equipment Needed: Maps and dots for map exercise, 11x17 detailed event lists, Pens, Flip chart, Flip chart markers

Purpose: To consider the influence of multiple hazards and their impact on the Port Credit area; To investigate the ways in which multiple hazards affect the overall risk of flooding in the Port Credit area; To recognize the various ways in which multiple hazards affect stakeholders differently; and, To identify what types of information is needed to better understand climate/extreme weather related hazards, risks and response in Port Credit.

Instructions

Part 1: Mapping the Risks in Context

- To provide context for subsequent discussion participants are encouraged to consider how a variety of hazards may impact the Port Credit area by identifying their interests, areas of responsibility, homes and/or businesses within the Port Credit area.

Identified hazards:

- Snow/ice storms
- High winds
- Extreme high versus low lake levels
- Extreme heat – i.e. heat waves
- Rapid freeze-thaw cycles
- Taking the hazards stated above into consideration, identify areas most likely to be impacted in Port Credit on the map using the dots provided.

Part 2: Multi-Hazard Identification

Participants are asked to consider the additional hazards identified above and the manner in which they may combine with each other or the already established hazards associated with flooding to significantly impact the Port Credit area in responding to the following questions.

At the beginning, have a Café Host explain the activity and ask everyone to divide into groups. (Side note: we could have the guidelines for the activity on a PowerPoint Slide which will be visible to everyone while the activity is occurring).

The activity is split into 4 rounds during which there will be four sets of discussion occurring simultaneously. Each round will last for 20 minutes each (total activity time: 80 minutes).

Explain that each table will have a Table Host who will facilitate the conversation at the table. At the end of the round, the Table Host will stay at the table to summarize the ideas and information that were discussed to the next round while the other stakeholders 'travel' to other tables.

Explain the role of the Graphic Recorder which is essentially to record the ideas and information being discussed. This Graphic Recorder will be able to 'travel' to another table at the end of the round.

Once the groups have been identified, have someone act as the Table Host and Graphic Recorder at each table.

Have the Table Host to read out the question at his/her table and lead the discussion while the Graphic Recorder takes notes.

At the completion of the first round, have the Table Host stay at the table while the other stakeholders travel to other tables. At the start of the second round of discussion, have the Table Host summarize the ideas and information that were discussed during the previous round.

Identify a new Table Host and Graphic Recorder and repeat the exercise.

Once the four rounds are complete, we can open up the discussion to the group as a whole (time permitting).

Question 1 | Establishing the Facts

What type of hazard events have occurred in the Port Credit of elsewhere nearby and what specifically happened?

Question 2 | Reacting to the Facts

Hazard X is one of the 5 hazards we identified with the potential to impact Port Credit – are there other hazards that should be considered?

What combination of hazards should be considered?

Question 3 | Understanding the Impacts

What about these additional hazards or combination of hazards would make them a significant issue for stakeholders in Port Credit?

What are the thresholds at which identified hazards become major issues?

For instance, how hot for how long? How cold for how long? How much snow/ice is too much?

Question 4 | Enough Information to Make a Decision?

What additional **information**, **data** or **analysis** is needed to move toward the prioritization and management of hazards?

What are the instruments for managing such hazards?

- Policy
- Operational changes
- Hard-infrastructure adaptation?

APPENDIX D: P-CRAFT TEMPLATES FOR PRIORITY IMPACTS

Throughout the duration of this project, literature reviews were conducted multiple times, each with a different duration and objective based on where it occurred throughout the project methodology. These literature reviews aimed to elucidate vulnerability factors, impacts, thresholds, and overall rationales to vulnerabilities that may lead to impacts of flooding, shoreline damage, impacts to the electrical distribution system, and human health from extreme heat in Port Credit.

Literature reviews were conducted using a standardized series of Microsoft Excel ® templates, known as the Peel Climate Risk Analysis Framework Tool (P-CRAFT). These were used to extract information from individual studies and reports, and interpret commonalities in the information to determine and codify the most salient Vulnerability Factors, Intermediate Impacts, and their relationships. The outputs of this process were reflected throughout the report and in the Vulnerability Factors and Rationales tables in Appendix H, J, K and L. The completed P-CRAFT tables are being made available on a request basis, please submit a requested by contacting the Ontario Climate Consortium (http://climateconnections.ca/).

Table D-1: Sample of data gathering table, part of P-CRAFT tool used to collect information from literature reviews.

Climate Driver	Component	Reference	Information	CLIMATE THRESHOLDS				COMPONENT VULNERABILITY		IMPACT	IMPACT LEVEL / IMPACT ESTIMATE
				Seasonality	Intensity	Frequency	Duration	Vulnerability Factor	Vulnerabiltiy Factor Category		
Extreme Precipitation	Roadway Infrastructure	Smith, 2006	The susceptibility of roadways to flooding and infrastructure damage depends on the **age of the road,** usage (high volume versus low volume road), and materials (paved, unpaved).					age		roadway flooding and damage	
Extreme Precipitation	Roadway Infrastructure	Smith, 2006	The susceptibility of roadways to flooding and infrastructure damage depends on the age of the road, **usage (high volume versus low volume road)**, and materials (paved, unpaved).					useage	high volume, low volume	roadway flooding and damage	
Extreme Precipitation	Roadway Infrastructure	Smith, 2006	The susceptibility of roadways to flooding and infrastructure damage depends on the age of the road, usage (high volume versus low volume road), and **materials (paved, unpaved)**.					material	paved, unpaved	roadway flooding and damage	

Databases used included:

- Springer Link
- Wiley InterScience
- Oxford Journals
- Science Citation Index Expanded
- Google Scholar
- Elsevier
- Scholars Portal
- Adaptation Community of Practice
- Scopus
- Medline
- Biological Sciences
- BioOne

The literature search also included reviewing grey literature from relevant organizations, as follows:

- Council, staff and consultant reports from the Region of Peel and City of Mississauga pertaining to the assets and infrastructure in Port Credit
- Technical reports from the LOISS characterization
- Ongoing vulnerability assessments for the Region of Peel on Public Health, Natural Heritage and several individual infrastructure elements conducted using the PIEVC methodology
- Design criteria and guidelines from the Canadian Standards Association, the Ontario Building Code, and other provincial standards

APPENDIX E: CRITERIA FOR VULNERABILITY INDICATOR SELECTION

Categories of criteria are presented to help assess the suitability of potential indicators. After reviewing a number of vulnerability criteria frameworks (U.S. EPA 2000; MEA 2005; Birkmann 2006; Foushee 2010; European Environment Agency 2013; Kenney 2014), categories were classified as *Feasibility of Assessment, Importance of Assessment* and *Scientific Validity of Assessment*. The feasibility category refers to a potential indicator's ease of use, including its data availability and simplicity. The importance category refers to how widely applicable an indicator is within the agricultural production system based on what makes it vulnerable (VFs). The scientific validity category refers to a potential indicator's measurability, sensitivity to changes in VF across the crop production system and its current scientific understanding.

These categories together make up a check-list used in identifying the most important, valid and feasible indicators analyzed in further detail as part of the vulnerability and risk assessment. Note it is not a requirement that a potential indicator meet all evaluation questions listed in this table, but that in comparison to all potential indicators examined it is optimal.

PROPERTY DAMAGE	**VULNERABILITY FACTORS**	
	INDICATORS	
	DATA SOURCE	
Feasibility of Assessing the Indicator		
1. The indicator is relevant to the project scope, to vulnerability factors identified, and to policy recommendations emerging from the work allowing for policy and management adaptation to be effective at the natural heritage component or larger system level (and not the indicator level). In this manner, the indicator is relevant and can be used effectively in further works with the purpose of monitoring and reducing vulnerability of the natural heritage system in Peel Region.	A. Is the indicator relevant to the project scope (management of the agricultural system component in question)?	
	B. Is the indicator relevant to agricultural climate vulnerability?	
2. Indicator data are readily accessible, robust, and collected in a manner that is applicable and useful.	A. Are indicator data available for the study areas?	
	B. Were the indicator data collected using a method or study design such that they are useful and relevant?	
	C. Has indicator data been QAQC processed?	

	D. Are the indicator data readily accessible?	
3. The indicator is simple, such that non-technical decision-makers understand why it was selected.	A. Is the indicator simple, such that non-technical decision makers could understand its use and application?	
Importance of Assessing the Indicator		
4. The indicator is widely applicable, such that it is linked to multiple system components. In this manner, the indicator can best represent the larger agricultural system and its management in Peel Region.	A. System components represented by the indicator	
Scientific Validity of Assessing the Indicator		
5. The indicator is measurable and sensitive to changes in the vulnerability factor across multiple natural heritage components regardless of impact causality. In this manner, the indicator has likely been empirically studied and sensitivities or tolerances are understood; ignoring specific causality (e.g., climate change or urbanization) allows managers to theoretically monitor for 'all' eventualities that may lead to the natural heritage system becoming vulnerable and impacting important ecosystem service delivery.	A. Is there a known threshold (impact tolerance or sensitivity) associated with this indicator?	
6. To the current state of knowledge, the indicator is accurate, valid and most appropriate based on one or more of the following: published literature, expert opinion or Community of Practice. In this manner, the indicator can be considered robust and scientifically vetted at an acceptable level prior to implementation in Peel Region.	A. Has this indicator been used elsewhere?	
**Adapted from U.S. EPA (2000), MEA (2005), Birkmann (2006), Foushee (2010), European Environment Agency (2013), Environment Canada & NOAA (2014), Kenney (2014)*		

APPENDIX F: CLIMATE IMPACTS IDENTIFIED BY PORT CREDIT STAKEHOLDERS

COMMUNITY ASSET / SERVICE	**EXTREME EVENTS**					**CLIMATE CONDITIONS**			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
All Assets and Services	**5**	**7**	**8**	**12**	**9**	**7**	**6**	**4**	**5**
Changes in operational practices and resource (staff, financial, time) needs				x		x			
Damage to urban tree canopy	x	x	x	x	x	x			
Damage/Loss of Infrastructure			x	x	x		x		
Difficulty removing snow				x	x				x
Enhanced UHI effect		x		x					
Less certainty flood frequency and impacts				x		x			
Longevity of materials / infrastructure	x	x	x	x	x	x	x	x	x
Loss or lowering of service capacity	x	x	x	x	x	x	x	x	x
Lower predictability of climate	x	x	x	x	x	x	x	x	x
Need for anticipating the unexpected in operations and design	x	x	x	x	x	x	x	x	x
Potential need for additional staff if issue is deemed a priority		x	x	x	x				
Time needed to repair urban infrastructure			x	x	x		x		
Agriculture & Food Security	**2**	**2**	**0**	**2**	**0**	**2**	**0**	**0**	**1**
Crop / garden damage	x	x		x		x			
Impacts to local agriculture production	x	x		x		x			x
Culture & Tourism	**3**	**2**	**5**	**5**	**5**	**4**	**0**	**0**	**0**
Damage to harbour, which is an important cultural asset	x		x	x	x				
Disrupted recreational access (boating, canoes, kayak, rowing, swimming, fishing)	x		x	x	x	x			
Disruption to cultural and special events		x	x	x	x	x			
Loss of tourism/visitors by		x	x	x	x	x			

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
boat									
Truncated season for boating and lake-based recreation	x		x	x	x	x			
Economic Development	**2**	**2**	**3**	**2**	**2**	**1**	**0**	**1**	**0**
Business closures (economic losses)		x	x		x				
Electrical equipment failure	x	x	x		x				
Limited redevelopment potential for flooded properties				x					
Loss of tourism/visitors by boat	x		x	x		x		x	
EMS & Fire Services & Emergency Planning	**1**	**2**	**3**	**3**	**4**	**0**	**0**	**0**	**0**
Damage to emergency facilities			x	x	x				
EMS service over-capacity			x		x				
Occurrence of fires	x	x	x		x				
Potential hazmat issues with industry in Port Credit				x	x				
Widespread disease Issues		x		x					
Energy	**0**	**5**	**3**	**4**	**7**	**1**	**3**	**0**	**1**
Additional energy and fuel needs		x		x	x	x			x
Backup power failures to critical infrastructure (traffic, water Treatment, emergency centres)			x	x	x				
Brownout		x			x				
Damage to equipment		x	x	x	x		x		
Deterioration leading to safety issue					x		x		
Loss of service (blackout)		x	x	x	x				
Reduced capacity/reliability of electrical grid (transformers, conductors)		x			x		x		
Environmental & Ecosystem Management	**9**	**13**	**11**	**12**	**6**	**14**	**3**	**8**	**11**
Algal bloom		x		x					

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze -thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
Backwater effects up Credit and local watercourses			x					x	
Bird and butterfly migration shifts						x		x	
Changes and new invasive species	x	x		x		x			x
Damage to urban tree canopy			x		x	x			
Debris causing flooding			x						
Decrease lake ice cover		x				x			
Ecosystem zone shift						x			
Effects on wildlife habitat (aquatic and terrestrial)		x							
Elevated creek water levels				x					
Elevated groundwater levels				x					
Elevated sediment loads in water courses				x					
Erosion of natural infrastructure (i.e., restoration projects)			x	x	x		x		x
Fish die-off		x							
Fish spawning	x	x				x			x
Ice jams in rivers due to excess snow/ice					x			x	x
Impacts to biodiversity	x	x	x		x	x	x	x	x
Impacts to tree buds and development						x			
Lack of winter snow cover / snowpack for species and hydrology						x			x
Lake water temperatures	x	x						x	x
Leaves lasting longer lead to larger accumulation				x		x			
Loss of shade provided by trees			x						
Loss of tree root stability				x					
Lower water levels	x	x							
More suspended sediment and sediment accumulation			x	x				x	
Mudslides				x					

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze -thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
New insects (pests)						x		x	
Species behaviour changes (e.g., turtles, birds)	x					x			x
Stormwater system & restoration project damage		x	x		x		x		
Stress on wildlife health	x	x							
Timing of ecological processes (e.g., hibernation)						x			x
Timing of hydrologic processes (e.g., freshet)						x			x
Tree damage			x		x				
Trees branch, leaves, debris accumulation			x						
Water quality impacts	x	x	x	x				x	
Wetland quality	x	x		x					x
Finance, Legal & Administration	**2**	**3**	**4**	**3**	**4**	**2**	**2**	**2**	**3**
Calls to maintenance to investigate widespread localized ponding				x					
Effectiveness of bylaws and operational policies	x	x	x		x	x	x	x	x
Effectiveness of information-sharing and communications	x	x	x		x	x	x	x	x
Over-load of communication systems (311)		x	x	x	x				
Restricted or block access to sites			x	x	x				x
Housing & Built Form	**0**	**3**	**6**	**8**	**5**	**1**	**2**	**1**	**3**
Additional indoor heating requirements					x				x
Destabilized building foundations				x					
Elevated groundwater table leading to basement flooding				x					
Elevator functioning compromised		x	x		x		x		
Excess AC usage		x							
Lot-level ponding and drainage issues				x					

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
Mould and moisture issues post-flooding, including wet/moist basements				x					
Occurrence of fires		x	x			x			x
Poor sanitary drainage and connected downspouts leading to basement flooding				x					
Property damage			x	x	x		x		
Roof collapse			x	x	x				x
Widespread impacts on multi-unit dwellings			x	x	x				
Wind-tunnel effect in certain areas			x					x	
Parks, Recreation & Education	**1**	**2**	**4**	**7**	**5**	**3**	**1**	**1**	**5**
Additional indoor heating requirements					x				x
Budget impact due to maintenance	x	x	x		x	x	x		x
Debris accumulation and deposits in parks and on facilities			x	x	x				
Destabilized structures				x					
Facility closures			x		x				x
Lack of winter snow on gardens and turf grass						x			x
Localized park flooding and ponding				x					
Park design						x		x	x
Softening of park surfaces				x					
Special events disrupted		x	x	x	x				
Turf grass and sport field quality degradation				x					
Washout of fields				x					
Planning & Zoning	**0**	**1**	**2**	**3**	**0**	**0**	**0**	**1**	**0**
Changes in hazard limits			x	x					
Impacts affecting land usage decisions		x	x					x	
Limited redevelopment potential for properties in flood plains				x					
Uncertainty in				x					

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
identification of inundation areas and properties subject to flooding									
Police	**0**	**0**	**2**	**3**	**2**	**0**	**0**	**0**	**0**
Control of access to flooded underpasses and damaged infrastructure				x					
Need to restrict or block access to sites			x	x	x				
Public safety concerns			x	x	x				
Port and Coastal Management	**2**	**0**	**16**	**12**	**5**	**0**	**2**	**5**	**1**
Ability to use Lake for boating (inability to launch boats)	x		x	x					
Changes to lake fetch directions and coastal transport processes								x	
Damage to boats and docks			x	x					
Damage to breakwaters			x	x	x				
Dangerous boating conditions			x	x					
Disrupted sediment flows			x	x				x	
Easterly wind creating wave action			x					x	
Increased need for dredging leading to risk of water quality degradation	x			x					
Infrastructure damage			x	x	x		x		
Navigation, marina, and commercial boating operations disrupted			x	x					
Nearshore water quality degradation				x					
Need for increased dredging following storm events			x	x					
Rescue capacity for boating			x						
Sedimentation and debris accumulation in harbours and embayments			x	x					
Shoreline erosion,			x	x	x		x	x	x

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
including behind armour stones									
Storm surges in harbours/marinas			x		x				
Wave pilling algae on shore			x					x	
Wave surges and coastal erosion/flooding			x		x				
White caps & dangerous boating conditions			x						
Public Health	**2**	**11**	**9**	**14**	**9**	**3**	**1**	**2**	**5**
Air quality (dust, smog, odours, ozone), including resulting from stagnant air		x	x					x	
Disease outbreak issues				x					
Displacement of populations			x	x	x				
Enhanced surveillance of recreational water needed		x		x					
Excessive UV exposure		x							
Failure of ventilators			x		x				
Food safety (storage, spoilage)		x		x					
Greater injury risk		x	x	x	x				x
Health care facility damage			x	x	x				
Health hazards from wastewater/septic overflows				x					
Heart attacks		x			x				x
Heat-related illnesses		x							
Hospital and health facility over-capacity		x	x	x	x				
Ideal West Nile & vector-born disease conditions		x		x		x			
Local food production and supply	x			x		x			x
Mental health/trauma (during storms)			x	x	x				
Occupational health impacts		x	x	x	x				x
Residential mould and moisture build-up following floods				x					

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
Unknown human health hazards	x	x	x	x	x	x	x	x	x
Telecommunications	**0**	**3**	**3**	**3**	**3**	**0**	**1**	**0**	**0**
Damage to equipment		x	x	x	x		x		
Loss of service		x	x	x	x				
Over-load of communication system		x	x	x	x				
Transportation	**0**	**5**	**7**	**10**	**11**	**0**	**4**	**0**	**6**
Additional road and railway maintenance		x	x		x		x		x
Bank washouts and mudslides onto roadways				x					
Debris accumulation and blockage of roadways			x	x	x				
Difficulty clearing ice									x
Erosion beneath rail line - rail foundation				x					
Flooding of underpasses				x					
Ice jams leading to bridge damage				x					
Infrastructure damage		x	x		x		x		
Leaves and debris obstructing road drainage systems				x					
Loss of transit service			x	x	x				
Refreezing of flooded road and rail				x	x		x		
Road and transit closures			x		x				x
Salt and de-icing					x				x
Sidewalk and road surface degradation		x			x		x		x
Surcharging of culverts				x					
Train accident					x				
Train derailment			x	x	x				
Transit disruptions		x	x		x				x
Warping/damage to rail lines		x							
Waste	**0**	**1**	**3**	**3**	**1**	**0**	**0**	**1**	**0**
Disruption of waste management services			x	x	x				
Hazardous runoff				x					

COMMUNITY ASSET / SERVICE	EXTREME EVENTS					CLIMATE CONDITIONS			
	Drought	Extreme Heat	Extreme Wind	Extreme Rainfall and Flooding	Snow/Ice Storms	Seasonal Shifts in Temp and Precip.	Weathering (Freeze-thaw)	Changes in Wind Patterns	Changes in Snowpack & Snowcover
Litter and debris blowing/migration			x	x					
Odours		x	x					x	
Water & Wastewater	**1**	**4**	**6**	**12**	**5**	**0**	**3**	**1**	**1**
Algae in raw water				x					
Blockage of Plant Driveway / access (i.e., Lorne Park WTP)			x	x	x				x
Broken watermains			x	x			x		
Combined sewer overwhelmed, leading to combined sewer bypass				x					
Difficulty treating raw water	x	x	x					x	
Drinking water source contamination and quality degradation		x		x					
Flooding of disinfectant areas (within water treatment plants)				x					
Infrastructure damage		x	x		x				
Infrastructure leakage (pipes)				x					
Leaky clay pipes due to tree root issues				x					
Loss / disruption of service			x		x		x		
Overflow of sewage intakes				x					
Snowmelt/freeze-thaw blocking catchbasins				x	x				
Treatment plant power loss		x	x		x				
Water main cracking and breaks							x		
Water taste				x					
Water treatment capacity				x					

APPENDIX G: HISTORICAL FLOODING EVENTS IN PORT CREDIT

Date	Details	Type	Source
Sep 13, 1878	In Port Credit both bridges crossing the river, in fact all bridges in the vicinity are carried away	Synoptic-scale storm	[1]
Apr 6-7, 1912	Lake Shore Highway bridge at Port Credit rendered impassable by the flow of water over the approach at the east end of the bridge	Rapid freshet	[2]
Jan 18, 1929	Credit reported high at Port Credit, no damage mentioned.	Rapid freshet	[2]
Feb 20, 1930	Flood said most serious in years.	Rapid freshet	[2]
Mar 4, 1934	Serious flood threatens damage at Port Credit.	Rapid freshet	[2]
Mar 20, 1934	Threat of flood seen in prolonged continuance of 2 foot ice on Credit River at Port Credit. No flood damage, but high risk.	Ice jam	[2]
Mar 11, 1936	Minor flooding at Port Credit	Spring freshet	[2]
Apr 4, 1950	Minor damage reported from flood at Port Credit	Rapid freshet	[2]
Oct 19, 1954	Hurricane Hazel flood. Major bridge at Port Credit damaged so seriously it was impassable. Houses flooded, evacuations required.	Synoptic-scale storm	[2]
Feb 10, 1964	Ice jam causes Credit River to raise 5 feet. Ice jam at CNR caused flooding of over 5 feet from CNR to north of QEW.	Ice jam	[2]
Jan 28, 1974	Ice jams caused extensive flooding at Mississauga Golf and Country Club.	Ice jam	[2]
May 16-17, 1974	Flooding at Stavebank Road, Mississauga	Synoptic-scale storm	[3]
Winter, 1980-1985	Annual damages from ice jams at Mississauga Golf and Country Club.	Ice jam	[4]
Jun 29, 1982	Extensive property flooding in Port Credit reported	Convective	[6]
Winter, 1985	Ice jam on Credit near Indian Road	Ice jam	[4]
Jan, 1986	Credit Valley Golf and Country Club had ice scour and flooding damage. Overbank spillage at Erindale Park.	Ice jam	[5]
Mar, 1986	Flooding at Credit Valley Golf and Country Club and Mississauga Golf and Country Club during ice breakup. Minor flooding upstream of Mississauga Road due to ice jam.	Ice jam	[5]
Winter, 1987	Mississauga Golf and Country Club ice jam, localized flooding, no damage reported.	Ice jam	[5]
Feb, 1988	Minor flooding at Credit Valley Golf Club and Mississauga Golf and Country Club due to ice jams. No damage reported.	Ice jam	[5]
Jul 26, 1993	Convective thunderstorm (detailed impact information not available)	Convective	[6]

Date	Details	Type	Source
Aug 5, 1995	Convective (weak, multi-day accumulations) (detailed impact information not available)	Convective	[6]
Sep13 & 14, 1996	Synoptic rainstorm (possible ground saturation) (detailed impact information not available)	Synoptic-scale event	[6]
May 12, 2000	Storm event led to localized flooding in Port Credit area	Convective	[6]
Mar 17, 2003	Localized flooding in certain properties in Mississauga	Freshet	[6]
Apr 1, 2008	Depths over bankfull at Burnhamthorpe Road and Erindale Park (overtopped bank on west side of ice control structure)	Rapid freshet	[7]
Aug 4 & 9,2009	Significant localized flooding in the Cooksville Creek watershed	Convective	[7,8]
Sep 28, 2010	Road flooding in Lorne Park, off of Indian Road or Spring Hill Road. Not associated with a watercourse.	Convective	[10]
Oct, 2011	Intense rainfall and storm drains clogged with leaves resulted in localized flooding in several low-lying areas	Synoptic-scale event	[10]
Oct, 2012	3 sections of Mississauga Road between Dundas St and Lakeshore closed due to flooding due to remnants of Hurricane Sandy	Synoptic-scale event	[11]
Apr 15, 2013	Resident reported backyard flooding near Mary Fix Creek (279 Donnelly Dr, Mississauga)	Convective	[10]
Jul 8-9, 2013	On July 8th rainfall of over 120 mm fell in less than 6 hours with addition rainfall on the days preceding and after, resulting in extensive riverine and urban flash-flooding	Meso-scale convective event	[12]

[1] Toronto Mail article, summarized in CVC's Flood Related Incidents Report

[2] CVC's Flood Related Incidents Report

[3] W.4.2.02 Flood Reports Credit

[4] Preliminary Engineering / Feasibility Report - Ice Damage Reduction - Credit River in the Vicinity of Mississauga Golf and Country Club, 1985 W.1.7.02.03

[5] W.1.7 Ice Surveys

[6] City of Mississauga flood complain records

[7] W.4.2.02 Flood Reports Credit

[8] http://www.mississauga.ca/file/COM/Cooksville_Creek_Flooding_v03_Draft.pdf

[9] http://www.mississauga.ca/file/COM/corporate_report_aug27.pdf

[10] http://www.mississauga.ca/file/COM/LisgarCommunityMeetingPresentation.pdf

[11] http://www.mississauga.com/news-story/3129475-flooding-creates-traffic-chaos

[12] AMEC (2014)

APPENDIX H: SUMMARY OF VULNERABILITY FACTORS AND RATIONALES FOR FLOODING IN PORT CREDIT

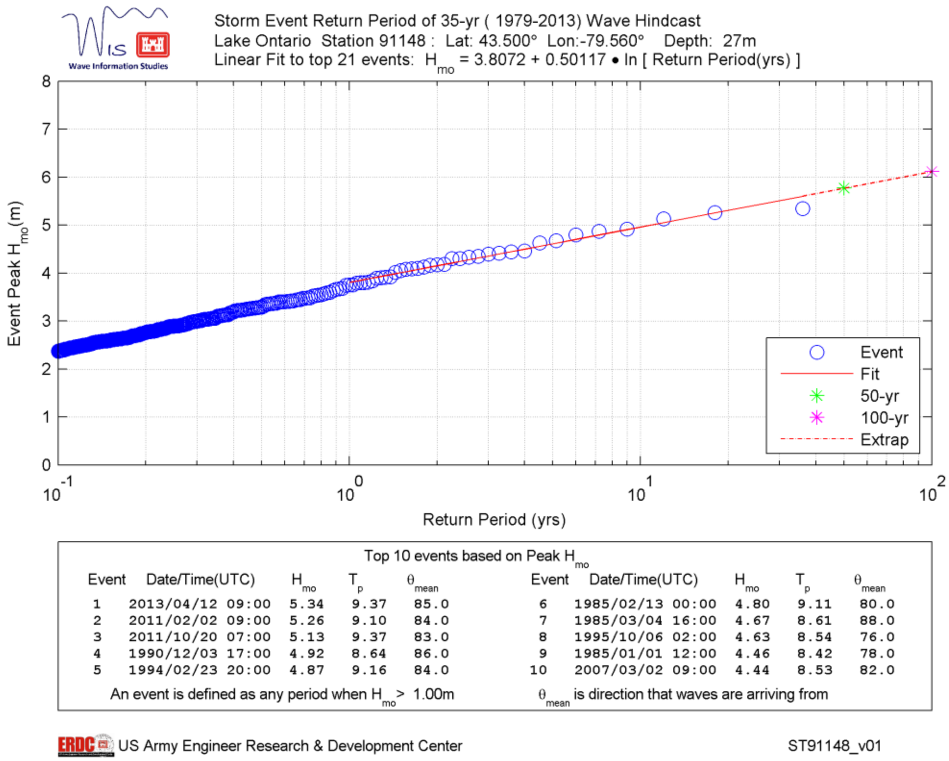
Vulnerability Factor	RATIONALE
Structure type and height	**What is it?** The type of structure (commercial/residential/industrial) will make it more of less vulnerable to flooding depending on the building characteristics including building material, stories, design etc. **Why does it matter?** Low-lying structures have been shown to experience more severe flooding damage associated with exposure to extreme precipitation than buildings with multiple stories. Generally, industrial buildings are more resilient due to their construction materials (concrete, steal, etc.) **How does it work?** The structural integrity of low-lying structures is more likely to become compromised, in part due to the building material (i.e. wood) and its inability to handle the velocity and depth of the floodwater. Ultimately, structures that are 1 or 2 stories in height (i.e. bungalows) are more vulnerable to flooding damage resulting extreme precipitation than multi-story buildings (i.e. apartments).
Age of asset	**What is it?** When the building/drainage infrastructure constructed. **Why does it matter?** Properties that are built in certain time periods (i.e. before 1960) are more likely to experience damage that is caused by flooding resulting from extreme precipitation, as a result, neighbourhoods where properties have been built before 1960 and are currently located in floodplains will collectively require a bigger response. **How does it work?** The vulnerability of older structures increases for two reasons: 1) ageing and deterioration that occurs overtime; and, 2) they may now be located in floodplains which did not exist at the time of construction.
Ice Jams	**What is it:** Blockage of the river due to ice accumulation **Why does it matter?** Blocked river can exacerbate/cause backwater effects in rivers, leading to enhanced upstream flood risk. **How does it work?** Ice accumulates at the confluence of a river and Lake Ontario under cold conditions. Wave action from the lake can cause water to further accumulate over the winter, resulting in a large mass of ice blocking the outflow of rivers.
Connection to minor system	**What is it?** The Minor storm drainage system is made of a collection of gutters, inlets, pipes etc. **Why does it matter?** Stormwater inlets have limited capacity to collect flow, especially from short very intense storm events therefore during extreme events the capacity of the pipes can be exceeded and cause backups or flooding if the water cannot properly drain away from the buildings. **How does it work?** The purpose of this system is to provide for the convenient disposal of storm runoff from streets, walkways, yards etc. through the use of downspouts that drain off and away from buildings into the minor system.
Combined sewer system	**What is it?** A combination of the sanitary sewer and the storm sewer. **Why does it matter?** Combined sewers are considered more vulnerable, as there is possibility for mixing of the two sewers during extreme rain

	events if capacity is exceeded. **How does it work?** If there is a lot of stormwater, the two sewers can get mixed, or backflow into one another as well as cause backups into basements, also means that sewer (sanitary) could backup and be discharged directly into the streams untreated.
Topography	**What is it?** Varying elevations within a location will impact how and where precipitation drains or pools. **Why does it matter?** Low topographic depressions may be more susceptible to slower draining, depending on the soil characteristics, which could lead to flooding and inundation. **How does it work?** Topographic depressions are low areas where surface drainage away from the area does not occur, therefore, water pooling and flooding can occur.
On Site Flood Controls	**What is it?** Flood controls and technologies such as Low Impact Development (LID) technologies, such as rain barrels, rain gardens, permeable pavement, weeping tiles, and backflow prevention measures. **Why does it matter?** Buildings with flood prevention measures are less vulnerable to flooding. **How does it work?** Flood control technologies can retain or direct water during a precipitation event, decreasing the amount of water that must be drained away from the building or attenuated.
Ownership status	**What is it?** Whether a building is owned, rented, subletted etc. **Why does it matter?** An individual's response to a flooding event resulting from extreme precipitation will depend on his/her ownership status. **How does it work?** Certain individuals (i.e. renters) will typically have fewer resources and fewer contacts which would help them prepare for and respond to these types events. Ultimately, the ownership status (i.e. renter) will impact an individual's preparation for and response to a flooding event resulting from extreme precipitation.
Soil infiltration properties	**What is it?** The various characteristics that make up the soil, including Its composition, profile, texture and structure that influence how soil drains. **Why does it matter?** Rate of infiltration of water into the soil is dependent on the soil composition and permeability. Soils with poor drainage may be susceptible to water logging, whereas soils that drain quickly may not be able to retain moisture well and may be more vulnerable during drought conditions. **How does it work?** In coarse soils, the rain or irrigation water enters and moves more easily into larger pores; it takes less time for the water to infiltrate into the soil. In other words, infiltration rate is higher for coarse textured soils than for fine textured soils.
Surface permeability	**What is it?** Permeable surfaces allow water to infiltrate into the soil; these surfaces are landscapes such as green spaces, permeable pavers, planting beds, mulches etc. Impermeable surfaces are those where water cannot percolate through, such as asphalt, concrete, brick etc. Urban areas are often highly impermeable. **Why does it matter?** The more impermeable surface area, the more likely flooding is to occur if water cannot infiltrate or be drained away fast enough. Additionally, the sudden influx of runoff into rivers/lakes can cause bank and shoreline flooding and erosion. **How does it work?** Permeable surfaces allow water to percolate into the

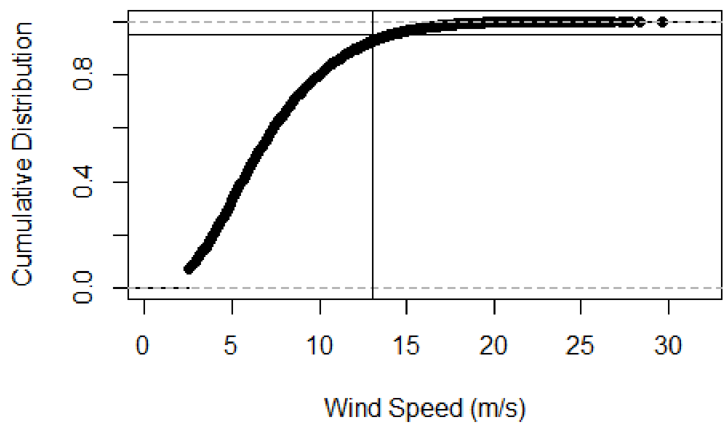
	soil. Impermeable/impervious surfaces are solid surfaces that don't allow water to penetrate, forcing it to run off.
Hazard limit	**What is it?** Mapped floodplains for both lake/shoreline and watercourses, it is a buffer distance away from these areas. **Why does it matter?** If a structure is in the hazard limit, it is much more vulnerable to overland flooding conditions from rivers and lake than those outside the limit. Additionally, older buildings may be located in areas that were not previously defined in the hazard limit, therefore those assets considered vulnerable. **How does it work?** There are specific methods prescribed by the MNR for how these hazards are delineated.
Maintenance and ownership	**What is it?** Whether the assets and infrastructure are regularly maintained and kept in good working condition and if the asset is owned or rented. **Why does it matter?** A system that has assets and infrastructure that is regularly maintained is considered less vulnerable, as damage or other problems can be recognized and fixed in order to maintain proper and efficient functioning. **How does it work?** Things that are maintained more regularly are less vulnerable because potential structural or maintenance issues will be identified and addressed, For example, if roadway culverts and storm drains are cleared, than there is less risk of them being blocked. For houses, if the property is well-maintained, drainage issues are more likely to be identified and addressed. Additionally, owners are more likely to address these issues than renters.
Antecedent watercourse/lake level	**What is it?** Current lake, river, stream etc. water level. **Why does it matter?** The vulnerability of an area may be increased if watercourses/lake levels are high, as additional precipitation can lead to flooding. **How does it work?** If water levels are considered lower than average, the impact of a rainfall will be less of an issue, as the chance of flooding or reaching the hazard limit is reduced. The inverse of that being if water levels are high before a rain event, it is more likely that an additional volume of water will lead to overland flooding if water cannot be drained fast enough to manage the excess precipitation.
Drainage infrastructure capacity	**What is it?** The municipal, lot-level and roadway drainage system infrastructures capacity, i.e. threshold, to efficiently drain water. **Why does it matter?** If the capacity of the drainage infrastructure is exceed, flooding can occur. If the infrastructure is older, it may not be designed to handle the current and expected capacity of rainfall and stormwater, as extreme precipitation events are expected to increase the intensity and frequency of extreme precipitation events. Therefore, systems with more capacity will be less likely to be surcharged. **How does it work?** Drainage infrastructure capacity is typically designed at a capacity for stormwater runoff from a major storm event, historically between 10-year 100-year return period storm. Drainage capacity can also be reduced through blockages in to inlets and outlets from debris, etc.

APPENDIX I: WIND AND WAVE HEIGHT DISTRIBUTIONS

Windspeed and Hmo wave height were extracted for station number 91148 for 1979 through 2012 from USACE hindcast modeling available at: http://wis.usace.army.mil/hindcasts.shtml. Threshold winds were calculated by taking the average the 95th percentile (1/20 year return period) wave height for each year, and the windspeeds modelled at the same time-step. These wave heights differ from Shoreplan Engineering (2005) because of the locations with significant wave height was calculated, however the purpose was to identify threshold windspeeds.

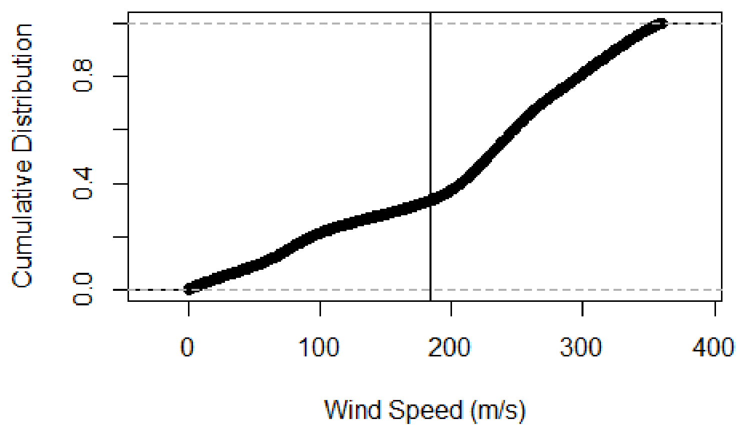


Wind Speed Distribution



Associated windspeed = 46.8 km/hr

Wind Direction Distribution



Associated wind direction = 183 degrees (due North)

APPENDIX J: SUMMARY OF VULNERABILITY FACTORS AND RATIONALES FOR SHORELINE DAMAGE

Vulnerability Factor	Rationale
Grading of Property	**What is it?** A management technique that involves manually shaping, designing and grading (altering slope and angle) to protect against shoreline erosion and facilitate drainage. **Why does it matter?** Most impacts of flooding occur when the property is not properly graded, therefore, a shoreline is considered more vulnerable if it is not properly graded in a way that facilitates and promotes drainage. **How does it work?** Most shoreline properties are graded to drain into the lake. The objective of bank grading is to reduce the steepness of the bank slope and decrease erosion caused by waves striking the bank toe.
Maintenance	**What is it?** Managed or unmanaged, manmade or natural. **Why does it matter?** Manmade and managed shorelines will be able to plan for and adapt to climate events (by monitoring and regulating shoreline materials, adding sand, building protection barriers etc.), therefor, managed shorelines are less vulnerable than natural and unmanaged shorelines in an urban setting where the entire shoreline is modified. **How does it work?** The type of shoreline, including whether it is manmade, natural, maintained or not, all play a role in how susceptible the shore is to erosion based on whether it is maintained.
Shoreline Materials	**What is it?** Basic shoreline materials include sand, rock, gravel, silt, clay, and organic material. **Why does it matter?** Increasing wave action and extreme precipitation events and the potential for increased erosion. **How does it work?** Different shoreline materials have varying abilities to resist erosion. Given that rocks and gravel are heaviest, and require large amounts of energy to move, they are the least susceptible to erosion. Sand, silt, and organic materials are the most erodible, while clay materials are not very erodible due to their cohesive properties.
Presence of Vegetation	**What is it?** Whether there is vegetation present on the shoreline or it is bare. **Why does it matter?** Natural areas with shoreline vegetation are less vulnerable to erosion and shoreline damage than those without shoreline vegetation. **How does it work?** Without the presence of a healthy vegetated buffer, shorelines have reduced resistance against erosion, potentially resulting in a loss of habitat, soil stability and land, as vegetation with helps secure the shoreline materials.
Lake Level	**What is it?** Shoreline waterbodies are divided into smaller segments or “reaches” which are determined by shoreline type (marine, river/stream, or lake system) and by similar physical characteristics (jurisdictional boundaries, land use, shape of river channel, geology, etc.). **Why does it matter?** Depth limited reaches are less vulnerable (due to less wave height capacity) than non-depth limited reaches. **How does it work?** The depth of water physically limits the wave height

	and therefore influences how vulnerable a shoreline is to erosion and wave impacts.
Structural Protection	**What is it?** Built infrastructure such as jetties, piers, waterbreaks, groynes etc. that reduce wave action erosion and sediment transport. **Why does it matter?** Shoreline structures will be at greater risk of exposure to larger waves if they are in deeper water; the shorelines in general are more vulnerable to erosion and wave impacts if there is no structural protection infrastructure. Increased frequency in wave events will result in a greater need for maintenance of constructed shoreline. **How does it work?** As waves hit the shore, the wave action can erode the area and carry sediment.
Coastal Geomorphology	**What is it?** Largely based on the sediment budget of an individual shoreline reach, refers to the balance between sediment added to and removed from the shoreline. **Why does it matter?** A shoreline is considered more vulnerable is the sediment removal is less than the deposition. **How does it work?** When more material is added than is removed, there is a surplus of sediment and vice versa. Shoreline erosion is a physical expression of a deficit in the sediment budget where nearshore processes (wind and wave action) remove more material from the shore than is added.
Structure and Asset Elevation	**What is it?** Height of the structure or asset. **Why does it matter? Higher structures/assets can reduce shoreline damage, as they offer greater protection.** **How does it work?** Higher structures/assets offer greater shoreline protection by helping reduce wave action/erosive processes that causes shoreline erosion.
Infrastructure Age and Condition	**What is it?** When the shoreline infrastructure was constructed. **Why does it matter?** Older infrastructure with lower design standards is more vulnerable to deterioration and damage. **How does it work?** The vulnerability of older structures increases from ageing and deterioration that occurs overtime and exposure to the elements.
Lake Ontario Water Level Management	**What is it?** Lake Ontario's water levels are monitored to help manage natural factors including precipitation and evaporation as well as human factors such as dredging, water withdrawals and regulating structures. **Why does it matter?** Water level management assists in reducing flooding and reducing erosion on the shoreline (among other benefits) **How does it work?** Controlling water levels can help reduce vulnerability during periods of high water level and increase water inputs during low periods.
Offshore Depth	**What is it?** How deep is the lake offshore. **Why does it matter?** Deeper lakes increase the vulnerability of shoreline damage as they have the ability to produce larger waves/greater damaging wave action. **How does it work?** The deeper the lake the greater the wave potential.

APPENDIX K: SUMMARY OF VULNERABILITY FACTORS ASSOCIATED WITH THE ELECTRICAL DISTRIBUTION SYSTEM IN PORT CREDIT

Vulnerability Factor	Rationale
Pole Materials	**What is it?** What material are the hydro poles made of? What are the conditions of those materials? **Why does it matter?** Although all poles are designed to withstand certain climate design loads, whether metal, steel or wood, different materials vary in are more susceptible to weathering or damage over time, in particular wood due to decay and potential for rotting. **How does it work?** Steel poles are seen as less vulnerable given their high strength, relatively light weight, long life, reduced maintenance costs. Concrete poles are considered slightly more vulnerable because they can be degraded by weathering processes, and their weight means that foundations can be susceptible to weakening more easily. Wood poles, although pre-treated, can be more vulnerable to processes that degrade the material over time including to woodpeckers, pole rot, or fires).
Pole Height	**What is it?** The total height of the support pole. **Why does it matter?** Although all poles, regardless of height, are designed to withstand specified climate design loads, taller poles have been shown to be weaker and more exposed to potential climate impacts. **How does it work?** Taller poles are inherently more exposed to potential tree impact, and stronger windspeeds at higher altitudes. This is particularly true for wood poles and is compounded by modeling and empirical evidence showing that taller poles, even those constructed to design standards, are more susceptible to damage from wind and ice/snow loads.
Equipment Age (Conductors, Transformers, Poles, Switches)	**What is it?** The year when equipment was installed or most recently refurbished **Why does it matter?** Older equipment is more susceptible to damage from a climatological stress. **How does it work?** Age matters because the older the equipment, the more exposure it will have had to forces that degrade materials and its intended design. Additionally, design standards have become more rigorous over time, with more recent standards requiring higher climatological load-bearing capacities.
Placement of Line	**What is it?** Is the equipment (conductors, transformers, switches) above ground or buried below ground. **Why does it matter**? Overhead placement as opposed to buried or underground places the system at increased vulnerability of failure or damage to exposure to multiple climate conditions, and trees. Weather events may increase the likelihood of damage if lines are exposed. **How does it work?** When lines are above ground, they are more exposed to the elements and weather events and can become disrupted or damaged. That being said, underground equipment may be vulnerable to different climate-related impacts, such as flooding.
Amount of upstream	**What is it?** Number of different potential nodes where power can be supplied to any given line segment.

connections in the network	**Why does it matter?** The severity of a given outage is partly influenced by the number of users that are affected. Having alternate routes of supply on the network means that in the event of equipment damage, managers can route power to downstream users through alternate pathways on the network. **How does it work?** Since electrical distribution systems are networks, lines further upstream in the network tend to conduct more voltage and loss of function to equipment that is further upstream means that more downstream nodes and users will be affected. If there are multiple possible ways of routing power to users, the loss of a single particular line or node means that managers can re-route power, minimizing the spatial extent of the outage.
Presence of Trees (and distance from line)	**What is it?** Whether trees are in close proximity to power lines. **Why does it matter?** Trees located close to overhead equipment increase the risk of service interruption due to falling tree limbs, and in rare cases collapse of the tree If trees are in close proximity to power lines, the line is more vulnerable to damage. Additionally, the more trees present within close proximity the greater the vulnerability. **How does it work?** Extreme wind, ice and snow build-up, along with other climate-related stressors can act to break tree limbs. Trees located close to power lines can cause damage, if freezing rain accumulates and causes the branches or limbs to break or sag on top of power lines. Trees located near power lines are a risk to power service in the events the tree breaks or if limbs fall.
Age of Trees	**What is it?** Age of the tree. **Why does it matter?** Once a tree begins to experience problems such as weathering damage or rot, which can happen over time, it is again considered more vulnerable. However, older, healthy trees are less vulnerable to wind damage due to their size and strength. **How does it work?** A trees' age (and related size) can influence how susceptible it is to breaking/collapsing during an extreme wind event. Older trees that are larger in diametre are sturdier and less vulnerable to wind damage. However, in urban environments, it is widely recognized that older trees are more vulnerable to limb, root and trunk issues.
Tree species	**What is it?** What type of tree, i.e. coniferous, deciduous, and what variety. **Why does it matter?** Trees with an excurrent branching habit (conical form) such as conifers, and species with less branch surface area showed the least damage due to ice accumulation. **How does it work?** Extreme weather events such as freezing rain can accumulate and cause branches or limbs to break. Additionally, extreme wind can also break branches.
Tree maintenance and monitoring	**What is it?** Whether trees are maintained (cut back) and their health monitored around overhead equipment. **Why does it matter?** Trees that are maintained, healthy, and cut back as to not disturb power lines are considered less of a vulnerability. **How does it work?** When trees are maintained, branches that may disrupt power lines/electrical infrastructure can be monitored and cut back to reduce the chance of damage to the power lines. Additionally, potential root and other tree health issues can be identified early-on and addressed.

APPENDIX L: VULNERABILITY FACTORS AND RATIONALES FOR HUMAN HEALTH IMPACTS IN RESPONSE TO EXTREME HEAT

Vulnerability Factor	Rationale
Population Age	**What is it?** The portion of a population with age brackets that place them at higher risk of heat-related illness – typically those under the age of 4 or over the age of 65. **Why does it matter?** Areas with demographic characteristics in age groups of under 4 years old and over 65 years old are at a heightened likelihood of requiring assistance through a coordinated public health response during or extreme heat events This is due to the fact that populations of seniors and young children can be expected to be in greatest need of assistance during heat emergencies. **How does it work?** Seniors and young children have been shown to have be more likely to experience health effects associated with exposure to extreme heat due to a variety of physiological (i.e., less heat regulation) and contextual factors (i.e. lack of mobility, dependence on others, etc.).
Health Condition	**What is it?** The portion of the population that has a pre-existing health condition. **Why does it matter?** Individuals who have pre-existing illnesses (i.e. diseases of the respiratory system, cardiac disease, etc.) are more likely to become ill under extreme heat conditions. This will likely require a greater public health response at the community scale because individuals with pre-existing illnesses are more likely to be faced with co-morbidities. **How does it work?** Higher temperatures and certain medications can affect thermoregulation in the body which can aggravate heat illness. Certain health conditions may also be exacerbated by extreme events.
Communication Barriers	**What is it?** Obstacles that prevent the effective exchange of information, such as language barriers. **Why does it matter?** Communication barriers such as language barriers may lower the effectiveness of preventative messaging around extreme heat, and the uptake of important information during emergencies. Therefor communities with a large population of individuals who do not understand the language are considered more vulnerable. **How does it work?** if there is a lack of understanding and communication about the event itself, what to do in the situation, news alerts etc. people may not get the necessary information to prevent illness or respond during emergencies
Social Isolation	**What is it?** A characteristic of those that live alone, do not have regular visitors, do not leave the home frequently, etc. **Why does it matter?** Individuals who are socially-isolated are more vulnerable during extreme heat events, as they may not get information and access to emergency resources as easily as those with a larger social network. Ultimately a population with a population of socially-isolated individuals is more vulnerable to morbidity during extreme heat events. **How does it work?** Evidence suggests that the extent of an individual's community integration and social network involvement is related to an individual's health status. Interventions and support often have difficulty

	reaching socially-isolated individuals due to their limited community integration and social networks.
Strenuous physical exercise	**What is it?** Activities that involve vigorous physical exertion such as playing sports, running outside or doing outdoor work **Why does it matter?** Individuals who take part in strenuous physical exercise have been shown to be more vulnerable to the effects associated with exposure to extreme heat. Ultimately, a population of individuals who take part in strenuous physical activity that exposes them to extreme heat conditions is more vulnerable to heat-related illness **How does it work?** A variety of physiological factors (e.g. salt depletion through sweating) can lead to symptoms such as weakness, dizziness, and fainting as a result of exertion under extreme heat conditions.
Urban Heat Island (UHI)	**What is it?** A city or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities and the absorption of heat by a built-up landscape with low albedo. **Why does it matter?** The physical environment of a community has been shown to influence its vulnerability to morbidity in the context of extreme heat due a variety of physical characteristics (i.e. tall buildings, concrete and blacktop roads, etc.) and contextual factors (i.e. use of air conditioning) which heightens individuals exposure to hotter temperatures. During a heat event, a metropolitan community that has these characteristics will require more resources for a coordinated and effective response. **How does it work?** Contributors of increased heat in urban areas include changes in the thermal properties of surface materials and lack of evapotranspiration (through lack of vegetation). Decreased vegetation results in a loss of shade and cooling effect of trees. Materials commonly used in urban areas such as concrete and asphalt, have different thermal properties including heat capacity, thermal conductivity, and surface radiative properties than the surrounding rural areas.
Air pollution levels	**What is it?** Air pollution levels including ground level ozone and particular matter concentrations. **Why does it matter?** Air pollution exposure, acute and chronic, is linked to a number of health impacts**.** At the community scale, areas that have a higher proportion of individuals exposed to air pollution will require a bigger response and more resources. Ultimately, a system with an increased exposure to air pollution is more vulnerable to morbidity and mortality as a result of rising temperatures. **How does it work?** Individuals with pre-existing illnesses have been shown to have more severe health effects associated with exposure to pollution (i.e. ground-level ozone, particulate matter, etc.) due to a variety of activity patterns that are altered as temperatures rise (i.e. individuals spend more time outside, smog and stagnant air is associated with high temperatures).
Building thermal properties	**What is it?** The characteristics of construction materials used in a particular building, the presence or absence of air conditioning, building orientation, amount of tree coverage, etc. **Why does it matter?** Ultimately, a neighbourhood's vulnerability to high related illness is increased by the presence of specific housing types that are constructed with materials that absorb heat, as well as a lack of tree coverage/shade. **How does it work?** The housing type (i.e. apartment building) can increase

	the vulnerability of individuals during extreme heat events. For example, living on the top floor of an apartment building may increase the vulnerability of individuals to heat because the top floor can be much hotter than the ground level, especially in the absence of air conditioning. Construction materials with low albedo can increase the building temperature.
Emergency preparedness	**What is it?** The degree to which emergency preparedness plans are in place in a community in the event of an extreme event (i.e. early warning systems, heat warnings, cooling stations, emergency evacuation etc.). **Why does it matter?** The timing and/or frequency of heat waves may threaten communities that have limited experience with such events and/or are not prepared for these events. Ultimately, a community that is not acclimatized to heat waves and lacks the response systems is more vulnerable to mortality. Communities are typically not acclimatized to heat at the beginning of the season; this makes them more vulnerable to mortality in the event that a heat wave does occur. However, the same population can be less vulnerable to heat waves as the season progresses, and this in turn reduces mortality rates. **How does it work?** If efficient and effective emergency preparedness mechanisms and plans are in place, a community is better able to prepare for emergencies through early warning systems, warnings and tools on what to do during the event, and knowing where to go and what to do during the event, and therefor recover quickly. Clear communication of emergency plans is essential.