VULNERABILITY ASSESSMENT

Natural Systems in Peel Region

Prepared for:

Region of Peel
working with you

Prepared by:

Toronto and Region Conservation for The Living City

Ontario Climate Consortium

Action on Climate Change in the Region of Peel

Addressing climate change is nothing new in 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 and considerably longer from the perspective of managing natural areas and hazards, a recognized component of adaptation. 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 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.

In 2017, this vulnerability assessment was completed, which studies the impacts of climate change on natural systems in the Region. The following summary of that assessment was prepared by Hutchinson Environmental Ltd. and Shared Value Solutions Ltd., in collaboration with the Toronto and Region Conservation Authority, the 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:

Tu, C., Milner, G., Lawrie, D., Shrestha, N., Hazen, S. 2017. **Natural Systems Vulnerability to Climate Change in Peel Region.** Technical Report. 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:

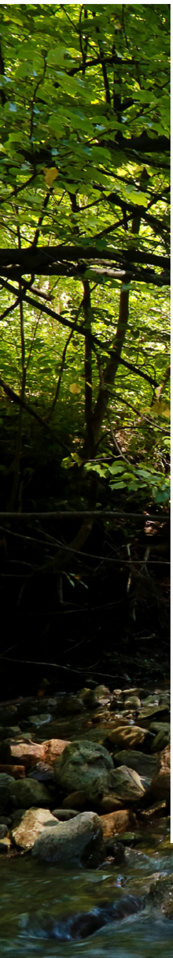
- ✓ Enhance the urban tree canopy and supporting efforts made through the Peel Climate Change Partnership on Heat Resiliency, especially in areas with little or no ability to effectively regulate summer land and water temperatures, including areas of acute thermal stress to fish.
- ✓ Start or continue adaptation and natural heritage planning, incorporating the implementation of new policies contained within the four amended plans[1] that take into account climate change, while leveraging this and other existing community assessments and system datasets.
- ✓ Increase the enhancement and protection of existing wetlands and tablelands and creating new wetland features where possible to build resilience and deliver numerous ecosystem services, including increased flood regulation.
- ✓ Protect, enhance and restore regional species diversity by increasing connectivity of natural areas through existing restoration programs, particularly in high priority areas.
- ✓ Incorporate climate change into watershed planning more directly, including identifying and protecting important local connections between shallow groundwater and surface features.
- ✓ Promote effective collaboration and information sharing between Conservation Authorities, and with adjacent and upstream municipalities through active participation in the renewed Peel Community Climate Change Partnership.

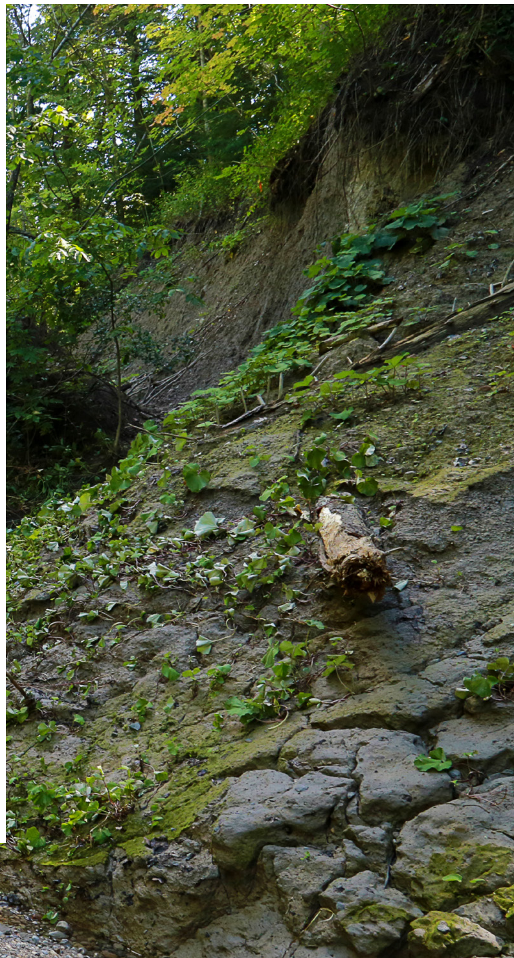
FOCUS OF THE NATURAL SYSTEMS VULNERABILITY ASSESSMENT

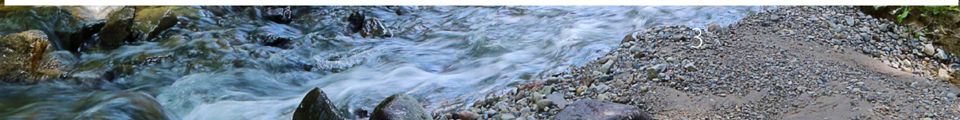
Peel's vulnerability assessment of the impacts of climate change on natural systems in the Region focuses on three types of systems:

- Groundwater systems: recharge areas, aquifers and discharge areas
- Aquatic systems: rivers, streams, lakes and wetlands
- Terrestrial systems: natural and urban forests, grasslands, wetlands, bluffs

[1] See the updated policies of the Growth Plan for the Greater Golden Horseshoe, the Greenbelt Plan, the Oak Ridges Moraine Conservation Plan, and the Niagara Escarpment Plan at www.mah.gov.on.ca/Page10882.aspx







There is a growing recognition that ecosystem services are not really free, and that we need to make a concerted effort to protect and enhance them.

How Does Climate Change Affect Natural Systems?

Impacts on Ecosystem Services

Natural systems provide a wide range of goods and services that benefit humans, such as food, timber, drinkable water, pollination, flood regulation, and clean air. These ecosystem services support us in many ways, by enriching our health and well-being, offering recreational, aesthetic and spiritual opportunities, and strengthening our economy. Ecosystem services also help us address climate change (for example through forest and wetland carbon sinks, and the provision of renewable energy sources).

There is a growing recognition that the benefits provided by ecosystem services are not really free, and that we need to make a concerted effort to protect and enhance them, especially in the face of climate change. This means protecting the natural systems that support and produce ecosystem services, including forests, wetlands, rivers, lakes and urban green spaces. Climate change is considered a major threat to biodiversity, which is the foundation of healthy and resilient natural systems. The increased frequency and severity of extreme weather projected under climate change will adversely affect biodiversity, and thus compromise ecosystem services we rely on.

The future of natural systems under climate change ultimately affects our future. We must act now to increase the protection of natural systems so that ecosystem services are continually delivered, sustainable over the long-term and resilient to climate change.

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."

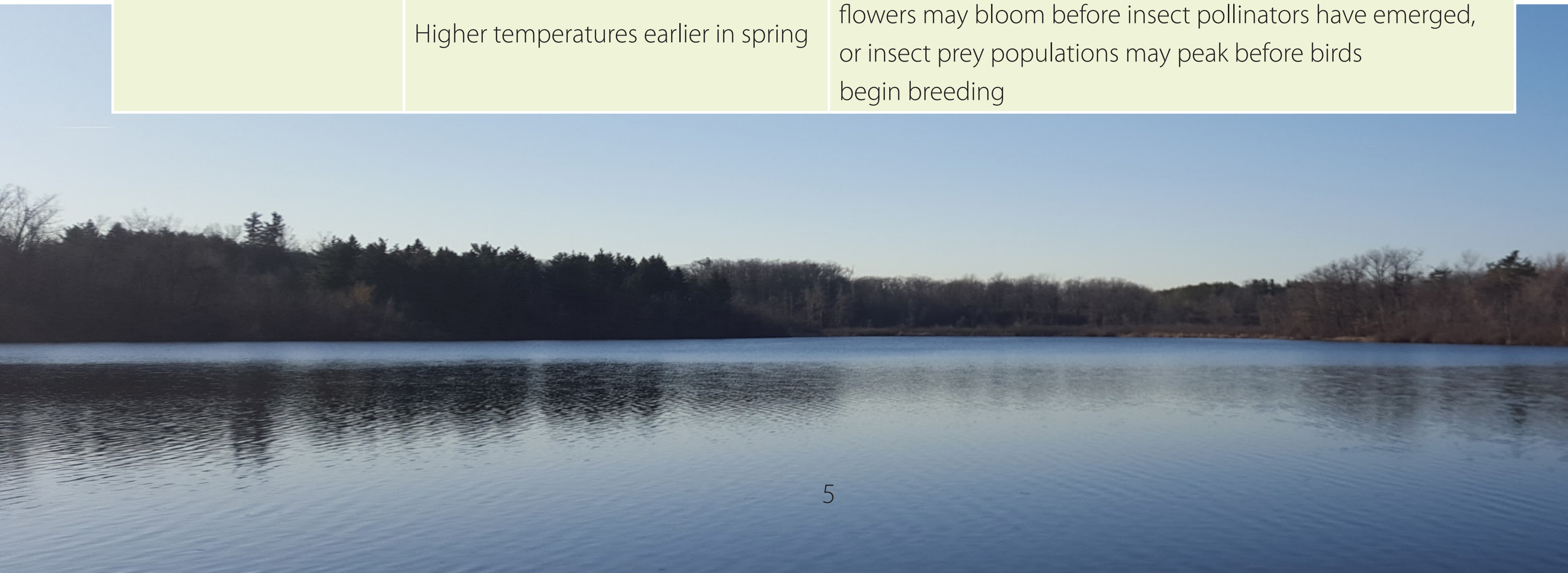
ECOSYSTEM SERVICES

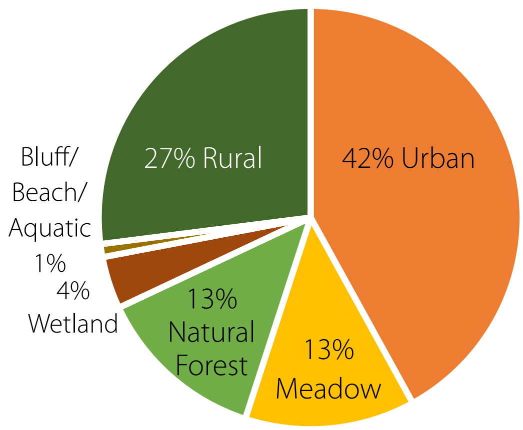
Humans derive countless benefits, or "ecosystem services," from natural systems. These services fall into four categories:

- Regulating Services, such as water and air quality
- Supporting Services, such as habitat diversity
- Provisioning Services, such as food and timber
- Cultural & Socio-Economic Services, such as recreational opportunities

Examples of Climate Change Impacts on Natural Systems

Natural System	Climate Driver	Potential Impacts to Natural Systems
Groundwater	Higher temperatures and more frequent extreme heat events	May cause higher evaporation rates, especially during the summer, reducing the amount of water soaking into the ground
	Increased winter rainfall	May extend the window for aquifer recharge (in temperate zones this currently occurs in early spring and late fall), potentially providing more opportunity for groundwater supplies to be replenished
	Short bursts of extreme rainfall	May be too brief for water to soak into ground and recharge aquifers
	More frequent and intense rainfall	May increase runoff in urban areas where recharge areas have been paved over, or where capacity for recharge is limited because of a high water table
Aquatic	Increased precipitation overall, as well as more frequent and intense	May increase runoff to rivers, wetlands and lakes, affecting flows and increasing delivery of nutrients and sediment
	Higher air temperatures and more frequent and intense drought	May cause low flow conditions and greater evaporation, which would reduce and degrade aquatic habitat
	Higher water temperatures	May affect what plant and animal species can live in aquatic systems, could threaten the survival of sensitive species
Terrestrial	Higher temperatures and more frequent and intense drought	May stress native plants and animals, making them more susceptible to disease and invasive species; could cause species to move further north to find suitable environmental conditions
	Higher temperatures earlier in spring	May disrupt synchrony in biological systems. For example, flowers may bloom before insect pollinators have emerged, or insect prey populations may peak before birds begin breeding





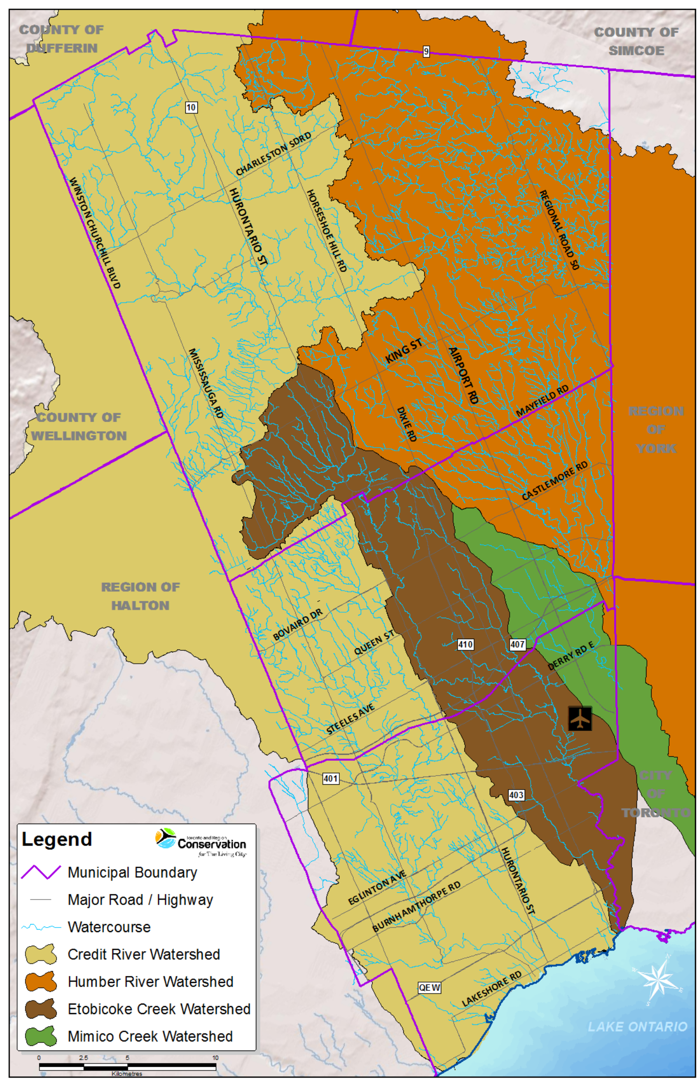
LAND COVER IN PEEL REGION

Natural Systems in Peel Region

Peel Region is situated in the "mixedwoods plains ecozone," which has one of the mildest climates in Canada, characterized by cool winters and long hot and humid summers. There are four major watersheds in the Region: Credit River, Humber River, Etobicoke Creek and Mimico Creek. All forests in the Region are fragmented, and most of the original wetlands have been lost.

Peel is one of the most densely populated areas in Canada, and all of its watersheds are under pressure from human activity, particularly urbanization. Other potential threats include aggregate extraction, agriculture and increases in recreational activity. Specific impacts on natural systems in the Region include the following:

- Forest fragmentation
- Pollution of streams by stormwater, fertilizers, pesticides, and livestock
- Lowering of the water table due to water taking
- Air pollution
- Wetland loss and degradation
- Spread of invasive species such as Emerald Ash Borer, Gypsy Moth, Butternut Canker, and Dutch Elm Disease



Major Watersheds in Peel Region

DEFINING RESILIENCE AND ADAPTIVE CAPACITY TO CLIMATE CHANGE

The vulnerability of natural systems 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.

Possible Futures Under Climate Change

Climate Trends in Peel Region

In general, temperature and precipitation patterns follow a north-south gradient in Peel Region, influenced by topography, elevation and land use activities. Temperatures tend to be higher in the southern portion, where the effects of Lake Ontario and highly urbanized areas trap heat. To the north, the higher elevation of the Niagara Escarpment and Oak Ridges Moraine combines with a less urbanized landscape comprised of farmland, natural forests and some grasslands, to produce cooler temperatures. Similarly, the southern portion of Peel is drier than the north, driven by geography and differences in regional storm tracks.

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. Over the next few decades, northern Peel is expected to warm faster than southern Peel, while the north-south gradient in precipitation patterns will likely intensify.

Natural System Vulnerabilities to Climate Change

Urbanization is the principal stress on natural systems in Peel, although aggregate extraction and agriculture are also important. Climate change will interact with these stressors to amplify and exacerbate impacts on natural systems.

The groundwater, aquatic and terrestrial systems examined in this assessment are tightly linked, and climate change will have complex and overlapping effects on them. Because many aspects of Peel's natural systems display a more or less north-south gradient in condition, climate change will have uneven effects throughout the Region.

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

Peel Region will be hotter at all times of year, with changes to seasonal precipitation patterns and more heat waves and rainstorms.

Groundwater plays a vital role in maintaining watershed health and resiliency by providing a constant, cold and clean source of water to the surface, supporting natural habitats, native biodiversity and residents of Peel Region.

Peel's Groundwater System

Groundwater plays a vital role in maintaining watershed health and resiliency by providing a constant, cold and clean source of water to the surface, supporting natural habitats, native biodiversity and residents of Peel Region. Groundwater generally flows from north to south in the Region, from the Niagara Escarpment and Oak Ridges Moraine down to Lake Ontario. The groundwater system is comprised of a mix of shallow and deep aquifers, which respond differently to climate change. Deeper systems are relatively protected from present day stressors (such as pollution or climate) because of the long time it takes water to filter down from the surface, recharge deep aquifers and then discharge to the surface again (on the order of 10, 000 years). Shallow aquifers, meanwhile, are more sensitive to environmental changes.

Groundwater and associated surface waters already under stress from urbanization will face further threats from climate change, such as the following:

- Reduced groundwater levels in shallow systems
- Reduced volume of water discharging to surface waters (such as streams and rivers)
- Increased risk of shallow aquifers drying out in summer
- Loss of stream habitat
- Warming of surface waters

POTENTIAL IMPACTS OF CLIMATE CHANGE TO NATURAL SYSTEMS


Shallow aquifers may dry out


Warming surface waters


Erosion


Algal blooms


Invasive species


Heat stress to plants

These impacts, in turn, will affect a variety of ecosystem services in Peel, such as regulation of water quality and quantity. Groundwater delivery to surface waters is projected to be more variable and intermittent, especially during summer months. While this is not expected to be a problem for potable water supply due to the Region's proximity to Lake Ontario, it may adversely affect non-potable water use, particularly in local areas already under stress, like Fletcher's Creek, and the West Humber and Etobicoke Headwaters.

Peel's Aquatic System

Peel's aquatic system delivers numerous ecosystem services, including a clean and stable water supply, control of flooding and erosion, and many recreational opportunities. Most watercourses are fed by groundwater in Peel. Streams south of the escarpment tend to have more intermittent headwaters and gather groundwater as they flow downstream, while streams above the escarpment and in the Oak Ridges Moraine are typically fed by groundwater-dominated headwaters.

Peel's aquatic system is experiencing a number of impacts associated with urbanization and resource use (recreational and sport fishing):

- Elevated stream temperatures
- Elevated levels of nutrients (such as phosphorus)
- Localized flooding
- Habitat fragmentation due to in-stream structures (such as dams and weirs) and ponds

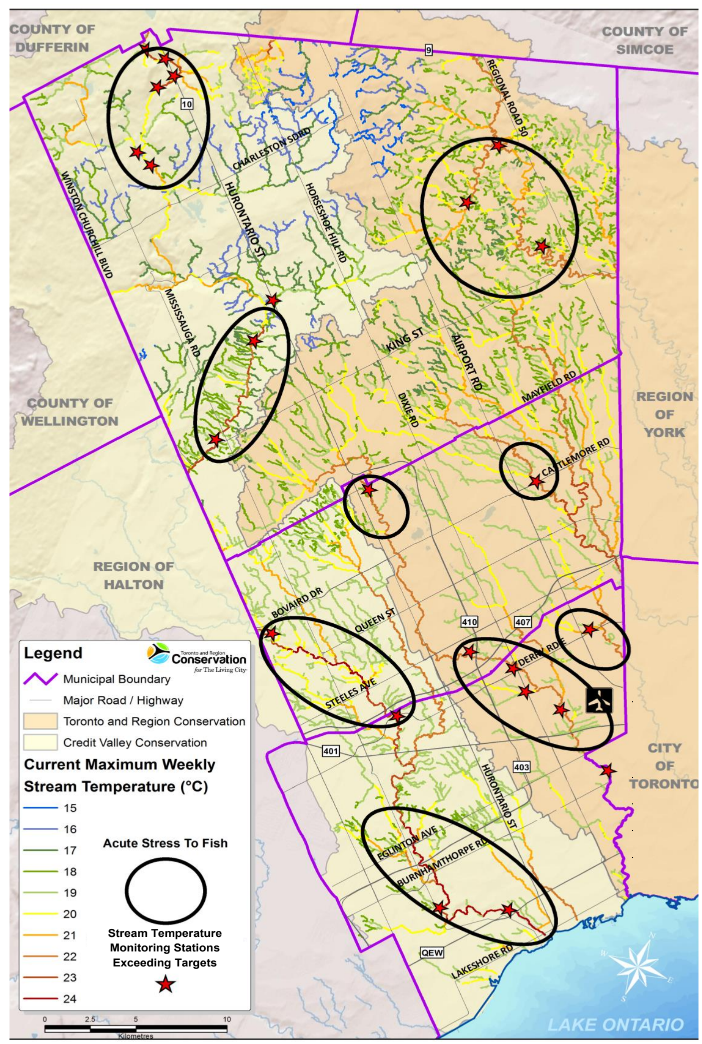
Some parts of the aquatic system are in good ecological condition and support an abundance and diversity of aquatic plants and animals. Other parts of the system, however, are not faring so well, especially in the highly urbanized lower portion of Peel. These areas will be particularly hard hit by climate change.

Nine highly vulnerable stream reaches have been identified in the Region due to their current low flows and elevated stream temperatures in summer. Under climate change, these hotspots may no longer be able to support sensitive fish species, such as Brook Trout and Redside Dace. Three aquatic species at risk are found in the Humber and Credit River watersheds (two endangered fish, Redside Dace and American Eel, and one endangered dragonfly, Rapid Clubtail).

Nine highly vulnerable stream reaches have been identified in the Region due to their current low flows and elevated stream temperatures in summer.

Climate change may further degrade Peel's aquatic system:

- Warming summer stream temperatures by as much as 2°C, making them unsuitable for many fish species
- Lowering seasonal water levels and summer flows, compromising fish movement and survival
- Increasing stream erosion and urban flooding due to more frequent and intense storms
- Increasing the spread of invasive species, as well as levels of pollutants and nutrients, through changes to flooding patterns
- Promoting favourable conditions for algal blooms, making them more common and intense
- Altering winter ecology because of warmer and wetter winter conditions, influencing survival of fish and fish eggs, and fish spawning in spring



Location of Nine Highly Vulnerable Stream Reaches Based on Stream Flow and Water Temperature

Peel's Terrestrial System

Land cover in Peel follows a distinct geographic pattern, with northern (or Upper) Peel mainly consisting of rural and natural habitats, compared with mostly urban or urbanizing areas in Middle and Lower Peel.

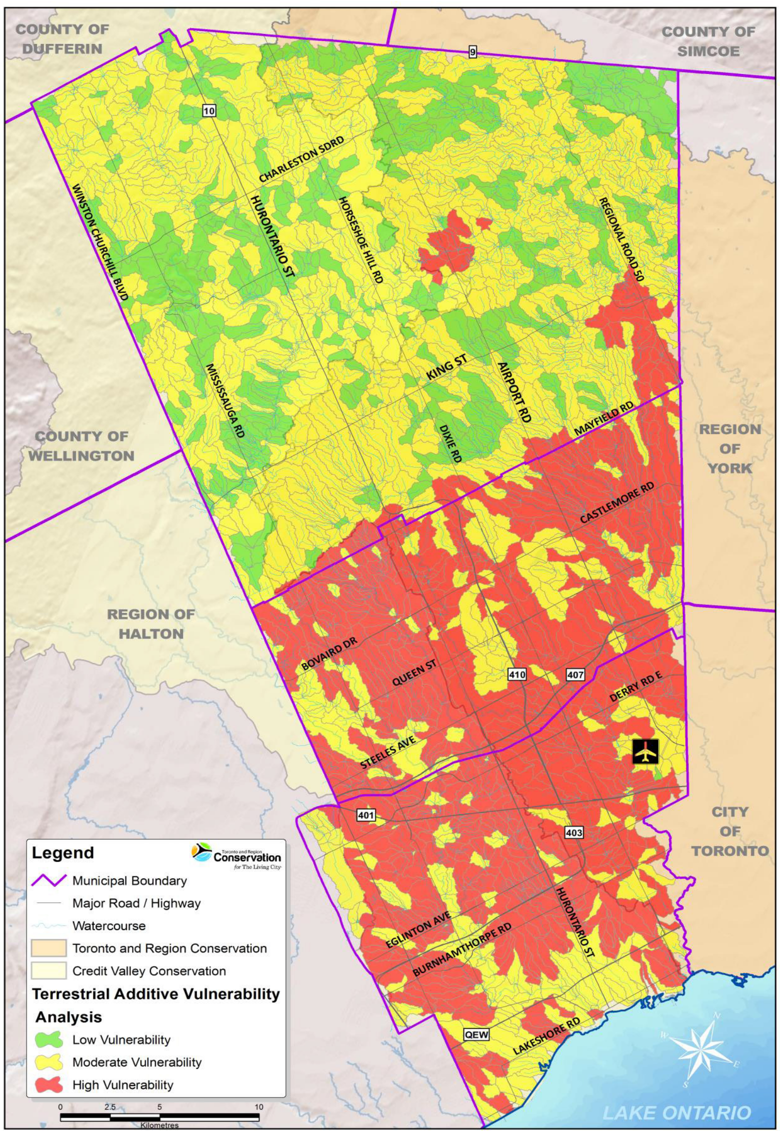
Climate change will amplify the effects of urbanization on the terrestrial system. Currently, 55% of the terrestrial system is considered highly vulnerable to increasing air temperatures and longer summer dry periods Most of these vulnerable areas are small isolated patches of natural habitat located close to urbanization, where they already face the following pressures:

- A shift from natural cover (which is 'pervious', allowing water to soak into soil and minimize flooding) to paved cover (which is 'impervious', preventing water from reaching soil)
- Loss of habitat connectivity (which reduces species movement and gene flow)
- Increased habitat fragmentation (which makes habitat patches more vulnerable to invasive species and disease)
- Reduced forest canopy (which reduces shading and cooling effects of vegetation)

In comparison, natural areas in northern Peel tend to be more widespread and well-connected. Although northern natural areas are currently in good ecological condition, they may experience drastic declines and shifts in species in the future, because they contain many climate sensitive plant communities, such as those found in swamps, marshes and fens far from watercourses.

Some of the potential impacts of climate change on Peel's terrestrial system include the following:

- Drying of wetlands (swamps far from watercourses and bogs are believed to be most vulnerable)



Terrestrial System Vulnerability

- Reduced snow cover, reducing beneficial insulation of plants and animals in winter
- More water flowing overland, leading to increased flooding especially in urban areas
- Increased heat stress for plants
- Increased spread of invasive species and frequency of pest outbreaks
- Shift in tree species from northern to southern species
- Intensified heat island effect in urban areas

Currently, 55% of the terrestrial system is considered highly vulnerable to increasing air temperatures and longer summer dry periods.

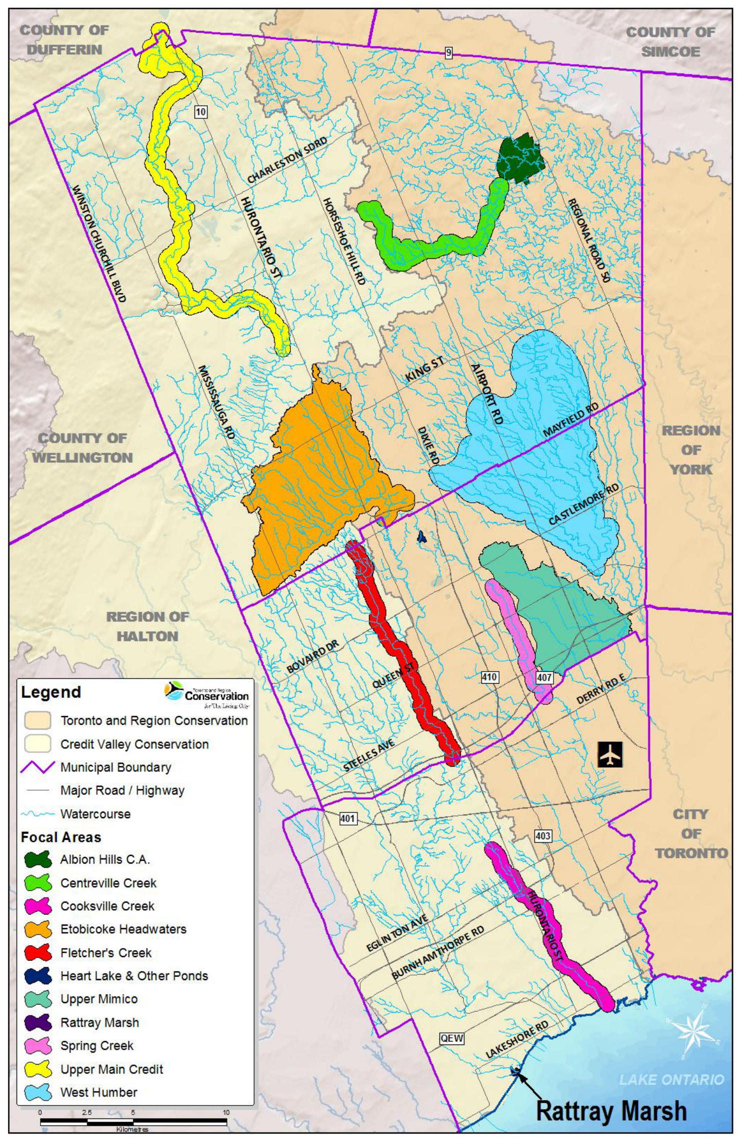
What the Storylines Tell Us

The natural systems assessment presented a series of 11 focal area storylines to provide more in-depth detail on climate change vulnerabilities across the Region. The storylines were selected based on areas that had sufficient information for identifying vulnerabilities, and are not uniformly distributed throughout Peel. They do not necessarily reflect priority areas of concern, but do represent case studies of how natural systems may respond to climate change within Peel Region.

Storylines were grouped into three categories covering conservation areas, subwatersheds and watercourse examples. One storyline from each category is summarized below.

- **Conservation Area Storyline: Rattray Marsh Conservation Area**
- **Subwatershed Storyline: Etobicoke Creek Headwaters**
- **Watercourse Storyline: Upper Main Credit**

Locations of Focal Area Storylines



Conservation Area Storyline: Rattray Marsh Conservation Area

Rattray Marsh Conservation Area is located in south Mississauga, within the Sheridan Creek watershed. It comprises 38 hectares of lakeshore, marsh, field and woodland habitats along the Lake Ontario shoreline. The marsh itself is one of the last baymouth bar coastal wetlands in western Lake Ontario, and one of the few remaining coastal wetlands in the Greater Toronto Area. Rattray Marsh supports a diversity of plant and animal species and has been designated an Environmentally Significant Area, Provincially Significant Wetland, and an Area of Natural and Scientific Interest. The Area provides important habitat for migrating birds, many aesthetic and recreational opportunities for local residents, and a cooling effect on surrounding built-up areas during summer.

Rattray Marsh supports a diversity of plant and animal species and has been designated an Environmentally Significant Area, Provincially Significant Wetland, and an Area of Natural and Scientific Interest.

The Conservation Area is surrounded by urban landscape, and over time has experienced substantial ecological degradation, including sediment build-up in Sheridan Creek, poor water quality, and spread of invasive species. Native species diversity in Rattray Marsh is considered degraded compared with wetlands in northern Peel Region.

Influence of Climate Change

Climate change is anticipated to influence the Conservation Area primarily through warmer and drier summer conditions. By the 2050s it is projected that Rattray Marsh may experience the following:

- Loss of forest habitat, replaced by shrubland and meadows
- Proliferation of existing invasive species, which are more tolerant than native species of a changing climate
- Loss of habitat connectivity for wetland species such as Spring Peeper and Wood Frog
- Degradation in habitat for migratory birds
- Increased occurrence of algal blooms
- Reduction in the cooling effect on surrounding urban areas during the hot summer

Management efforts are already underway in Rattray Marsh to strengthen its climate resilience. For example, dredging to remove sediment is helping to restore deep water habitat, while limiting access for the invasive Common Carp is increasing habitat diversity in the wetland.

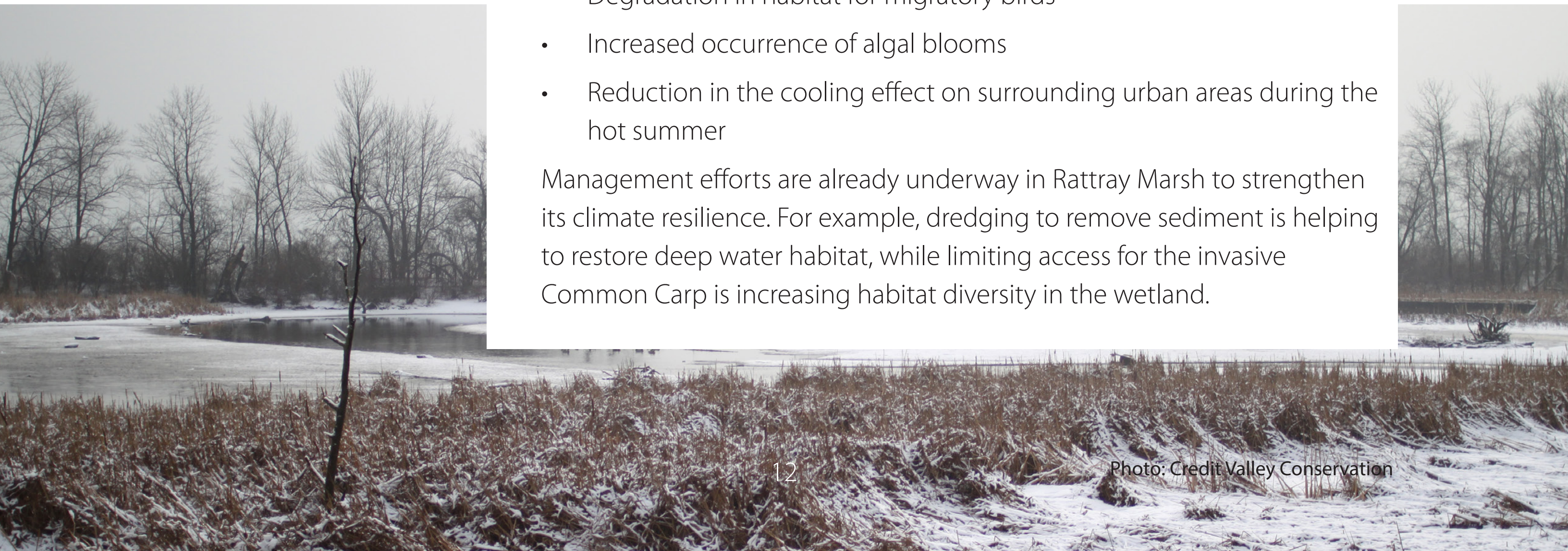


Photo: Credit Valley Conservation

Subwatershed Storyline: Etobicoke Creek Headwaters

The Etobicoke Creek Headwaters is situated in the northern portion of the Etobicoke watershed, in lower Caledon. Compared with the rest of the watershed, this area is in relatively good shape ecologically, with limited urban development (mainly in the south) and mostly natural or agricultural land cover (mainly in the north).

The groundwater system in the subwatershed is characterized by shallow aquifers, with among the lowest recharge levels in all of Peel, which makes this system particularly vulnerable to climate change. Some headwater tributaries commonly dry up during summer, limiting fish habitat and aquatic connectivity. Water quality is generally higher here than in downstream areas.

Natural forest cover is low and fragmented throughout the Etobicoke watershed, and most occurs within the Headwaters subwatershed. The area contains numerous climate sensitive vegetation communities (such as swamps and marshes) and species (such as beech and hemlock).

The vulnerability of the Headwaters subwatershed to climate change will be largely influenced by future development in the area. Although the Headwaters subwatershed currently has relatively good ecosystem function, if urbanization continues at the same pace, climate change impacts will be amplified and exacerbated.

Influence of Climate Change

Climate change is anticipated to influence the Etobicoke Creek Headwaters primarily through warmer and drier summer conditions, punctuated by heavy rainfall events. By the 2050s, the area may experience the following:

- Reduced water reaching the groundwater system
- Limited water availability in the aquatic system, especially in summer
- Increased overland flow, contributing to flooding downstream (e.g., in Brampton and Mississauga)
- Watercourses becoming wider and shallower, and drying up or having more frequent low flow conditions
- Higher surface water temperatures, adversely affecting aquatic life and recreational fishing
- Increased turbidity to surface waters; degraded water quality
- Declines in climate sensitive vegetation and replacement by more tolerant southern or shrubby species

STAKEHOLDER ENGAGEMENT

Because natural systems support us all in a variety of ways, it was important to gain input from as wide a cross-section of the Peel community as possible for this assessment process. Stakeholders were consulted through project meetings, interviews, and focus group workshops. Participants included representatives from Peel Region, TRCA, CVC, the Ontario Climate Consortium, the Ontario Centre for Climate Impacts and Adaptation Resources, the Ontario Ministry of Natural Resources and Forestry, as well as 19 subject matter experts from academic, government and non-government organizations.

Stakeholder participation was key to defining the project scope and conducting the vulnerability analysis. Participants identified what components of natural systems to consider in the assessment and which ecosystem services were most valued by them.

The ecosystem services provided by the Upper Credit Watershed are highly important for maintaining the ecological integrity of Peel's entire natural system.

Watercourse Storyline: Upper Main Credit

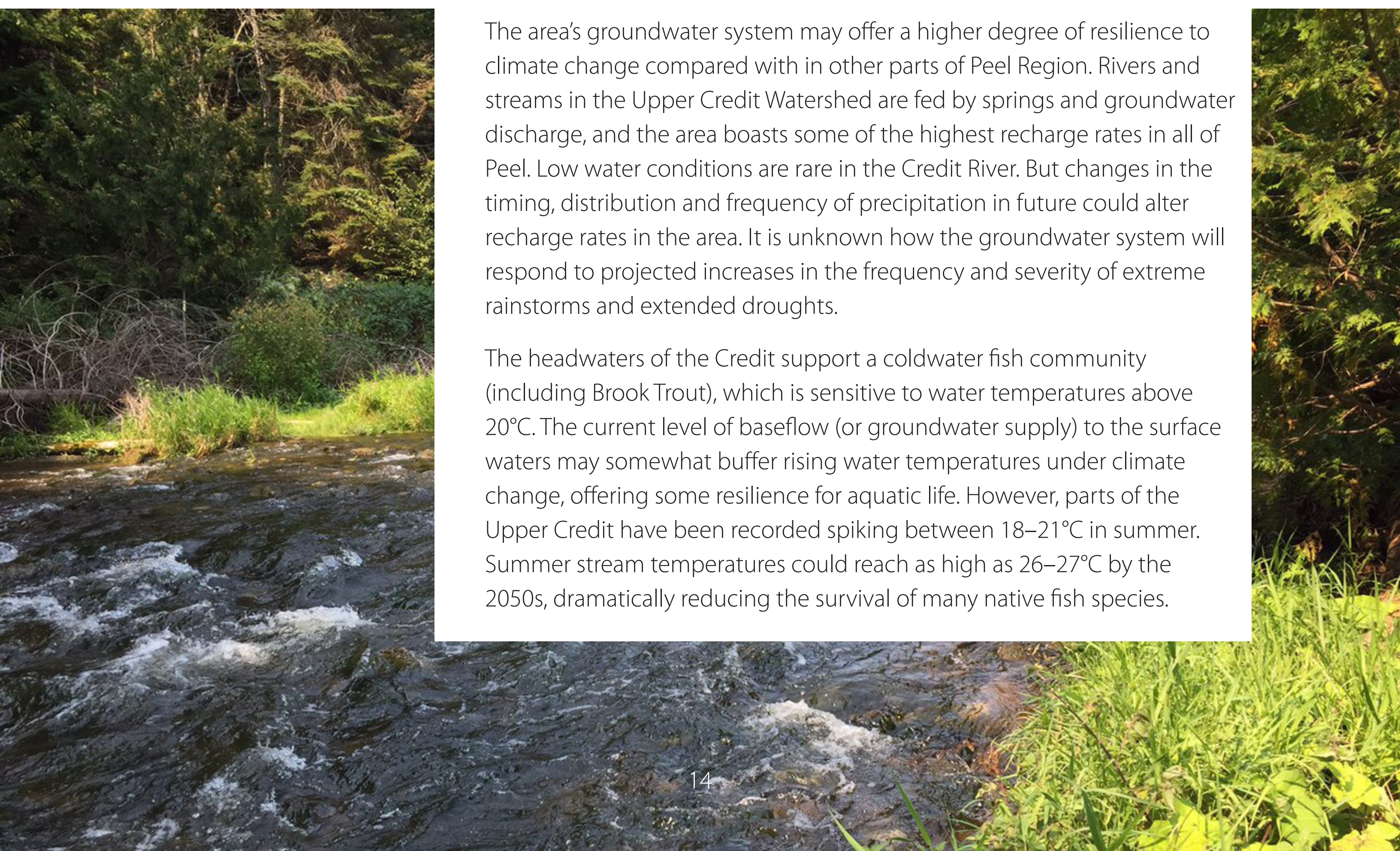
The Credit River begins north of Orangeville and flows into the northwest part of Peel Region above the Niagara Escarpment. This storyline focuses on the Upper Credit Watershed, covering the main branch of the Credit River from Melville to Cheltenham.

Most of the Credit River watershed is in good ecological health, despite historic and ongoing land use changes. The area is heavily forested, with only about 12% of the land cover under urban use. Compared with parts of the lower watershed, the Upper Credit retains high levels of pervious cover, forest and wetland habitat, natural habitat connectivity, and native species diversity. Its natural beauty is enjoyed by thousands of people throughout the year, including hikers, birdwatchers, and anglers.

Sections of the Upper Credit do face localized pressures and are areas of concern in the face of future climate change. For example, aggregate extraction, urban development and agricultural activity are creating water quality issues in the Shaw's Creek subwatershed, which flows into the Credit. Similar pressures affect the watercourse downstream, in Melville to the Forks of the Credit subwatershed.

The area's groundwater system may offer a higher degree of resilience to climate change compared with in other parts of Peel Region. Rivers and streams in the Upper Credit Watershed are fed by springs and groundwater discharge, and the area boasts some of the highest recharge rates in all of Peel. Low water conditions are rare in the Credit River. But changes in the timing, distribution and frequency of precipitation in future could alter recharge rates in the area. It is unknown how the groundwater system will respond to projected increases in the frequency and severity of extreme rainstorms and extended droughts.

The headwaters of the Credit support a coldwater fish community (including Brook Trout), which is sensitive to water temperatures above 20°C. The current level of baseflow (or groundwater supply) to the surface waters may somewhat buffer rising water temperatures under climate change, offering some resilience for aquatic life. However, parts of the Upper Credit have been recorded spiking between 18–21°C in summer. Summer stream temperatures could reach as high as 26–27°C by the 2050s, dramatically reducing the survival of many native fish species.



Influence of Climate Change

Climate change could affect the Upper Credit River in the following ways in future:

- Increased warming of surface waters could degrade water quality (which would be further worsened by urban expansion and associated increases in human activity).
- There could be an influx of coolwater fish species, and possibly invasive species expanding their ranges northward (which could change angling opportunities).
- Some or all Brook Trout populations could be lost in the area (especially from watercourses not buffered by groundwater).

The ecosystem services provided by the Upper Credit Watershed are important for maintaining ecological integrity within Peel Region. The Upper Credit is still in relatively good ecological condition, with large amounts of natural cover and a groundwater system supported by deep aquifers. These natural features mean that the Upper Credit has some buffering capacity against future climate change, which could help bolster the resilience of other downstream systems in Peel as well. But this adaptive capacity will not be possible under a "business as usual" approach in future. If human pressures continue to intensify in the area, the Upper Credit will not be able to withstand the added impacts of climate change.

Where Do We Go From Here?

This assessment is intended as a tool for identifying and prioritizing action to minimize vulnerability and maximize resiliency of natural systems in Peel under climate change. Current provincial land use policies, such as the Growth Plan, Greenbelt Act, Oak Ridges Moraine Act, and the Niagara Escarpment Act, represent steps in the right direction. This report offers a way to link these larger scale approaches to watershed and regional levels. Coordinating efforts at all these scales will contribute toward building a resilient Region with a high functioning natural landscape that delivers a full suite of ecosystem services to its residents.

The vulnerability assessment identified strengths and weaknesses in Peel's natural system that need to be factored into a coherent and effective plan to adapt to, and mitigate the effects of, future climate change. The following section outlines specific action Conservation Authorities and other stakeholders in Peel Region could take to build resilience in the natural systems.

The collective impact of a coordinated effort could be a resilient Region with a high functioning natural landscape that delivers a full suite of ecosystem services to its residents.

Habitat connectivity is recognized as one of the most important and effective ways to bolster species diversity under climate change.

Priorities for Action

1. Increase Connectivity

Protect, enhance or restore regional species diversity by increasing connectivity of natural areas, including forests, meadows, wetlands and watercourses. The focus should be on enhancing or expanding areas that currently function well and have low to moderate vulnerability to climate change. In Peel Region these areas include the northern portions of watersheds and/or headwater areas, which are strongholds for community diversity and high quality habitat.

Rationale:

- Biological diversity is the foundation of a resilient landscape.
- Habitat connectivity is recognized as one of the most important and effective ways to promote species diversity under climate change.
- This action will contribute to the overall resiliency of the entire landscape by protecting areas that act as sources of diversity.

2. Protect & Restore Natural Features

Protect existing and restore or create new natural features such as forests, meadows and wetlands across Peel. The immediate priority should be to protect, restore or create wetlands (especially swamps), which provide numerous protective mechanisms against climate change, but are also vulnerable to climate impacts.

Rationale:

- Drier summers punctuated with bursts of extreme rainfall will increase the risk and magnitude of flooding.
- Natural features minimize the adverse effects of flooding by blocking, storing and slowing surface runoff.
- Wetlands are among the most effective natural features at providing flood protection, but swamps fed by rainfall are particularly sensitive to climate change.

3. Enhance Urban Forest Canopy

Support municipalities to maintain and enhance the urban forest canopy. The initial focus should be on areas that currently have little or no ability to effectively regulate summer land surface temperatures. Intensive forest

Photo: Laura Taylor

management activities, such as introducing more southern tree species or planting more resilient native varieties may be warranted. New, innovative management approaches should be carefully monitored to ensure there are no undesired effects and that the expected outcomes are achieved.

Rationale:

- Heat stress in urban areas is expected to worsen with climate change, affecting not only humans, but also fish, wildlife and sensitive vegetation.
- Shading by the urban forest canopy can dramatically reduce the urban heat island effect.

4. Lower Maximum Water Temperatures

Increase efforts to lower summer maximum stream water temperatures. The priority should be on protecting coldwater habitats, as well as warmwater habitats that currently have elevated summer temperatures. Management initiatives should be coordinated across Conservation Authorities and integrated into existing restoration, retrofit and stewardship programs (through riparian planting for shade and infiltration of runoff, for example).

Rationale:

- Coldwater habitat is projected to significantly decline or disappear due to climate change.
- Temperature increases in warmwater habitat may exceed the tolerance level of native warmwater fish.

5. Protect and Improve Stream Baseflow

Protect and improve stream baseflow to minimize vulnerability to aquatic systems. The immediate focus should be on protecting coldwater networks (reaches, watercourses and subwatersheds). Action to protect baseflow may include operation of dams designed to augment baseflow (such as Island Lake Dam), as well as public awareness campaigns on water conservation.

Rationale

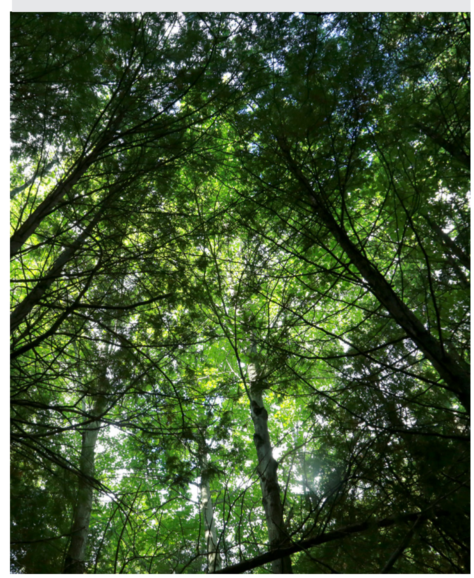
- Coldwater networks rely heavily on baseflow to support ecological function and are at greatest risk of habitat decline or loss under climate change.
- The maintenance of baseflow in coldwater networks will contribute to reducing vulnerabilities downstream.

THE HEAT ISLAND EFFECT

Urban areas are generally hotter than rural or natural areas because of the heat island effect. Vegetation is reduced in urban areas, and replaced with pavement and buildings, which leads to less shade and moisture to cool surroundings, especially in summer. The heat island effect has many negative consequences for urban dwellers, including increases in

- peak energy demand
- air conditioning costs
- air pollution
- greenhouse gas emissions
- heat-related illness and mortality

Some urban areas in Peel already experience a marked heat island effect in summer. In downtown Brampton, for example, daytime surface temperatures as high as 45°C have been recorded. Climate change will further intensify this effect.



WHAT THIS VULNERABILITY ASSESSMENT IS

- Part of the research phase of the adaptive management process Peel is conducting to respond to climate change
- Technical assessment to understand how natural systems in Peel respond to climate change
- Describes current climate vulnerability and how this might change in the future under climate change
- Provides evidence and information needed to inform adaptation
- Precursor to developing an adaptation strategy for protecting natural systems
- Provides background information that could be used in future risk assessments
- Developed through widespread consultation with local stakeholders

WHAT THIS VULNERABILITY ASSESSMENT IS *NOT*

- Not a prescriptive plan for addressing vulnerabilities and impacts
- Does not rank the relative significance of different climate change effects on natural systems
- Does not evaluate resources or programs available in Peel Region to support adaptation planning and implementation

6. Reduce Surface Water Pollution

Focus on reducing surface water pollution. Areas with degraded water quality and/or algal blooms should be targeted for management. Conservation Authorities should consider innovative approaches, such as promoting low impact development, establishing pollution offsetting, restoring wetlands and removing dams. In addition, Conservation Authorities should advocate for the best available technology for new and proposed wastewater treatment plants, including those draining into Peel.

Rationale

- Climate change is expected to worsen existing water quality issues in the Region.
- More frequent, intense and/or chronic algal blooms could destabilize aquatic food webs, foul public areas, and damage drinking water filtration infrastructure.

7. Protect Shallow Water Flow Paths

Identify and protect important local connections (or flow paths) between shallow groundwater and surface features, such as streams and wetlands.

Rationale:

- Groundwater supply from shallow aquifers is highly vulnerable to climate change and other stressors.
- While the provincial Sourcewater Protection Program has helped to identify priority groundwater areas and drinking water wells across southern Ontario, knowledge of critical connections at the local scale in Peel Region is lacking.

8. Review Natural System Monitoring Programs

Review current natural system monitoring programs carried out by Conservation Authorities and municipalities to ensure they include a focus on climate change impacts. If necessary, revise programs so that they effectively track vulnerabilities, and establish an evaluation system to measure the success of adaptation efforts in achieving watershed resiliency.

Rationale:

- Conservation Authorities are leaders in natural system monitoring, but some programs were designed before climate change was a major concern.
- A review of current programs and evaluation of adaptation action would help ensure a coordinated and consistent regional approach to climate change.

9. Implement & Update Conservation Policies

Continue to implement policies and programs related to sustainability and natural system protection and continue to update these guidance documents with new science, evidence and approaches for reducing natural systems vulnerability, starting with the information provided in this and other vulnerability assessments.

Rationale:

- Many existing policies contain management recommendations that contribute to climate change adaptation.
- However, many technical and guidance documents for Peel Region were developed before climate change was a major concern and thus lack focus on this issue.

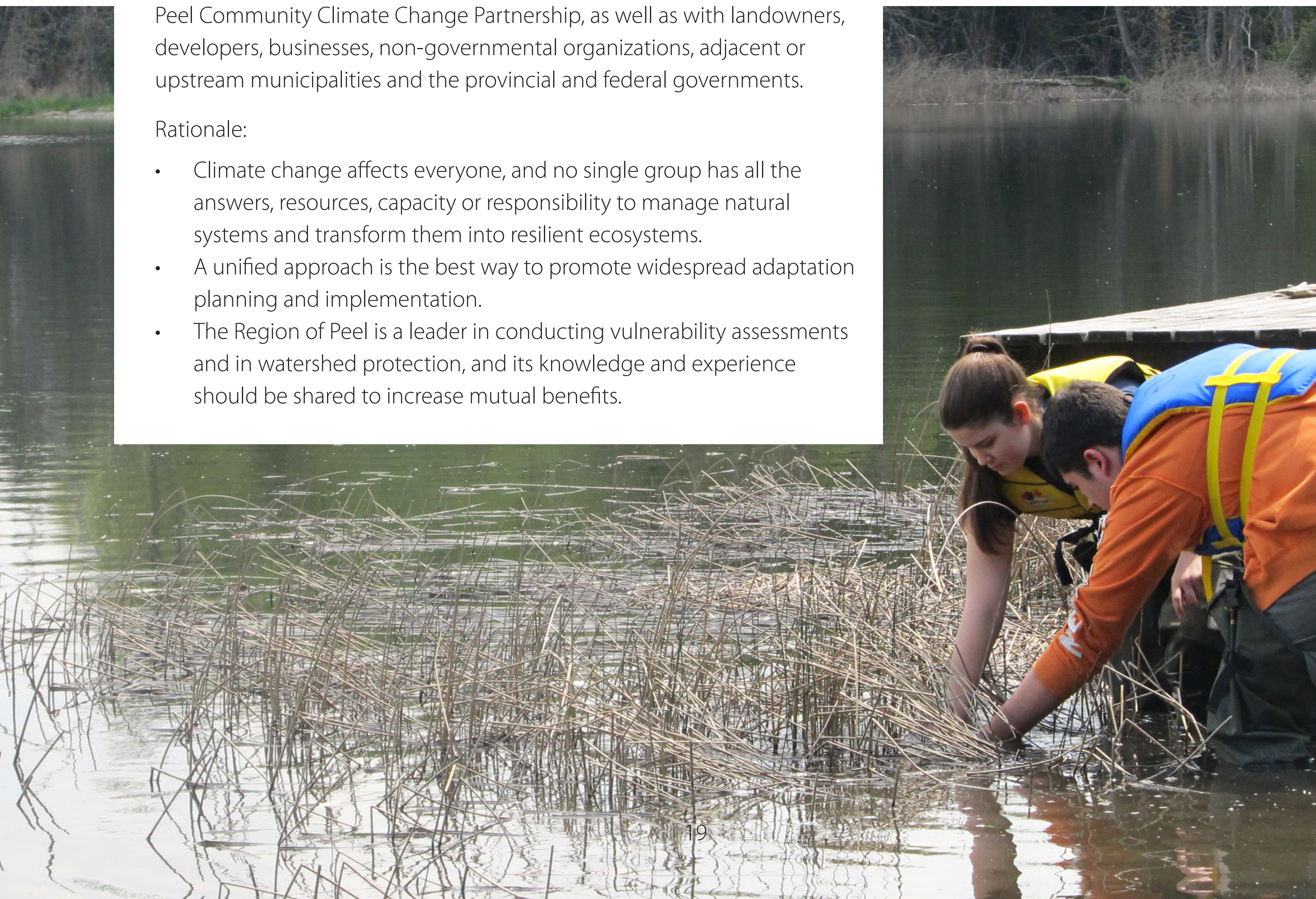
10. Collaboration

Promote effective collaboration, cooperation and streamlined information sharing amongst regional Conservation Authorities, municipalities, and the Peel Community Climate Change Partnership, as well as with landowners, developers, businesses, non-governmental organizations, adjacent or upstream municipalities and the provincial and federal governments.

Rationale:

- Climate change affects everyone, and no single group has all the answers, resources, capacity or responsibility to manage natural systems and transform them into resilient ecosystems.
- A unified approach is the best way to promote widespread adaptation planning and implementation.
- The Region of Peel is a leader in conducting vulnerability assessments and in watershed protection, and its knowledge and experience should be shared to increase mutual benefits.

The future of natural systems under climate change affects our future. We must act now to protect natural systems so that ecosystem services are continually delivered, sustainable over the long-term and resilient to climate change.



Natural Systems Vulnerability to Climate Change in Peel Region

Complete Technical Report







Prepared for:

Region of Peel
Working for you

Prepared By:

Toronto and Region Conservation for The Living City

Ontario Climate Consortium

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ACRONYMS

AR5	IPCC Fifth Assessment Report (IPCC, 2013)
CANGRD	Canadian Gridded-Observed Climate Dataset
CA	Conservation Authority
CAT	Core Advisory Team
CMIP3	Coupled Model Intercomparison Project Phase 3 (2007)
CMIP5	Coupled Model Intercomparison Project Phase 5 (2013)
CVC	Credit Valley Conservation
EAB	Emerald Ash Borer
ECCC	Environment and Climate Change Canada
ES	Ecosystem Services
ET	Evapotranspiration
FMP	Fisheries Management Plan
GCM	General Circulation Model
GHG	Greenhouse Gas
GSFLOW	Coupled Groundwater-Surface Water Flow Model
HLCA	Heart Lake Conservation Area
ICLEI	International Council for Local Environmental Initiatives
IPCC	Intergovernmental Panel on Climate Change
LASMF	Lowest Average Summer Mean Flows (LASMF)
MNR	Ontario Ministry of Natural Resources (pre-2015)
MNRF	Ontario Ministry of Natural Resources and Forestry (2015 onward)
MOECC	Ontario Ministry of Environment and Climate Change
MWAT	Maximum Weekly Stream Temperature
NS	Natural Systems
OCC	Ontario Climate Consortium
OCCIAR	Ontario Centre for Climate Impacts and Adaptation Resources
ORAE	Oak Ridges Moraine or Equivalent (i.e., ORAE aquifer)
ORM	Oak Ridges Moraine
PCCS	Peel Climate Change Strategy (2011)
P-CRAFT	Peel Climate Risk Analysis Framework and Tool
PGMN	Provincial Groundwater Monitoring Network
RCP	Representative Concentration Pathway (e.g., the RCP8.5 scenario)
SWM	Stormwater Management
TRCA	Toronto and Region Conservation Authority
USEPA	United States Environmental Protection Agency
USS	Urban Stream Syndrome
VA	Vulnerability Assessment
VF	Vulnerability Factor

1. INTRODUCTION

The most recent assessment report on climate change in 2013 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. The IPCC concluded that if greenhouse gas (GHG) emissions are not significantly reduced, warming trends will continue into the latter half of this century, leading to more devastating and frequent extreme weather events than are currently experienced. An international meeting of nations in 2015 (COP21) created the Paris Agreement which established, among other items, a binding target of limiting warming to an increase of 2˚C globally by 2050. The IPCC has emphasized that adaptation by governments everywhere is critical as warming over the coming decades is no longer reversible even with mitigation efforts.

At the local level in Ontario, Conservation Authorities (CAs) are a vital link to building resilience across the natural environment at the watershed level, including enhancing the terrestrial, aquatic and hydrologic health of watersheds. This report focuses on natural systems in the Regional Municipality of Peel, consisting of the City of Mississauga, City of Brampton and the Town of Caledon (see Figure 1). Two CAs regulate, monitor and work to protect the natural environment in the region: the Toronto and Region Conservation Authority (TRCA) and the Credit Valley Conservation (CVC).

Addressing climate change in Peel Region is not new. The TRCA first responded to that call in 2007 by producing *Meeting the Challenge of Climate Change: TRCA Action Plan for the Living City*; a proactive strategy to address the impacts of climate change within its jurisdiction and set a planning framework for the coming decade. Similarly, CVC has also been actively responding to the need for climate expertise and services in their watershed. In 2007, CVC completed a substantial literature review investigating the impacts and adaptation for terrestrial and aquatic ecosystems and species in the Credit River watershed, published in *2degreesC*. CVC has since hosted expert workshops facilitating discussions on how we can adapt our natural areas to climate change and to develop climate change strategies for the Credit River watershed.

In 2011, TRCA in partnership with York University founded the Ontario Climate Consortium (OCC), marking another milestone in collaboration and commitment to evidence-based planning and decision making, one that Peel Region (“The Region”) quickly joined and continues to support today.

The imperative for climate leadership was further met with ongoing Peel Region funding for local CAs to undertake climate change work and with the development of the *Peel Climate Change Strategy* in 2011 (“The Strategy”); which is a collaborative strategy that built on existing policies and programs to deal with the effects of climate change at the local level. To produce the Strategy, the Region partnered with the cities of Brampton and Mississauga, the Town of Caledon, TRCA, and CVC in 2009. The Strategy was adopted by Peel Regional Council on June 23, 2011 as a direct response to the growing need to adapt to and mitigate climate change. The author agencies, which are responsible for the implementation of the Strategy, formed the Peel Climate Change Partnership (“The Partnership”). The Partnership is driven by its core values:

- Open and Accountable: Be open about decision-making and report actions and in-actions;
- Share and Integrate: Integrate knowledge and ideas and transfer to others to build our collective strength;
- Lead: Innovate, lead by example and advocate for action; and
- Collaborate: Leverage our strengths while building on our weaknesses.

The Strategy is a roadmap for addressing climate change impacts and identified six main objectives, as follows:

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

For each objective, The Strategy identified specific actions that The Partnership could initiate, within five years, to support effective mitigation of, and adaptation to climate change. Consistent with the focus on adaptation, the current approach to implementing The Strategy is undertaking activities that reduce community vulnerability (relevant to Objective 1). In early 2013, the TRCA and Peel Region discussed priority actions coming from the Strategy and advanced the implementation of *Action 1.1 Complete a vulnerability and risk assessment of all infrastructure, of the community (such as assessment of human health impacts) and of natural heritage.* Within months, the interest, expertise and commitment of a network of partners evolved into the project’s Core Advisory Team (CAT) to provide expertise and guidance on natural systems. The following report represents the collaborative efforts of that team’s oversight and the dedication of TRCA staff to assess the science, and access reliable expertise, to qualify and to the extent possible, quantify current and future vulnerabilities of natural systems to the threat of climate change in Peel Region. A definition of ‘natural systems’, and numerous other terms used throughout this report, is provided in the Glossary in Appendix A.

1.1. Outline of Report

This report consists of nine sections, which are described below:

- Section 1: Sets the project context, scope, objectives, and presents a common understanding of vulnerability.
- Section 2: Provides subject matter background, a bird’s-eye view of the complex relationships between natural systems, climate change and introduces discussion of ecosystems services. This section concludes with defining what will be examined as part

of this vulnerability assessment in Peel Region, including identifying existing policies, plans and frameworks that would support future implementation to reduce vulnerabilities of natural systems.

- Sections 3 and 4: Provide a detailed accounting of methods and climate information used to characterize current and future vulnerability.
- Section 5: Summarizes limitations and assumptions associated with the methods used in this assessment.
- Section 6: Shares assessment results as a series of structured evaluations of natural system components, processes, vulnerability factors and indicators. Current conditions and future estimates of vulnerability are provided together with the implications to ecosystem service delivery if underlying ecological processes are disrupted by climate change and, of course, future urban development and the development of rural areas in Peel as well. Two scales are used to present and help craft the stories: Peel-wide (6.1) and focal area storylines (6.2). Spatial mapping of vulnerability indicators, where data were available, is presented throughout section 6, which provides large aid in understanding the indicator analysis and characterization of current vulnerability.
- Sections 7 and 8: Summarize key findings according to future climate conditions, urban influences and natural systems component, and offers a set of management considerations that largely speak to Conservation Authority policy and program opportunities but also present the imperative for enabling greater municipal and provincial discourse that speaks specifically to future land use planning and reform.
- Section 9: Finally presents a list of resources that provide some insight what our own adaptive capacity looks like on the path of adaptation.

1.2. Project Purpose, Scope, Objectives and Study Area

The purpose of this project is to implement the Peel Climate Change Strategy and advance the partnerships ability to adapt to climate change. Its scope is to define the natural systems within Peel Region, understand how the physical, chemical and ecological processes that govern ecological structure and function respond to climate drivers and assess their potential vulnerability to climate and future climate conditions and extreme weather. Consideration for existing conditions, effects of other stressors and the link to ecosystem service delivery are also presented to provide stakeholders with comprehensive picture of natural systems vulnerability. Modelling analysis to quantify current and future vulnerabilities is provided for two case studies only: groundwater discharge using historic drought conditions in the West Humber River and stream temperature under the A2 scenario out to 2050s. The following research question guided the assessment:

- What is the degree of vulnerability of natural systems, and the key ecosystems they provide, to climate change and extreme weather impacts in watersheds throughout Peel Region?

To answer this research question the following objectives were defined:

- Determine, through literature review and subject matter expert consultations, qualitative estimates of current vulnerability (High, Medium, Low) of natural systems, and their components, in Peel Region based on vulnerability factors and indicators, and describe directional trends in future vulnerability;

- Analyze and produce spatial mapping of the distribution and relative current vulnerability estimates of natural systems and/or their components across all watersheds within Peel Region: Humber River, Credit River, Etobicoke Creek and Mimico Creek; and,

- Examine, through case studies, quantitative estimates of current and future vulnerability based on modelling of specific systems or components.

The study area is the geographic boundary of Peel Region, located within the Great Lakes Basin on the north shore of Lake Ontario in South-Central Ontario, Canada (Figure 1). The total land area of Peel Region is 1,256.8 square kilometers (Greater Municipality of Peel 2012) and includes the local area municipalities of City of Mississauga, City of Brampton and Town of Caledon.

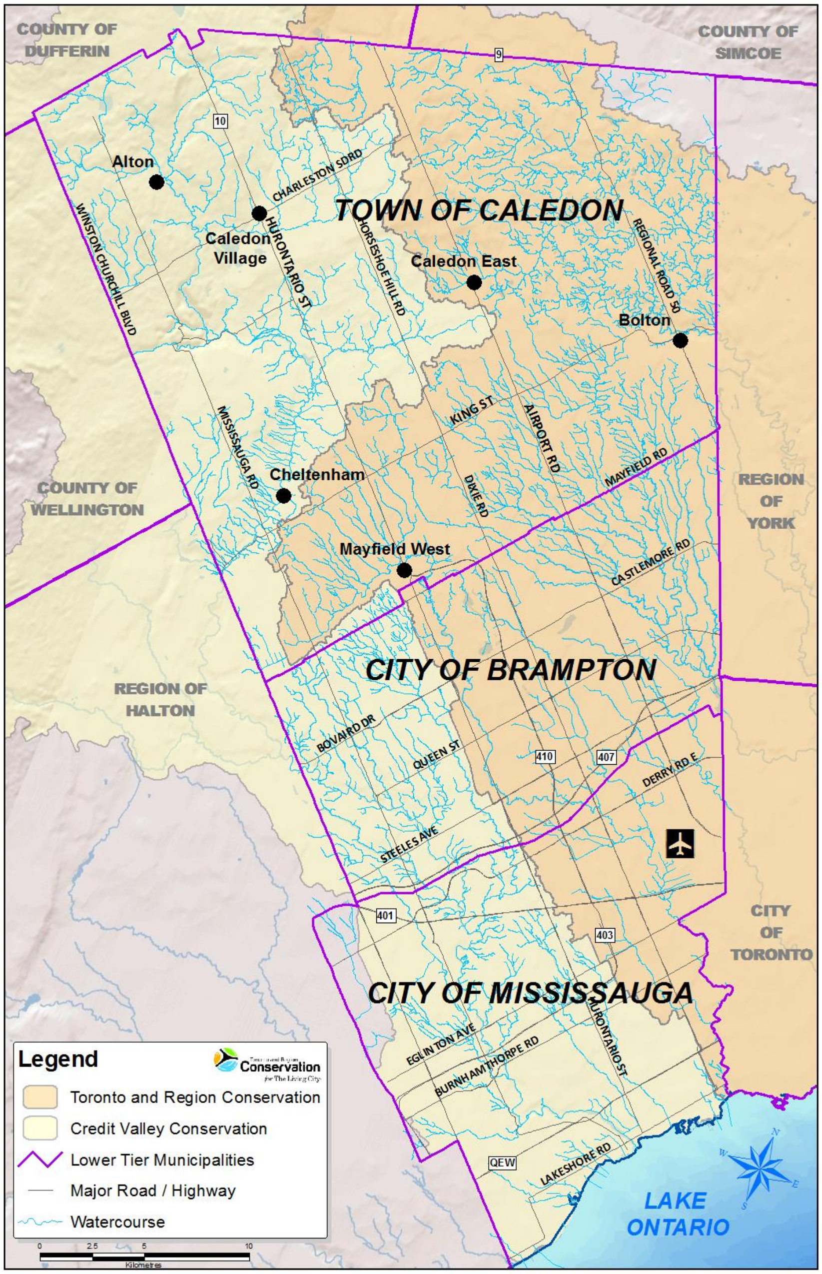


Figure 1: Study Area Boundary, Peel Region in South-Central Ontario, Canada

Peel Region's northern boundary extends to the Counties of Dufferin and Simcoe and is bounded in the West by Wellington County and Halton Region; and in the East by York Region and the City of Toronto. Four major watersheds are partially or nearly fully contained within Peel Region: Humber River, Mimico Creek, Etobicoke Creek and Credit River (Figure 2). The first three watersheds are within the jurisdiction of the TRCA and the fourth watershed is managed by CVC. Notably, small portions of two other watersheds extend into Peel in the northeast (Nottawasaga River in the jurisdiction of Nottawasaga Valley CA, and West Holland in the jurisdiction of Lake Simcoe Region CA) and one other watershed extends into Peel in the southwest (Sixteen Mile Creek Watershed in the jurisdiction of Halton Conservation); however, these three watersheds were considered out of scope for this assessment.

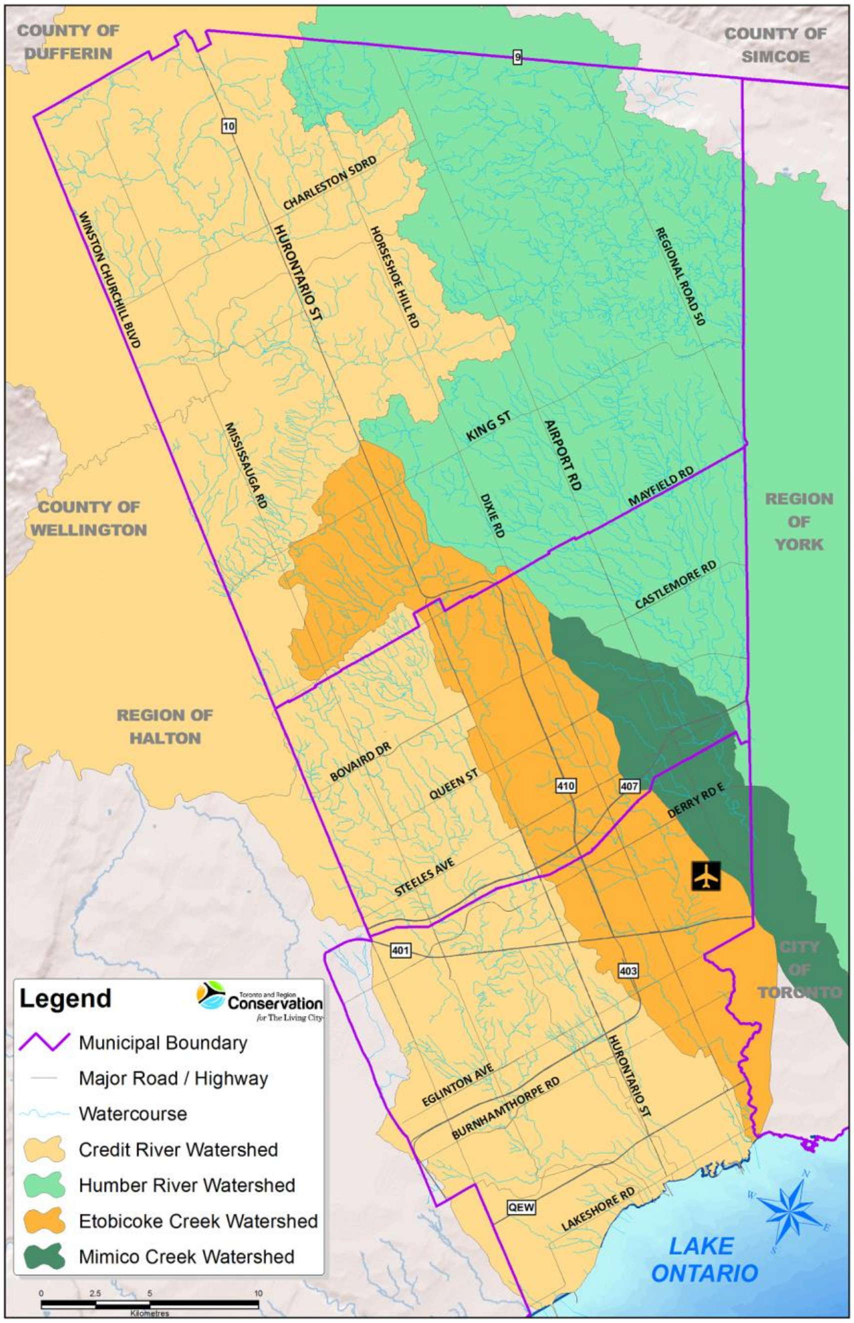


Figure 2: Major Watersheds in Peel Region

1.3. Intended Audience

This technical report is intended to be used by regional and municipal planning staff, conservation authorities, decision makers and interest groups within the natural heritage sector to inform the policy and planning activities needed to adapt to local climate change impacts and reduce vulnerabilities. In addition, this technical report could be used as a general reference for other municipalities and Conservation Authorities looking to understand natural systems and ecosystem services within urban watersheds and Southern Ontario. A summary report for policy and decision makers will be issued after the technical report is final.

1.4. Defining Vulnerability to Climate Change

The IPCC identifies that a first step in addressing climate change is to assess and understand vulnerabilities of a system of interest (IPCC 2014). The definitions of vulnerability with respect to climate change are quite varied (IPCC 2012; United Nations Framework Convention on Climate Change 2011), though consensus has generally formed around the concept of "potential for loss" within a given system. For this assessment, the IPCC's 2014 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 (2014) 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 climate 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)

2. BACKGROUND

The following section pulls from the literature and provides a high-level summary describing the natural components and ecological processes that are anticipated to respond to climate drivers and result in either disruption or potential enhancement of ecosystem services. Natural systems found in Peel Region and key ecosystem services are more specifically defined to provide context for the analysis in later sections; current stressors on Peel's natural systems are also identified. To complete this background section, information is presented from the suite of existing natural heritage system policies, plans and management frameworks. These establish a level of responsibility and ability of The Partnership to practice sound ecosystem management.

Existing frameworks that are presently available speak more to the issue of urbanization or sustainability objectives and are likely insufficient to address the broader, complex and penetrating impacts of climate change.

2.1. Natural Systems and their Connection to Climate Change

Climate change is already impacting ecosystems, and is poised to further challenge the future integrity of ecosystems found across the planet. Many uncertainties remain about the magnitude of change, and whether thresholds of habitat stability, suitability or species tolerances will be crossed. A lot will depend on the resiliency of natural systems, that is, their adaptive capacity to cope with climate drivers that are expected to affect fundamental physical and chemical processes which govern ecological dynamics and biological limits. It is important to note that even in an unaltered state; the band-width of adaptive capacity (a component of vulnerability) varies amongst and within natural systems. This imposes a baseline of degraded ecological structure and function, and as a result diminished intrinsic resilience of natural systems, due to cascading effects of land use change, water taking and other human-related impacts (Wiens *et al*. 2009). For the purpose of this assessment, the natural systems and associated ecological processes of interest are groundwater, aquatic and terrestrial systems found within temperate eco-regions of the Great Lakes Basin.

Higher seasonal air temperatures and extreme heat associated with climate change are expected to increase evaporation rates, particularly during months in and around the summer season (TRCA 2009; IPCC 2013; Abtew and Melesse 2013). Correspondingly, the amount of water infiltrating into the ground will likely be reduced in the summer, and shift throughout the rest of the year as future precipitation patterns change, which are summarized from climate modeling conducted for Peel Region in section 4 (TRCA 2014b; Aquafor Beech Limited 2011a). In essence, climate change is expected to influence and shift the hydrologic regime (Allen *et al*. 2004).

Starting with the groundwater system, increasing precipitation, particularly as rainfall during warmer winters, may change the timing and annual amount of aquifer recharge (Eckhardt and Ulbrich 2003; Allen *et al*. 2004; Doll 2009; AquaResource Inc. and EBNFLO Environmental 2010; Mishra and Singh 2010; Green *et al*. 2011). Currently, recharge in temperate regions is generally confined to two periods: early spring, after the ground has thawed but before vegetation leaf-out; and a relatively shorter window in late fall, prior to the ground freezing and after vegetation has entered the dormant period (pers. comm. Don Ford, 2014). Thus, with warmer temperatures, the window for recharge may extend into winter and provide an opportunity for increased aquifer maintenance if fall and spring precipitation patterns are reasonably maintained (Jyrkama and Sykes 2007b). However, if future extreme rainfall events are shorter in duration and higher intensity as projected (and described later in this report), they may not allow sufficient time for water to infiltrate and recharge the groundwater system. In other words, recharge conditions are optimal under slower, more drawn out rainfall events. Runoff, on the other hand, might increase in urban areas where either recharged areas have been paved or recharge capacity is limited due to a high groundwater table.

Following from above, discharge to aquatic surface features, including streams, wetlands and lakes, will likely shift as well, although by how much will depend on local conditions of the groundwater system and future patterns in precipitation (see section 4). As the flow regime is the master controlling variable in rivers and streams (Karr 1991; Poff *et al*., 2002), the changing nature of precipitation is likely to have a profound effect on the state of aquatic ecosystems and how they are shaped, how they evolve, and how they function over time (Poff *et al*., 2002). Specifically, changes in snow patterns and the seasonal distribution of rainfall are of high interest (Berghuijs *et al*., 2014; Campbell *et al*., 2014; Warren & Lemmen, 2014). It is not anticipated that extremely low flow conditions will become common; however, certain areas may exhibit more surface water stress due to lesser discharge and greater evaporation if prolonged periods with little rain or drought (little precipitation and high air temperatures) occur.

Climate change will indirectly disrupt chemical processes in natural systems; importantly nutrient dynamics. The availability of nutrients, sediment and moisture will depend on increasing temperatures and patterns of precipitation into the future (Bazzaz & Miao, 1993; Edward *et al*., 2012). For instance, if precipitation increases overall or is delivered in more frequent and extreme bursts, the result is greater runoff volumes that may deliver higher seasonal loadings of nutrients to the detriment of aquatic components such as rivers, streams and inland lakes particularly if they are downstream of agricultural lands (Staudinger *et al*., 2013). On the other hand, nutrient or moisture poor components of the terrestrial system, and their resident biota, may become highly stressed if drought conditions occur more frequently (Environment Canada, 2013; Fang & Stefan, 2000; Poff *et al*., 2002; Vincent, 2009; Woodward *et al*., 2010).

There will also be indirect impacts, including increases in direct radiative heating of rivers and streams which could increase the frequency and severity of thermal spikes in water temperatures, shift thermal regimes and threaten sensitive species due to their specific tolerances (Dove-Thompson *et al.*, 2011; Kinkead, 2008; Wherly *et al.*, 2007; Wisconsin Initiative on Climate Change Impacts, 2011). Terrestrially, differing plant tolerances to moisture or heat stress could shift species ranges further north, increase susceptibility to disease, limb breakage or invasive species, or reduce leaf areas depending on the future moisture regime (Kenney, 2000; Melles *et al.*, 2015; Melles *et al.*, 2011) thereby changing habitat, lowering species diversity and reducing canopy that provides shading. Climate change ultimately will interact physically and chemically in the natural systems to shift thermal and moisture levels, which could limit survival or exceed biological tolerances for native species. Climate change may have additional effects on terrestrial ecosystems such as the reduction or loss of synchrony in co-evolved and adapted systems. The timing of critical ecological events and activities such as flowering emergence and migration of species has the potential to become decoupled, as they either advance or become delayed in their timing, leading to a negative ecological response or outcome (Nituch and Bowman 2013). One troubling example of many is the asynchrony between flowers that bloom before the emergence of their insect pollinators. In the face of these realities and uncertainties, it is critical to understand the impacts of climate change in order to direct adaptation actions that are effective at enhancing or building resilience into natural systems.

2.2. **Ecosystem Services**

Ecosystems are made up of various biotic (living organisms) and abiotic (chemical and physical) structural elements, which are constantly interacting with each other through various ecological processes. These interactions and processes are highly complex in some cases and relatively simpler in others. Likewise, some of these interactions and processes are well-understood and visible while others are less so. Regardless of the gradient of complexity and level of understanding by humans, these processes allow for various ecosystem functions to occur, which in turn provide a range of goods (e.g. timber, food) and services (e.g. climate regulation, nutrient cycling) that benefit and are valued by human populations (Costanza *et al.* 1997; De Groot *et al.* 2002; Millennium Ecosystem Assessment 2005a; Tallis *et al.* 2008). Over the past two decades there has been increasing recognition that ecosystem services are imperative to human as well as planetary well-being, with this importance reflected in watershed planning and management to ensure ecosystem services are sustainable and resilient in the face of climate change but also to the effects of land use and some resource management practices. Management emphasis is on maintaining and enhancing the ecosystem structure, processes, and functions that provide them, especially when some of the more complex ecosystems are extremely difficult, if not impossible, to replicate and/or replace with the similar efficiency and effectiveness using anthropogenic means and techniques.

There are a number of ecosystem services identified in ecological systems literature, which have been broadly grouped into four categories for the purpose of this natural systems vulnerability assessment framework (further details in Section 3.2). They mainly reflect regulating, provisioning, cultural, and socio-economic services to humans. This is based on a number of similar assessment frameworks identified across the literature (e.g., Landers & Nahlik, 2013; Landsberg *et al*., 2013; Mader *et al*., 2011; Millennium Ecosystem Assessment, 2005a; Mooney *et al*., 2009; Staudinger *et al*., 2012; Troy & Bagstad, 2009). Up until recent decades, these ecosystem services were considered to be “free” as we receive and use them at no visible financial cost. Nevertheless, the advances in ecological economics have highlighted the financial costs as well as benefits associated with these services. For example there have been substantial public and private financial investments made in natural systems management for protection and enhancement of urban greenspaces, forests, wetlands, rivers, and lakes to ensure continual delivery of services such as regulation of floods, provision of clean air and water, formation of fertile soil, production of wild fish populations, pollination by insects, provision of habitat for diverse species and communities, and provision of recreational, aesthetic, and spiritual opportunities across the landscape (Landsberg *et al*. 2013; Mader *et al*. 2011). These investments ensure that the desired ecosystem services are continually delivered, are sustainable over long term, and are resilient to the changes such as climate and land use. In addition, recent advances in ecosystem management, public health and ecological economics literature have highlighted that there are numerous financial and other benefits associated with ecosystem services (Constanza *et al.* 1997, Ackerly *et al.* 2012, DeGroot *et al.* 2012). Some of the ecosystem services affect people in a very direct way, such as air quality improvement, urban heat island regulation, water quality regulation, noise reduction, and the improvement of physical and mental well-being. Further, there are services that will ultimately help us meet mitigation targets for GHG emissions, including the absorption of carbon (carbon sequestration by wetlands and forests) and the provision of renewable energy sources (e.g. biomass) (Mader *et al*. 2011).

Climate change has been identified as a major threat to biodiversity (Alvey, 2006; Groffman *et al*., 2014; Heller & Zavaleta, 2009; Mooney *et al*., 2009; Ryan *et al*., 2008; Staudinger *et al*., 2012; Wiens, Stralberg *et al*., 2009). It is expected that the extent and frequency of extreme events associated with climate change will reduce biodiversity, which will compromise the ecosystem structures and processes to function in its full capacity, which will challenge the delivery of many associated ecosystem services that are important for human and planetary wellbeing. Thus, it is imperative that biodiversity, at multiple scales, is maintained and conserved as the building blocks of the ecosystem to ensure functioning and resilient ecosystem.

Section 3.2.1 provides more information on the relationship between natural system components and ecosystem services in Peel Region such that implications of damage or disruption to the component on service delivery can be described as part of the vulnerability characterization (Section 6).

2.3. Natural Systems in Peel Region

As described in *The Ecosystems of Ontario, Part 1: Ecozones and Ecoregions* (MNR 2009), Peel Region is situated within the mixedwood plains ecozone, delineated as ecoregions 6E in the north (Caledon, Brampton) and 7E in the southern portions (Brampton, Mississauga). Ecoregion 6E corresponds to the Great Lakes – St. Lawrence Forest Region and the 7E corresponds to the Carolinian Forest Region, also known as Deciduous Forest Region and covers the band along Lake Erie that extends up along the edge of Lake Ontario to the City of Toronto. The climate in this ecozone is one of the mildest in Canada and has been classified in the *Humid High Moderate Temperate Ecoclimatic Region*; winters are cool and the summers are long, hot, and humid. The average annual temperature ranges from 6.3 to 9.4°C, depending on the year and location within the ecoregion. The current growing season typically ranges between 150 to 243 days, with annual precipitation falling between 776 and 1,018mm and summer rainfall is between 196 and 257 mm (MNR 2009; Auld *et al.* 2015).

Only forest remnants remain in the mixedwood plains ecozone and include dense deciduous forest covers, sparse deciduous forest, and mixed deciduous forest. Although the majority of wetlands have been eliminated, some coastal marshes, deciduous and coniferous swamps, and open fens remain scattered throughout the ecoregion (MNR 2009), including within Peel.

Land cover specifically within Peel Region is composed of approximately 12.9% natural forest, 12.6% meadow, 4.1% wetland, 0.9% bluff/beach/aquatic, 27.1% rural and 42.4% urban or urbanizing (TRCA land cover data for 2012). Peel Region also contains many kilometers of incised valley corridors with their glacial-alluvial rivers and streams networked across the landscape, including the Humber River which was designated as a Canadian Heritage River in 1999 (TRCA 2008c). The upper most headwaters of the Credit River watershed drains the

Horseshoe Moraines, Guelph Drumlin Field and Hillsburg Sandhills before passing through the escarpment and ORM, where it continues to flow downstream into Peel. Headwaters of the Credit River and Etobicoke Creek originate from the Oak Ridges Moraine (ORM), Niagara Escarpment in the north, or equivalent aquifer complex in middle Peel, and culminate as flows into Lake Ontario. Limited freshwater estuary and coastal wetland habitat, together with shoreline areas (natural and altered), connect the watersheds to Lake Ontario across the southern boundary of Peel Region.

Cold, cool and warmwater thermal regimes are supported in the network of both riverine and inland lake environments. Groundwater-fed streams, inland lakes and wetlands are unevenly distributed through the Region, sourcing water from deep regional aquifers and/or shallow, sandy covered lenses. There is a growing understanding of the important spatial and specific groundwater to surface water connections (i.e., flow paths) that support the range of stream and wetland habitats; however, gaps in knowledge that remain introduce challenges to developing and implementing strong, evidence-based water management guidance.

2.3.1. *Natural System Components and Key Ecosystem Services*

For the purposes of this assessment, the natural systems are organized into three categories: groundwater, aquatic and terrestrial with various defined components making up each system (see Table 1). Although many different ecosystem services are provided by these natural systems, some are considered more critical to the issues and needs of urban centres. Assessing vulnerabilities through the ecosystem service lens can thus be a practical way of identifying adaptation actions that address high priority municipal concerns (Morecroft *et al.*, 2012). Following this line of thinking, the key ecosystem services of interest to Peel Region were identified through stakeholder consultation and are listed below:

- **Regulating Services** for water quality, air quality, urban heat island, erosion, flood attenuation, ice and wind damage and rate of spread/establishment of invasive species;
- **Supporting Services** for habitat diversity;
- **Provisioning Services** for water use (potable and non-potable); and,
- **Cultural & Socio-Economic Services** for energy conservation and recreational experiences (e.g., reducing the need for air conditioning where trees provide sufficient shading).

Table 1: Natural Systems Components in Peel Region

Ecosystem	Component	Definition*
Groundwater System	Recharge Areas; Aquifers; Discharge Areas	Water originating as precipitation, runoff and snowmelt that infiltrates into the ground to the water table, where it is contained beneath the Earth's surface in soil pore space and rock formation fracturing. This component encompasses groundwater flow paths (e.g., interstitial/interflow, artesian/springs, hydraulic connections to rivers/wetlands), storage (e.g., deep and shallow aquifers) and functional processes (e.g., recharge/discharge, baseflow contribution, infiltration, chemical cycling and thermal regulation of surface water). This also includes consideration for groundwater chemistry more from an ecological perspective, not drinking water context.
Aquatic System	Rivers and Streams	Watercourses (e.g. river, stream, creek, headwaters) of any temperature regime (ranging from cold through cool into warm water) that are fed from, or start with a permanent or periodic natural source of groundwater discharging at surface; or where overland surface flow accumulates and begins to flow in a particular/defined direction and develops a defined channel. These have a bed and banks or sides, and usually discharge into some other watercourse or body of water. Watercourses need not flow continually as they may periodically or seasonally be dry.
	Valley Corridors	Apparent or Confined: Depressional features associated with a river or stream, with defined slopes extending from the long term stable slope projected from the predicted stable toe of slope. Note: this includes floodplain areas and river or stream riparian wetlands; however, watercourses themselves are excluded as they are defined as Rivers and Streams distinctly. Not Apparent or Unconfined: Depressional features associated with a river or stream system, with ill-defined slopes extending from the maximum extent of the predicted meander belt allowance of the river or stream. Note: this includes floodplain areas and river or stream riparian wetlands; however, watercourses themselves are excluded as they are defined as Rivers and Streams.
	Lake Ontario (Nearshore)	This zone is defined by the area approximately 5 km offshore where the water supply intakes are located, and the highest recorded maximum monthly mean / year level records on Lake Ontario (e.g. 75.73 a.s.l recorded in 1973).
	Freshwater Estuaries	We normally think of estuaries as places where rivers meet the sea, but this is not always the case. Freshwater or Great Lakes-type estuaries do not fit the definition of a brackish water estuary where freshwater and seawater mix (NOAA 2008). Freshwater estuaries are semi-enclosed areas of the Great Lakes in which the waters become mixed with waters from rivers or streams. Although these freshwater estuaries do not contain saltwater, they are unique combinations of river and lake water, which are chemically distinct. Unlike brackish estuaries that are tidally driven, freshwater estuaries are storm-driven. In freshwater estuaries the composition of the

Ecosystem	Component	Definition*
		water is often regulated by storm surges and subsequent seiches (vertical oscillations, or sloshing, of lake water). While the Great Lakes do exhibit tides, they are extremely small. Most changes in the water level are due to seiches, which act like tides, exchanging water between the river and the lake (NOAA 2008).
	Inland Lakes and Ponds	Naturally occurring enclosed bodies of standing water with a wide diversity in size, configuration, water chemistry, and biota.
Aquatic & Terrestrial Systems	Wetlands (Riparian, Coastal & Upland)	Lands that are seasonally or permanently flooded by shallow water as well as lands where the water table is close to surface; in either case the presence of abundant water has caused the formation of hydric soils and has favoured the dominance of either hydrophilic or water tolerant plants. The four major types of wetlands are swamps, marshes, bogs, and fens. This includes riparian areas of lakes (i.e. coastal wetland) and shallow aquatic ponds where water is known to be less than 2m deep. For the purpose of this study, treed swamps are excluded where identified as defined under Natural Forest; river or stream riparian wetlands are excluded where identified as defined under Valley Corridor.
Terrestrial System	Bluffs	A cliff, headland, bank or hill with a broad, steep slope. Bluffs are significant geological features resulting from the accumulation of sedimentary deposits and formed by the natural processes of wind and water erosion.
	Natural Forests	All trees, shrubs, and understory vegetation, and the soil that sustains them, which are located on public or private lands where the unit of management is the forest stand or vegetation community and landscape ecology of silvicultural practices are applied (e.g., woodlands and natural areas). It includes all coniferous, mixed, deciduous forest communities, plantations, successional lands, and treed swamps (unless otherwise defined as wetlands).
	Urban Forests	All trees, shrubs, and understory plants and the soil that sustain them that are located in public or private property within an urban setting where the unit of management is the individual trees and standard arboricultural practices are applied (i.e. street trees, backyard trees).
	Meadows and Grasslands	Meadows are the land cover type that is in a state of natural regeneration after natural or anthropogenic disturbances. This includes abandoned field, cultural meadows, natural tall-grass prairie, sand barren and sometimes meadow marsh.
	Shrublands	A given vegetated area (>10% ground cover by woody vegetation) is considered shrubland if shrubs compose either ≥ 10% of ground cover; or > ⅓ of the total vegetation cover. Shrubs are considered woody perennial plants, both evergreen and deciduous, that have a relatively low growth habitat, and are generally multi-stemmed, rather than having one bole. They differ from a tree by their low stature (generally < 10 m) and non-treelike form

*Adapted from select literature, TRCA and CVC staff expertise, and the TRCA *Living City Policies* (2014). See Appendix A for a glossary of terms that includes more details such as the literature sources from which these were adapted from.

2.3.2. *Current Influences and Anthropogenic Stressors*

To varying extents, all four major watersheds within Peel Region are under stress from human activities. Urbanization poses many harmful effects on water balance, water quality, natural cover, aquatic and terrestrial communities, and air quality. These effects are significant, pervasive and include increased surface runoff, warmer summer stream temperatures, more water pollution, greater annual flow volumes in rivers and streams, increased erosion and sedimentation, channel instability, smog, and losses of species diversity (TRCA 2008c). While urbanization is a major current stressor, another (historical and current) stressor is aggregate extraction (i.e. Caledon Pits) where these activities have the potential to flatten the water table, an affect that may become exacerbated by climate change

In terms of the aquatic system, these impacts are together known as an 'illness' termed Urban Stream Syndrome (USS); in areas without proper stormwater management (SWM) (i.e., older neighbourhoods in Peel Region), the volume of stormwater is high and runoff collects sediment, nutrients, heat and contaminants as it travels across hard surfaces, causing streams to function more like sewers (Wallac *et al*., 2013). Direct relationships between road density (used as surrogate of urbanization) and symptoms of USS were identified for streams in the TRCA jurisdiction (Wallace *et al.*, 2013). The development of roads has also been shown to alter both groundwater and stream flow, which is in turn expected to have direct impacts on some forest and wetland vegetation (O'Reilly *et al*., 2010).

Within the TRCA portion of Peel, all upland forest connections have been severed in the City of Brampton and the southern portion of the Town of Caledon, and more natural vegetation is scheduled for removal, according to current urban development plans (TRCA 2008c). Current stressors to wetlands reported for the Credit River watershed include habitat removal, nutrient enrichment, organic loading, contaminants (e.g. road salt), sedimentation, turbidity, thermal changes, dehydration, inundation, exotic species, habitat fragmentation and unsustainable use (e.g. water taking) (K. O'Reilly *et al*. 2010). Remaining wetlands in the Humber River and Etobicoke Creek watersheds face similar negative influences.

Overall, the extent and configuration of natural versus urban land cover in the landscape has the ability to alter ecosystem processes, nutrient availability, water availability, and dispersal. These changes can then alter flora and fauna communities across tablelands, through valley corridors and in the rivers and streams that make up the natural systems in Peel watersheds.

Agricultural practices of land clearing, water taking, fertilizer and pesticide application, and livestock management may also be impacting water quantity and quality in local stream reaches. Existing open and tile drains, installed in past decades, contributed to wetland habitat loss and may still influence drainage to headwater features today.

Invasive species, both aquatic and terrestrial (e.g., invasive plants, insects, fish), and diseases present additional stressors to community resilience, which are more evident in, but not limited to, urban areas. Making recent headlines is the Emerald Ash Borer or EAB (*Agrilus planipennis)* which has had devastating impacts on ash trees in Peel Region, the GTA, and across southern

Ontario. Tolerant of a wide range of growing conditions, ash trees (*Fraxinus* species) are common along streets, in parks and throughout natural areas in the Cities of Mississauga and Brampton. Approximately 3.2 million trees (9 percent of the total tree population) in the GTA study areas, which includes Peel Region, may be lost to the impact of this beetle (TRCA 2015c).

Asian long-horned beetle (*Anoplophora glabripennis)*, beech bark disease (*Neonectria faginata*), and butternut canker (*Sirococcus clavigignenti-juglandacearum*) are relatively recent non-native threats of concern; while chestnut blight (*Cryphonectria parasitica*), Dutch elm disease (*Ophiostoma novo-ulmi*) and gypsy moth (*Lymantria dispar dispar*) have been impacting forests in Peel and the surrounding GTA for quite some time. Once introduced, the spread of these organisms is often accelerated or caused by the human movement of firewood and other infested material.

2.4. **Current Policies, Planning and Adaptation Frameworks**

The following sections provide a list of existing legislative planning tools, available management plans and strategies aimed to protect, enhance and restore natural systems that partners in Peel Region are using to proactively assess and reduce vulnerabilities to climate change.

2.4.1. *Policies*

- Ontario *Provincial Policy Statement* (2014)
- *Ontario Water Resources Act* (2011)
- *Aggregate Resources Act* (2009)
- *Niagara Escarpment Act (currently under review)*
- *Oak Ridges Moraine Conservation Act (currently under review)*
- *The Greenbelt Act (currently under review)*
- *Places to Grow Act* (2005)
- *Ontario Regulation 166/06* for conservation authorities, provide increased protection for landforms, environmental resources (2006)
- *Living City Policies* (TRCA 2013)
- Watershed Planning and Regulations Policies (CVC 2010)
- *Peel Region Official Plan* (1996, with subsequent 5 –year review periods)
  - *Peel-Caledon Significant Woodlands and Significant Wildlife Habitat Study* (2009)
  - *Natural Heritage Policy Review Discussion Paper* (2008)
- Area Municipal Official Plans (various)

2.4.2. *Natural Heritage System Protection and Planning*

- Greenbelt Plan
- Oak Ridges Moraine Conservation Plan
- Niagara Escarpment Plan

- CA Watershed and Resource Plans (e.g., Humber River Watershed Plan, TRCA 2008; Integrated Watershed Restoration Strategy, CVC 2010)
- TRCA Terrestrial Natural Heritage System Strategy (TRCA, 2007)
- Water Balance for Protection of Natural Features (TRCA, 2012)
- CVC Natural Heritage System Strategy (CVC 2015a; CVC 2015b)
- Watershed-based Fisheries Management Plans
- Peel Region's Urban Forest Strategy (2011)
- Town of Caledon Urban Forest Study (2011)
- Town of Caledon's Environmental Progress Action Plan (2011)
- Town of Caledon's Woodlands By-Law (2004)
- City of Brampton Urban Forest Study (2011)
- City of Brampton's Woodlot Conservation By-Law (2012)
- City of Brampton's Grow Green Environmental Master Plan (2013)
- City of Brampton's Natural Heritage and Environmental Management Study (2014)
- City of Mississauga Urban Forest Study (2011)
- City of Mississauga's Natural Heritage and Urban Forest Strategy (2014)
- City of Mississauga's Credit River Parks Strategy (2013)

2.4.3. *Adaptation Framework*

The Partnership adopted the International Council for Local Environmental Initiatives (ICLEI) adaptation planning framework (Figure 3) to assist with the assessment of vulnerabilities associated with climate change across sectors. Partners are in process of transitioning from Milestone 2: Research to Milestone 3: Plan.

Figure 3 represents a conceptual framework of the five milestones identified as the key steps of adaptive management, which is specifically intended to inform municipal planning (ICLEI 2010). This framework shows the cyclical nature of adaptive management and the importance of research as an input to planning phase. Milestone 2 of the ICLEI framework (i.e. "Research" step in Figure 3) 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 2010).

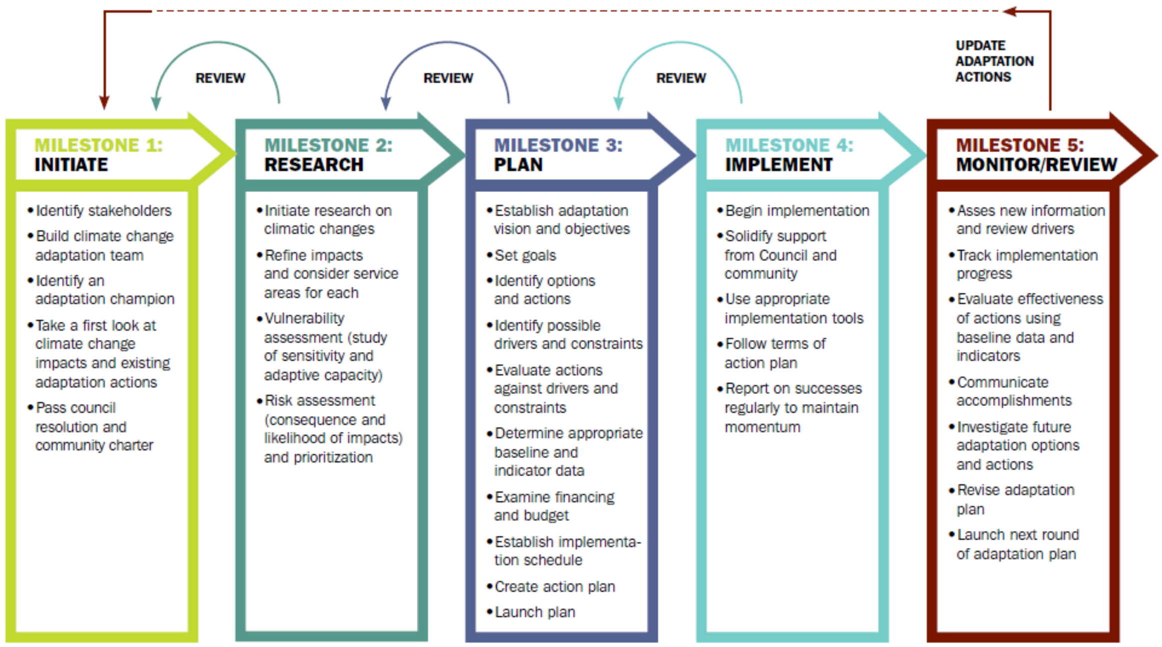


Figure 3: Framework for Adaptation Planning (from ICLEI 2010)

3. METHODOLOGY

3.1. Overall Approach

In order to understand the meteorological, biophysical and human factors that influence the effects of climate change and to determine impacts and opportunities for natural systems in Peel Region, the overall approach was iterative and evidence based. The project was also guided by a Core Advisory Team (CAT) that represented technical expertise, broader experience in vulnerability assessment and partner stakeholders. The following organizations participated on the CAT: Peel Region, TRCA, CVC, the Ministry of Natural Resources and Forestry (MNRF), Ontario Centre for Climate Impact and Adaptation Research (OCCIAR), University of Waterloo and the OCC.

A Project Charter was developed with the CAT and Figure 4 provides a detailed overview of the steps followed in this assessment, which are consistent with assessments completed in Peel Region on themes of agricultural production, public health, and the community assets in Port Credit. While Figure 4 presents the project phases as linear, it should be noted that certain steps proceeded in tandem and many involved iterations to incorporate stakeholder feedback and input.

Overall, the methodology was based on provincial guidance for conducting ecosystem-based climate change vulnerability assessments (Gleeson *et al.*, 2011). Similar assessment approaches have been applied specifically to natural systems while incorporating ecosystem services (Ackerly *et al.*, 2012; Finnish Environment Institute, 2011; Landers & Nahlik, 2013;

Landsberg, Treweek, Stickler, Henninger, & Venn, 2013; Mader, Patrickson, Calcaterra, & Smit, 2011; Millenium Ecosystem Assessment, 2005; Nelitz, Boardley, & Smith, 2013). Sections 3.2 through 3.7 provide more details on how each step was completed.

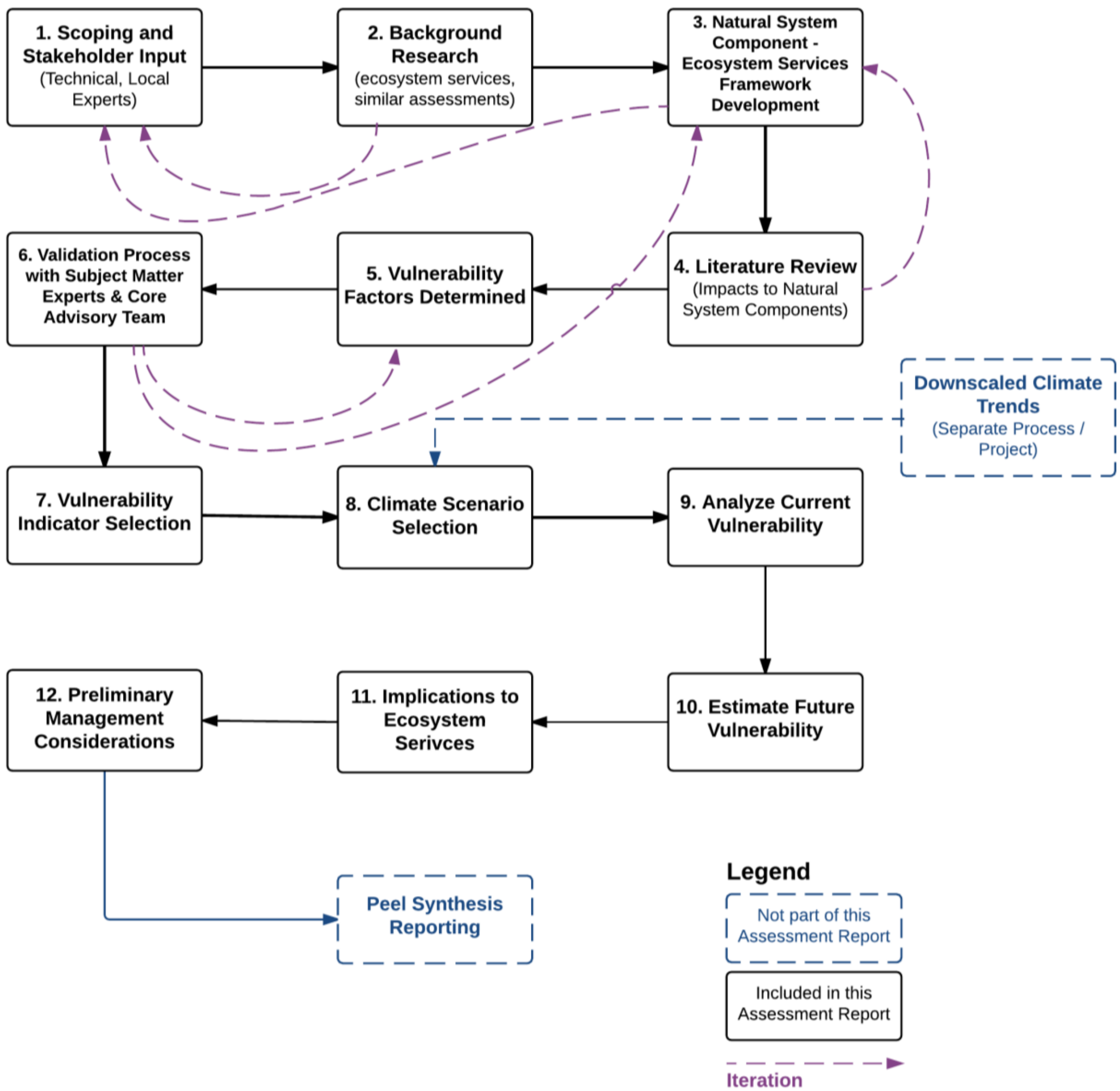


Figure 4: Flow Chart Illustrating the Methodology Followed in this Assessment.

3.2. Scoping the Analysis and Stakeholder Input

Given that the natural systems is intrinsic to a diverse range of sectors in Peel Region, and that decisions made at the site level can influence the natural systems at the landscape scale (Klausmeyer *et al.*, 2011), a critical first step in a vulnerability assessment is setting the context and scope for the study (IPCC 1994). Accordingly, the scoping was led by TRCA, guided by the CAT and involved two workshops:

1. Broad Stakeholder Engagement Workshop on November 13, 2013

2. Technical Stakeholder Workshop on May 8, 2014

The November 2013 workshop launched the project and received input from a broad group of stakeholders on the importance of natural systems and what ecosystem services were most valued by participants living and/or working in Peel Region. Prominent services were initially identified as: flood attenuation, mitigation of urban heat island, access to green space/trails and supporting healthy, native species diversity in urban areas.

The May 2014 workshop convened participants from the CAT as well as technical staff from TRCA and CVC to identify the natural system components to be used in the assessment. The concept of linking natural systems to ecosystem services was further refined and followed up with a focused literature review to identify best practice in defining ecosystem services (e.g., Mader *et al.*, 2011; Millennium Ecosystem Assessment, 2005).

Using the input from both workshops and the literature review, a framework that linked key ecosystem services to natural systems components was developed and reviewed by the CAT and technical stakeholders. This framework proposes how strong (direct or indirect) are the links between natural systems components and ecosystem services; and was later used to guide the extensive literature review to determine: 1) climate change and extreme weather impacts on the natural systems components, 2) relevant vulnerability factors, and 3) consequences to key ecosystem services.

Stakeholder engagement and input was significantly used in defining the project scope and in conducting the vulnerability analysis. This was accomplished through a combination of project meetings, formal subject matter expert interviews and focus-group workshops. A summary of the key stakeholder engagement processes conducted throughout the duration of this assessment is presented below (Table 2).

Table 2: Timeline of Stakeholder Engagement within the Natural Systems Vulnerability Assessment

Date	Purpose	Description
April - July, 2013	Determining Interest in Project Undertaking	The TRCA project manager facilitated 2 meetings between potential agency partners interested in participating in a vulnerability assessment on natural systems, including initial discussions of required resources, parties involved, and developing a Project Charter.
Sept 2013	Initial Core Advisory Team (CAT) Meeting	TRCA Project Manager convened the first CAT meeting to discuss a process to scope the project; initial CAT members included: Peel Region, TRCA, CVC, OCC, MNRF, and OCCIAR

Date	Purpose	Description
Nov 2013	Broad Stakeholder Workshop	First workshop to introduce the project and receive input from a broad group of stakeholders on the importance of natural systems and what ecosystem services were most valued by participants living and/or working in Peel Region.
April 2014	Project Charter	Working with the CAT, the Project Charter was written and approved.
May 2014	Technical Stakeholder Workshop	The project team facilitated a workshop with members of TRCA, CVC, MNRF, OCCIAR and Peel Region to scope what 'natural systems' should include and which ecosystem services are most relevant (or a framework to conduct literature review). This date also marks the first meeting of the Core Advisory Committee, which provided oversight and input throughout the duration of the assessment.
Oct-Nov, 2014	Subject Matter Expert Interviews	A total of 19 subject matter experts were consulted over this time period from a variety of academic, government and non-government organizations. The purpose of these was to validate literature review being conducted on the natural systems and climate change.
March 2015	Peel Adaptation Municipal Working Group	The project team presented preliminary findings, methods and objectives associated with the natural systems assessment to the Peel Adaptation Municipal Working Group, including highlighting alignment with other ongoing vulnerability assessments on agriculture and in Port Credit.
Jan 2014 - Aug 2016	Ongoing CAT Consultation Meetings	The project team regularly checked in with the CAT on scope changes as they arose, decisions pertaining to level of effort and key findings. Meetings occurred six times over the course of this timeframe.

3.2.1. *Natural Systems Components and Ecosystem Services Framework*

A milestone associated with the scoping stage of this assessment was the completion of a framework for literature review. This includes identifying what components are within scope of Peel's natural systems and which ecosystem services are most (and least) strongly tied to each component. Table 3 presents components of the Natural Systems (NS) and relates each to the corresponding Ecosystem Services (ES) they produce. ES are categorized in this report as Regulating, Provisioning, Cultural and Socio-Economic based on similar frameworks (e.g., Landers & Nahlik, 2013; Landsberg *et al*., 2013; Mader *et al*., 2011; Millennium Ecosystem Assessment, 2005a; Mooney *et al*., 2009; Staudinger *et al*., 2012; Troy & Bagstad, 2009).

As discussed in Section 2.2. some NS components are more complex in structure and function and also provide a variety of ecosystem services (e.g. wetlands), whereas others are less complex and unique in providing a fewer number of services (e.g. bluffs).Table 3 highlights the major ES provided by the NS components but does not break down the NS components into their specific structural attributes and functions that actually lead to the production of the ES. The general relationship between the NS component and ES is based largely on the broader literature.

The last column of Table 3 highlights the human and non-human (aquatic and terrestrial) beneficiaries of the ES. The intent is to highlight who received the direct benefits of the ES provided by the NS components When aquatic and terrestrial biota are listed as beneficiary, it is also indicating that these biota are vital components of the ecosystem that contribute to the physical, biological, and chemical processes to deliver functions that provide the specific ES. This approach ensures that both structural and functional aspects of NS components are captured in this methodical framework, which is important for resilient and functioning ecosystems.

Table 3 does not present ES and NS components in any order of importance and no relative weighting has been applied. Instead, it is used to guide the research process and in understanding where linkages between NS component and ES exist, and how important these linkages are in providing benefits to humans under a changing climate.

Table 3: Natural Systems Components and Ecosystem Services: Framework for Project Scoping and Literature Review

Ecosystem Services	Aquatic System					Terrestrial System				Beneficiary (those *directly* benefitting from the ecosystem service)
	Rivers, Streams and Valley Corridors	Lake Ontario and Freshwater Estuaries	Inland Lakes / Ponds	Groundwater	Wetlands	Bluffs	Natural Forests	Urban Forests (natural areas in urban envelope & street trees)	Meadows, Grasslands and Shrublands	
Legend Black Services: identified as key importance based on input from the project's core advisory team (CAT), Peel Region staff and additional stakeholders, and thus have been given more effort throughout the literature review. Green Services: identified as relevant services but as secondary to Peel; preliminary investigation only and not analyzed in detail. "Yes" vs "No" - A link exists (yes) or not (no) between component and service. * Minor (indirect) link is present ** A direct link is present *** Multiple direct links between component and service present										
Regulating Services										
Water quality regulation (of runoff contaminants and assimilation of wastewater)	**Yes (**)**	**Yes (***)**	**Yes (***)**	**Yes (***)**	**Yes (***)**	**No**	**Yes (**)**	**Yes (**)**	**Yes (*)**	Humans, Aquatic, and Terrestrial life
Air quality regulation (uptake of pollutants)	**Yes (**)**	**No**	**No**	**No**	**Yes (***)**	**No**	**Yes (***)**	**Yes(***)**	**Yes(**)**	Humans, Aquatic, and Terrestrial life
Regulation of Urban Heat Island Effect	**Yes(*)**	**Yes(***)**	**Yes(**)**	**No**	**Yes(***)**	**No**	**Yes (***)**	**Yes(***)**	**Yes(**)**	Humans, Aquatic (e.g. lichens), terrestrial (e.g. plants unable to adapt) - not all species benefit from cooling: species with southern affinities are finding shorter winters an opportunity. Historically local species, especially those with northern affinities, benefit from urban heat regulation.
Regulation of erosion (soil, sediment)	**Yes(***)**	**Yes(***)**	**Yes(***)**	**No**	**Yes(**)**	**Yes (**)**	**Yes(***)**	**Yes(***)**	**Yes(*)**	Humans, Aquatic (e.g. shoreline animals and in stream life), Terrestrial (shoreline plants)
Moderation of extreme wind damage	**No**	**Yes(**)**	**No**	**No**	**No**	**Yes(**)**	**Yes(***)**	**Yes(**)**	**No**	Humans and Terrestrial (e.g. habitat loss is reduced for species)
Moderation of ice damage (healthy trees may moderate the amount of ice damage)	**Yes(*)**	**No**	**No**	**No**	**No**	**No**	**Yes(***)**	**Yes(**)**	**No**	Humans
Flood attenuation	**Yes(***)**	**Yes(***)**	**Yes(***)**	**Yes(**)**	**Yes(***)**	**No**	**Yes(***)**	**Yes(**)**	**Yes(**)**	Humans
Moderation in rate of spread/establishment of Invasive species (non-native) and disease control (i.e. EAB)	**Yes(**)**	**Yes(**)**	**Yes(**)**	**No**	**Yes(**)**	**No**	**Yes(**)**	**Yes(**)**	**Yes(**)**	Humans, Aquatic (e.g. fish), Terrestrial (e.g. trees)
Soil production and quality regulation (texture, moisture, nutrients, amount)	**Yes(**)**	**Yes(**)**	**Yes(**)**	**No**	**Yes(***)**	**No**	**Yes(***)**	**Yes(**)**	**Yes(*)**	Humans, Aquatic, Terrestrial life
Fire suppression	**No**	**No**	**No**	**No**	**No**	**No**	**Yes(***)**	**Yes(*)**	**Yes(*)**	Humans and Terrestrial (e.g. habitat loss is reduced for species)
Provision of Shade (health)	**No**	**No**	**No**	**No**	**Yes(*)**	**Yes (**)**	**Yes(***)**	**Yes(***)**	**No**	Humans and Aquatic

Ecosystem Services	Aquatic System					Terrestrial System				Beneficiary (those *directly* benefitting from the ecosystem service)
	Rivers, Streams and Valley Corridors	Lake Ontario and Freshwater Estuaries	Inland Lakes / Ponds	Groundwater	Wetlands	Bluffs	Natural Forests	Urban Forests (natural areas in urban envelope & street trees)	Meadows, Grasslands and Shrublands	
Carbon storage and sequestration	No	Yes(**)	Yes(*)	No	Yes(**)	Yes (**)	Yes(***)	Yes(***)	Yes(**)	Terrestrial species (e.g. plants, trees)
Pollination	No	No	No	No	Yes(***)	No	Yes(**)	Yes(**)	Yes(***)	Terrestrial species (flora and pollinators)
Cultural & Socio-Economic Services										
Recreational (hiking, cycling, swimming, angling, bird-watching, wildlife viewing, paddling, camping, etc.)	Yes(***)	Yes(***)	Yes(**)	No	Yes(***)	Yes(***)	Yes(***)	Yes(***)	Yes(**)	Humans
Mental, emotional, spiritual health (passive experience)	Yes(***)	Yes(***)	Yes(***)	No	Yes(***)	Yes(***)	Yes(***)	Yes(***)	Yes(***)	Humans
Outdoor education and learning	Yes(***)	Yes(***)	Yes(***)	No	Yes(***)	Yes(**)	Yes(***)	Yes(***)	Yes(**)	Humans
Tourism (e.g., waterfront)	Yes(***)	Yes(***)	Yes(**)	No	Yes(***)	Yes(***)	Yes(***)	Yes(***)	Yes(**)	Humans
Aesthetic appreciation and inspiration for culture/art/design	Yes(***)	Yes(***)	Yes(***)	No	Yes(***)	Yes(***)	Yes(***)	Yes(***)	Yes(**)	Humans
Increased property value	Yes(**)	Yes(**)	Yes(**)	No	Yes(**)	Yes(**)	Yes(**)	Yes(**)	Yes(**)	Humans
Provisioning Services										
Energy use and conservation	Yes(*)	No	No	No	Yes(*)	No	Yes(***)	Yes(***)	Yes (*)	Humans
Water use (potable)	Yes(***)	Yes(***)	Yes(*)	Yes(***)	Yes(**)	No	No	No	No	Humans, Aquatic and Terrestrial life
Water use (non-potable)	Yes(***)	Yes(***)	Yes(**)	Yes(***)	Yes(*)	No	No	No	No	Humans and Terrestrial (crops, plants)
Provision of Baseflow (e.g., during drought)	Yes(***)	Yes(**)	Yes(*)	Yes(*)	Yes(*)	No	No	No	No	Humans and Aquatic species
Oxygen	Yes(**)	No	No	No	Yes(**)	No	Yes(***)	Yes(***)	Yes(**)	Humans, Aquatic and Terrestrial life
Food hunting (not including angling) and gathering (dandelions, fiddleheads, etc.)	No	No	No	No	Yes(**)	No	Yes(***)	Yes(**)	Yes(*)	Humans
Medicinal resources	No	No	No	No	Yes(**)	No	Yes(**)	No	Yes(**)	Humans
Building Materials (Timber, fiber, fuel, etc.)	No	No	No	No	Yes(**)	No	Yes(***)	No	Yes(***)	Humans
Supporting Services										
Habitat diversity	Yes(***)	Yes(***)	Yes(***)	Yes(*)	Yes(***)	Yes(**)	Yes(***)	Yes(***)	Yes(**)	Aquatic and Terrestrial species
Maintenance of genetic diversity (range)	Yes(***)	Yes(***)	Yes(***)	Yes(*)	Yes(***)	Yes(*)	Yes(***)	Yes(**)	Yes(**)	Aquatic and Terrestrial species
Primary production	Yes(***)	Yes(***)	'Yes(***)	No	'Yes(***)	No	'Yes(***)	Yes(**)	Yes(*)	Aquatic and Terrestrial species

3.3. **Literature Reviews and P-CRAFT**

Throughout the duration of this project, literature review was conducted three times, each with a different duration and objective based on where it occurred throughout the project methodology. The first round of literature review was associated with project scoping (Step 2 in Figure 4), and encompassed a brief review of existing vulnerability assessment frameworks, guidelines and assessments for comparison. The second involved substantial systematic research on climate impacts to natural systems components and the identification of vulnerability factors based on the ecosystem service-natural systems component framework that was created from scoping the assessment (Steps 3 and 4 in Figure 4). This literature review is elaborated in greater detail below. Finally, a third literature review was conducted as part of characterizing current vulnerability (Step 9 in Figure 4) and involved scanning numerous current condition reporting documents. This third literature review is described in greater detail in section 3.7.

The following keywords were used in the literature review search, and represent the system components, climate variables and ecosystem services under consideration:

- Vulnerability assessment, ecosystem services
- Groundwater, wetlands, freshwater estuaries, rivers, streams and valley corridors, lake Ontario, inland lakes and ponds, bluffs, natural forests, urban forests, meadows, grasslands and shrublands
- Precipitation, rain, rainfall, drought, temperature, extreme precipitation, extreme temperature, extreme heat, extreme wind, weather, extreme weather, climate change, and ice storms
- Air quality regulation, water quality regulation, urban heat island mitigation, flood attenuation, recreational services, water provisioning, erosion regulation, moderation of extreme wind, energy conservation, invasive species moderation, moderation of ice damage, habitat diversity

Databases used were:

- Springer Link
- Google Scholar
- Web of Science
- Science Direct
- JSTOR Archival Journal

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

- Toronto and Region Conservation Authority (TRCA)
- Credit Valley Conservation (CVC)
- Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR)
- Environment Canada (EC)

- US Environmental Protection Agency (US EPA)
- Ministry of Natural Resources and Forestry (MNRF)
- Ministry of Environment and Climate Change (MOECC)
- World Resources Institute (WRI)
- The Economics of Ecosystems and Biodiversity (TEEB)
- International Council for Local Environmental Initiatives (ICLEI)

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. Two completed example P-CRAFT tables are provided in Appendix B: one for the wetlands component and one for the groundwater system.

3.4. Validation Process with Subject Matter Experts

Preliminary findings from literature included a suite of climate impacts for each component in the natural systems of Peel Region, factors influencing the vulnerability of each component, and which ecosystem services may be disrupted based on the component-ecosystem services framework table (Table 3). These findings then were cross-validated using a series of formal subject matter expert interviews conducted from October to November 2014. Table 4 summarizes those interviewed, their affiliation and area of expertise. Following the completion of each interview, information was inputted into P-CRAFT tables in the same manner as literature findings, and was used to revise information collected up to this point.

Table 4: Subject Matter Experts Consulted in the Natural Systems Vulnerability Assessment

Name	Title	Affiliation	Area of Expertise
Dr. Sapna Sharma	Associate Professor	York University	Inland Ponds and Lakes
Dr. Brian A. Branfireun	Assoc. Professor & Canadian Research Chair	Western University	Wetlands, Rivers & Streams, Lake Ontario
Jing Yang	Graduate Student	University of Guelph	Forest
Cindy Chu	Contract Researcher (formerly Trent U)	University of Toronto	Rivers and Streams, Wetlands
Dr. Tenley Conway	Associate Professor	University of Toronto	Urban Forest, Biogeography, Land use modeling
Don Ford	Senior Manager	TRCA	Groundwater
Dr. Danijela Puric-Mladenovic	Associate Professor	University of Toronto & MNRF	Urban Trees, Forest, Private Woodlots
Steve Colombo	Research Scientist	MNRF (Sudbury)	Forest
Hans Durr, Phillipe Van Cappellen	Research Assistant Professor,	University of Waterloo	Rivers, streams, groundwater, ponds, Lake

Name	Title	Affiliation	Area of Expertise
	Canada Excellence Research Chair in Ecohydrology (respectively)		Ontario, Wetlands
Dr. Bruce MacVicar	Assistant Professor	University of Waterloo	Streams & Rivers, Valley Corridors, Freshwater Estuaries
Scott MacRitchie	Senior Hydrogeologist / Climate Change Vulnerability Specialist	MOECC, Environmental Monitoring and Reporting Branch (EMRB)	Groundwater
Eleanor Stainsby	Water Modeller, Sportfish & Biomonitoring Unit	MOECC, Environmental Monitoring and Reporting Branch (EMRB)	Inland lakes and ponds, Lakes
Lionel Normand	Project Manager	TRCA	Wetlands (inland and Costal), Forests, Meadows, Grasslands, Bluffs
Meaghan Eastwood	Project Manager	TRCA	Urban Forest, Forest
Ralph Toninger	Sr. Project Manager	TRCA	Wetlands (inland and coastal), Forests, Meadows, Bluffs
Sue Hayes	Project Manager, Terrestrial Field Inventories	TRCA	Forests, Meadows, Grasslands, Bluffs, Wetlands (inlands & coastal)
Gavin Miller	Biologist (Floral) (Don/Highland)	TRCA	Forests, Meadows, Grasslands, Bluffs, Wetlands (inlands & coastal)
Natasha Gonsalves	Flora Field Assistant	TRCA	Forests, Meadows, Grasslands, Bluffs, Wetlands (inlands & coastal)
Paul Prior	Fauna Biologist	TRCA	Forests, Meadows, Grasslands, Bluffs, Wetlands (inlands & coastal)
Gary Bowen	Watershed Specialist	TRCA	Lake Ontario and nearshore

3.5. Identifying and Selecting Vulnerability Factors and Indicators

Given that the natural systems across Peel Region are incredibly diverse, so too will be the vulnerability of the natural components in a given area. A natural component, depending on its spatial location will be defined by different physical, chemical and biological factors. For instance, a component with insufficient tree canopy has less thermal regulation through shading and thus may be more vulnerable to increases in temperature or extreme heat events whereby biota may be stressed or lost. In this case, tree canopy is a vulnerability factor which, if considered high enough in a component, can reduce its vulnerability. 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 for effective ongoing adaptation monitoring and evaluation (Gleeson *et al*. 2011).

3.5.1. *Vulnerability Factors*

In this study, we use the concept of "Vulnerability Factors" (VFs) to represent a quality or characteristic of a natural component to be more or less vulnerable to a given climatic condition or event. Such factors can be physical, chemical or biological aspects of the natural environment. Given that many of the impacts of interest result from a series of intermediate processes, an important part of understanding vulnerability is the elucidation of these, which are termed "Intermediate Impacts", for this study. Vulnerability Factors and Intermediate Impacts were elucidated through a systematic literature review of existing studies on the interactions between climate and the natural systems using P-CRAFT templates. Table 5 summarizes the rationales behind each vulnerability factor identified as part of this vulnerability assessment. It should be noted that urbanization and some other stressors will impact all factors and exacerbate many of the vulnerabilities described, although this is not explicitly described in the rationales in Table 5.

A more comprehensive table is available in Appendix E, which describes more details and distinguishes between the *Natural State* (assuming no vulnerabilities caused by urbanization or anthropogenic influences) and the *Contextual State* (exacerbated vulnerabilities as a result of urbanization and anthropogenic influences). This appendix also identifies literature sources from which each vulnerability factor was developed.

Table 5: Vulnerability Factors and Rationales

Vulnerability Factor	Rationale
Physical Factors	
Area to Depth Ratio	**What is It**: The depth and surface area of standing water in a component, including the recharge area associated with the groundwater system. **Why does it Matter:** In components with shallow water depths and relatively large surface areas, increases in evaporation rates and heat loading may decrease thermal suitability for species (i.e. fish) thereby impacting habitat diversity, decreasing water quality through the release of phosphorus, and increasing primary production thereby producing algal blooms.
Aquifer Maintenance	**What is It:** The degree to which the surface is maintaining the groundwater system through infiltration of water into soils and recharge into aquifer systems. **Why does it Matter:** It is not known whether high levels of recharge occurring in one area is supplying the aquifers present directly below the surface in that area; however, it is assumed that high (local) areas of recharge are important for maintaining the health of the groundwater system in Peel Region as a whole. Where soils have limited infiltration capacity, or recharge becomes more variable under a changing climate (increases overall but decreases in summer), aquifer maintenance may change.
Degree of Connectivity	**What is It**: The hydraulic, spatial or functional connection between components such that the component is supported by baseflow, adjacent habitat, adequate gene flow, etc. More specifically, this refers to the size, shape and matrix characteristics of a habitat patch, which are important for supporting community diversity, shaping species life cycles and maintaining metapopulations. **Why does it Matter:** Connectivity concerns can arise during hot, dry summers when baseflow contributions may be less, and surface water is lost to greater rates of evaporation, especially if riparian vegetation and/or canopy cover is lacking. Low flows or water depths through culverts, for example, may limit fish passage between aquatic components. In isolated terrestrial components, increasing temperatures may reduce community diversity through increased 'edge effects', may constrict gene flow, reduce the maintenance of metapopulations and shift species life cycles.
Urban Forest Canopy	**What is It:** The degree to which tree canopy characterizes a component (e.g. meadows, grasslands, wide rivers, which have naturally low canopy cover). **Why does it Matter:** Urban forest canopy, where present, intercepts in-coming solar radiation and helps regulate interior habitats, ground and water temperatures through shading. Without this regulation, evaporation rates from surficial soils can increase; promoting drying and water stress in plants and waters can warm beyond thermal tolerances for fish.
Pervious Cover	**What is It:** The presence of sufficient natural, pervious cover in a component (e.g. thick, well drained soils, vegetated areas). **Why does it Matter:** In components with inadequate natural, pervious cover, increasing temperatures and drought lead to higher evaporation rates and thus reduce the amount of water infiltrating into the ground (disrupting the hydrologic cycle). This vulnerability of a component varies depending on the soil type present (i.e. soils considered well drained versus those that are very poorly drained).

Vulnerability Factor	Rationale
Rooting Depth and Strength	**What is It:** The characteristics of vegetation and tree roots in a component: particularly, rooting depth and strength. **Why does it Matter:** In general, deeper and stronger rooting structures have the potential to store more water, improve infiltration, stabilize banks and soils, and buffer impacts from extreme events. The groundwater system is an exception, where deeper roots may actually reduce recharge and depending on the flow regime, smaller roots may be preferable. This factor relates to soil drying, the water table and water stress issues; and more generally the water interaction with rooting area will likely be altered due to climate change. It is important to note that change may not all be linear, where water shortages could drastically change rooting depth and plant storage.
Topography and Grade	**What is It:** The characteristics of topography (elevation) and grade (slope) in a component. **Why does it Matter:** Components which are located in regions of topographic highs or with very flat slopes may be more vulnerable to drying as a result of increasing temperature, evaporation and ET rates. Components with a steep slope, on the other hand, may be vulnerable to precipitation shifts due to infiltration limits being reached sooner, to increased overland flow, and to erosion thresholds being reached.
Water Taking and Wastewater Assimilation	**What is It:** The presence of water taking in a component, particularly the groundwater system; or the presence of wastewater treatment facilities in a component whereby wastewater assimilation capacity in the rivers (baseflow) may be limited due to water supply. **Why does it Matter:** In a component that supports water provisioning or wastewater treatment with a limited amount of water, increases in temperature and drought events will increase evaporation rates thereby decreasing the amount of surface water available to recharge the system, for water taking, and for wastewater assimilation.
Soil Quality	**What is It:** The characteristics of soil found in a surficial component that influence its permeability as well as vegetative health at the surface - particularly the amount of organics found in the soil and its depth. **Why does it Matter:** A surficial component characterized by inorganic soils (e.g. sands, gravels, tills) or extremely dry organic soils (i.e. where the soil has fractured), is more vulnerable to precipitation increases and extreme events due to low absorption processes and increased water loss to the soil and subsurface flow paths. In this manner, vegetation present on top of the soil may be more vulnerable to drying during times of drought due to less water being stored in soil pores and providing a buffer to drying vegetation during times of drought.
Ice Cover	**What is It:** The amount, or depth, of ice cover in an aquatic component in and around the winter season. **Why does it Matter:** A component characterized by flowing water may be more vulnerable to increasing winter air temperatures that may result in less extensive ice cover and/or shorter duration. A component characterized by ponded water may be more vulnerable to extreme (prolonged sub-zero) temperatures due to increased risk of anoxic under-ice conditions (e.g. winter fish kills).

Vulnerability Factor	Rationale
Snow Cover	**What is It:** The amount, or depth, of snow cover in a component in and around the winter season. **Why does it Matter:** Snow cover in general provides thermal insulation for terrestrial biota throughout the winter season (e.g., frogs, salamanders). Reduced snow cover may stress biota seeking refuge from sub-zero temperatures. Further, the frequency and duration of snow during the spring season may cause damage to bud-outbreak and change the phenology of terrestrial components. This springtime snowpack will also influence aquatic components whereby the spring freshet may be reduced but prolonged.
Chemical Factors	
Nutrient Availability	**What is It:** The availability of nutrients and moisture within a component, ranging from moisture poor (e.g., urban forests, meadows)to those with sufficient moisture and nutrients (e.g., natural forests) to those with potential nutrient excess (e.g., rivers and streams). **Why does it Matter:** A component with naturally poor nutrient and/or moisture state (e.g. Urban forests, shrublands, meadow) are more vulnerable to increased temperature and decreased precipitation as it will intensify the water stress through increased evapotranspiration. Increasing temperatures could increase the rate of chemical and metabolic processes as well, which could affect decomposition rates, respiration, nutrient availability. Species better suited to those conditions may have an advantage; however, many of these species could be non-native invasive species. On the other hand, a component with sufficient or excess nutrients may also be vulnerable to increases in precipitation and extreme events whereby higher amounts of runoff, or deep drainage, may leach nutrients from soils and transport it downstream into other components.
Water Chemistry	**What is It:** Water chemistry refers to the chemical, physical and biological characteristics of water in an aquatic component (e.g., naturally or due to wastewater treatment effluent is present) and is a measure of the condition of water related to the requirements of biotic species. **Why does it Matter:** A component with naturally occurring poor water quality (e.g. high nutrients/eutrophied, stagnant water) because it is shallow or because wastewater effluent is present may contain higher nutrient concentrations, eutrophication and/or stagnant water. These conditions are more vulnerable to increasing temperature and precipitation because the component's ecological limits (and relevant biological limits of biota present) are almost reached.
Biological Response Factors	
Species Diversity	**What is It:** The number and/or evenness of genes and species within a component. This includes genetic diversity (or the diversity of genes within a species), and species diversity (or the diversity of species within a habitat or component). **Why does it Matter:** A component that has lower diversity (e.g. urban forest with low species diversity) may be more vulnerable to increased extreme weather events (e.g. ice storm, drought) as well as indirect effects (e.g. pest infestation) due to lower resiliency and lesser capacity in terms of buffering the impacts of these events (an aspect of functional diversity).

Vulnerability Factor	Rationale
Community Range	**What is It:** The geographic range and distribution characterizing a community of species within a component that is determined by climatic conditions suited to the community. **Why does it Matter:** Differing conditions of soil, hydrology, and fertility favour certain vegetation communities, some of which are highly-specific and support particular species of concern. These types of species or biota are more vulnerable to increasing temperature and shifting precipitation if climatic conditions become unfavorable for their growth requirements, and species shift northward or out of Peel Region.
Flow Variation	**What is It:** The degree to which the flow regime of a watercourse has been altered as a result of hardening, straightening and/or disconnection from its floodplain. **Why does it Matter:** When it comes to flow variation, watercourses that have been hardened, straightened and/or disconnected from the floodplain are considered more vulnerable since the adaptive capacity to deal with higher volumes of surface runoff and associated erosive forces is either naturally low (more adapted to stable and /or lower flows) or has been severely reduced in highly altered streams.
Thermal Gradient/Regime	**What is It:** The varying temperature at different depths in an aquatic component, or the warming of the ground surface in the terrestrial system (e.g., as a result of the changing water density with temperature in the aquatic system or urban heat island in the terrestrial system). **Why does it Matter:** In most cases an aquatic component deep or extensive enough to experience thermal stratification/gradient (or regime) is more vulnerable to increases in temperature which can lead to seasonal shift, regime change and/or prolonged (deeper) stratification conditions. Components located in proximity to urban lands are more vulnerable due to ground surface warming and increased 'edge effects.'

3.5.2. *Vulnerability Indicators*

Following the identification of vulnerability factors, metrics were selected for representing these factors locally in Peel, termed “Vulnerability Indicators”. These indicators were screened (see Appendix D) and selected from a long list using a set of criteria (see Table 6). These criteria were developed to help assess the suitability of potential indicators. After reviewing a number of vulnerability criteria frameworks (Birkmann 2006; Foushee 2010; Hildén and Marx 2013; Kenney and Janetos, n.d.; United States Environmental Protection Agency 2000; Millennium Ecosystem Assessment 2005b), 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 based on what makes it vulnerable. The scientific validity category refers to a potential indicator’s measurability, sensitivity to changes in VF across the natural systems 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 assessment. Note it is not a requirement that a potential indicator me*et al*l evaluation questions listed in this table, but that in comparison to all potential indicators examined it is optimal. Appendix D illustrates an example of applying the selection criteria in Table 6 to screen potential vulnerability indicators. An effective vulnerability indicator is considered to be a representation of a natural systems component or attribute able to provide information regarding its adaptive capacity in response to a climate-induced impact.

Table 6: Vulnerability Indicator Screening Criteria

Criteria*	Applying the Criteria - Evaluation Questions
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).	A. Is the indicator relevant to the project scope?
	B. Is the indicator relevant to policy recommendations emerging from the work?
	C. Is the indicator relevant to the vulnerability factor of the natural heritage system?
2. Indicator data are readily accessible, robust, and collected in a manner that is applicable and useful.	A. Are indicator data available for Peel Region?
	B. Are the indicator data useful and relevant?
	C. Has indicator data been quality controlled?
	D. Are the indicator data readily accessible?
3. The indicator is simple, such that non-technical decision-makers understand.	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 natural systems components through the vulnerability factors (see *table 7*); and relates strongly to the direct human benefits derived from ecosystem services (see *table 3*). In this manner, the indicator can best represent the larger natural heritage system and ecosystem services most important to Peel Region.	A. Does the indicator represent a sufficient number of natural systems components?
	B. Does the indicator relate to direct human benefits derived from ecosystem services?
	C. Does the indicator also relate to non-human beneficiaries, as a bonus?
	D. Does the indicator represent an imbalance in the NHS?
Scientific Validity of Assessing the Indicator	
5. The indicator is measurable and sensitive to changes in the vulnerability factor across natural heritage components regardless of impact causality. In this manner, an indicator can represent the vulnerability of the NHS as a whole conservatively (vulnerability will not be under-represented due to climate change nor anthropogenic impacts) and imply what components may need to be managed to reduce that vulnerability.	A. Is the indicator measurable (does it contain units)?
	B. Is there a known threshold associated with this indicator?
6. To the current state of knowledge, the indicator is accurate and valid based on one or	A. Does the literature or expert opinion support the use of this indicator?

Criteria*	Applying the Criteria - Evaluation Questions
more of the following: published literature, community of practice or expert opinion. In this manner, the indicator can be considered robust and scientifically vetted at an acceptable level prior to implementation in Peel Region.	B. Do other science-based organizations (Community of Practice) use this indicator?
	C. Can the choice between a physical, chemical or biological indicator be distinguished and defended?

**Adapted from* (United States Environmental Protection Agency 2000; Millennium Ecosystem Assessment 2005b; Birkmann 2006; Foushee 2010; Hildén and Marx 2013; Kenney and Janetos, n.d.)

Vulnerability indicators differ in what ecological function and service they represent, the pathways (both direct and indirect) of which they are a part of, their spatial scale and how they may respond to climate change. For instance, some vulnerability indicators are relevant spatially throughout all of Peel (e.g., natural cover and distribution) whereas others are tied to specific natural features (e.g., wetland type). Further, some of these vulnerability indicators are more suitable for monitoring (e.g., groundwater levels, water temperatures) than others (e.g., organic carbon in A-Horizon, soil drainage). It was therefore important to define the selected vulnerability indicators to illustrate thought processes behind how they are used in vulnerability characterization (see Table 8).

Vulnerability indicators were selected to either represent the natural systems due to their wide applicability or spatial coverage (termed system indicators in Table 7) or represent a subset of components or a component (termed component indicators in Table 7).

All vulnerability indicators are responsive to climate change in general, although depending on which climate driver manifests their responses may differ. A vulnerability indicator may respond directly to a climate driver or indirectly. For instance, a direct response to increasing temperatures occurs for the indicator of water temperature. Warmer air temperatures would directly heat waters thereby reducing thermal suitability for habitat extent for fish species which require cold water. On the other hand, water temperature would indirectly respond to increases in precipitation. Higher amounts of total precipitation in late spring or summer may alter water temperatures due to higher amounts of warmer runoff and precipitation making their way into rivers and streams, but precipitation falling directly onto rivers and streams is not expected to warm waters significantly.

Much more detail is presented for each indicator in Appendix F, such as the indicator's relation to climate drivers, its anticipated response time, units of measure, and interactions with other indicators

Table 7: Vulnerability Indicator Definitions and Interpretation for Use in the Assessment

Indicator*	Definition	Ecological Service (Function) Represented
Groundwater Levels	**System**: A characterization of depth to water table over time (based on hydrographs) can provide a direct measure of groundwater/aquifer condition and an indirect consideration of hydraulic connectivity to surficial soils and surface water features throughout the natural system.	1) Hydrological Cycle Regulation (recharge, discharge) 2) Habitat Diversity (hydraulic connectivity) 3) Water Use (potable and non-potable supply)
Baseflow	**System**: A characterization of (summer) low flow response in watercourses that can provide a direct measure of aquatic habitat conditions reliant upon groundwater discharge and an indirect consideration of hydrologic pathways, particularly the extent of hydraulic connection between /amongst terrestrial, groundwater and aquatic components throughout the natural heritage system.	1) Hydrological Cycle Regulation (in-stream flow variation, water source/discharge and evaporative losses) 2) Habitat Diversity (fish habitat, hydraulic habitat connectivity directly within the stream and potentially amongst natural systems components, e.g. wetlands) 3) Thermal Regulation (thermal refuge within the stream and, to an extent, within the valley corridor) 4) Water Quality Regulation (dilution)
Natural Cover Type & Distribution (Pervious Cover)	**System**: A characterization of all vegetative land cover types (based on ortho-interpretation and ELC information) across the landscape that can provide a direct measure of amount of connected terrestrial habitat and an indirect consideration of hydrologic pathways, particularly the state of the following functions: attenuation, infiltration and ET. Ultimately, changes in this indicator are governed by vegetation response and survival/adaption to climate change, therefore, the adaptive capacity of ELC communities (when known) is also represented in the evaluation.	1) Hydrological Cycle Regulation (attenuation, infiltration, ET and E) 2) Erosion Regulation (top soil stability/structure, valley and stream bank stability) 3)Habitat Diversity (physical habitat connectivity through valley-corridors and across table lands) 4) Thermal Regulation (shading/ thermal refuge in streams, through valley-stream corridor, and on table lands) 5) Air Quality Regulation (transpiration processes) 6) Water Quality Regulation (contaminant uptake)

Indicator*	Definition	Ecological Service (Function) Represented
Climate Sensitive Native Vegetation	**Component(s)**: A characterization of the different native flora species that are sensitive to climate-driven criteria (based on ELC and species inventory list for both CAs): hydrology, fertility and/or dynamics. These provide an indication of the range of vegetation in a particular terrestrial habitat, as well as the general resilience of the terrestrial system for dieback in stressed conditions under climate change. For instance, an area with numerous climate sensitive native vegetation should be considered more vulnerable, especially if this sensitive vegetation is highly vulnerable (to two or more climate-driven criteria).	1) Habitat Diversity (species-specific wildlife/bird breeding habitat, food resource, over wintering habitat, general cover 2) Moderation of invasives (competition) 3) Resiliency (maintenance of species diversity)
Organic Soil in A-Horizon and **Soil Drainage Rating**	**System**: A characterization of top soil quality, based on % organic (A Horizon - CanSIS dataset), can provide an indirect consideration for growing conditions across the landscape, particularly the potential for soil moisture retention. This speaks to vegetative health and potential for survival during drought or extreme heat. Linking drainage properties (e.g., geologic layers and slope) can provide a direct identification of where high infiltration or run off may lead to compounding system vulnerability.	1) Soil Quality Regulation (moisture absorption/retention, microbial activity, nutrient cycling, pH balance, texture) 2) Hydrological Cycle Regulation (infiltration and run off potential) 3) Erosion regulation (topography based)
Total Phosphorus	**System:** A characterization of phosphorus concentrations in receiving waters can provide a direct measure of water quality and an indirect consideration for aquatic primary productivity/food web dynamics and phosphorus distribution throughout the natural system, particularly flagging catchments likely contributing high loadings.	1) Primary Production (algal growth/decomposition, aquatic food web response; terrestrial equivalent also exists)
Water Temperature	**Component(s)**: A characterization of the seasonal intensity (not amount) of heat stored in streams and rivers can provide a direct measure of fish habitat suitability and an indirect consideration for fish survival and stream water quality conditions from a chemical and physical perspective.	1) Habitat Diversity (thermal suitability for fish, ice cover formation) 2) Water Quality Regulation (interactions with chemical constituents, including DO and P release)

Indicator*	Definition	Ecological Service (Function) Represented
Wetland Type and Cover	**Component**: A characterization of wetland type, distribution and extent across the landscape can provide a direct measure of habitat availability and an indirect consideration of flood attenuation potential and water quality mitigation attributable to wetlands. Vulnerability of wetlands was assessed using its water source, or the number of water sources available to a wetland based on its functional type.	1) Hydrological Cycle Regulation (attenuation, infiltration/recharge, flow variation, ET and E) 2) Habitat Diversity (different wetland types, habitat connectivity, spawning/breeding) 3) Thermal Regulation (shading/thermal refuge for wetland-dependent species; cooling of flow-through water if groundwater fed wetland) 4) Water Quality Regulation (nutrient and contaminant uptake/storage)
Recharge	**System**: A characterization of the degree to which the surface is maintaining the groundwater system ("Aquifer Maintenance"). It is not known whether high levels of recharge occurring in one area is supplying the aquifers present directly below the surface in that area; however, it is assumed that high (local) areas of recharge are important for maintaining the health of the groundwater system in Peel Region as a whole.	1) Hydrological Cycle Regulation (recharge, discharge) 2) Habitat Diversity (hydraulic connectivity) 3) Water Use (potable and non-potable supply).
Land Surface Temperature (Mid-Morning and Mid-Afternoon)	**System**: A characterization of heat stress and thermal regulation associated with summer temperatures. Elevated land surface temperatures imply increased amounts of impervious cover and lack of natural features to buffer the UHI influence in Peel Region.	1) Thermal Regulation (shading/thermal refuge for species; cooling of flow-through water and terrestrial system) 2) Regulation of Urban Heat Island Effect (areas with high land surface temperatures indicate increased UHI influences and thus could be considered higher priority to mitigate using natural cover) 3) Energy Use and Conservation (indirectly implies which areas may require more cooling or higher energy amounts in the summer season)

Indicator*	Definition	Ecological Service (Function) Represented
Habitat Patch Quality (Size, Shape and Matrix)	**System**: A characterization of (terrestrial) habitat connectivity based on patch analyses conducted by the TRCA (L-Ranks) and CVC (quality descriptions). Areas of Peel with higher quality (or larger) habitat patches contain higher connections for species movements and thus can facilitate habitat diversity more effectively.	1) Habitat Diversity (physical habitat connectivity through valley-corridors and across table lands) 2) Hydrological Cycle Regulation (attenuation, infiltration, ET and E) 3) Erosion Regulation (top soil stability/structure, valley and stream bank stability) 4) Thermal Regulation (shading/ thermal refuge in streams, through valley-stream corridor, and on table lands) 5) Air Quality Regulation (transpiration processes) 6) Water Quality Regulation (contaminant uptake)

3.6. Key Climate Variable Selection and Analysis

Typically, a much larger suite of up to 50 climate variables are used in climate impact studies (e.g., the World Meteorological Organization's GCOS Essential Climate Variables). However, for the purposes of this assessment, climate variables had previously been made available through the Peel Climate Trends report and analyses conducted therein (Auld *et al*. 2015). The suite of climate variables associated with the Peel Climate Trends report are based on the most recent IPCC report (2014) and were modeled using the most recent ensemble of climate models, but focus on atmospheric variables most relevant to Peel Region, rather than others available from climate models like those in the oceanic domain. Climatological variables are used to inform vulnerability associated with a specific climate driver, such as extreme heat (IPCC 2014). Historical analysis of climate data along with future projections relevant in Peel Region are presented in Section 5.3 of this report and further detail on trends and projections is presented in Auld *et al.*, (2015). Table 8 summarizes the climate variables that are considered most relevant to Peel Region's natural systems based on what climate drivers may manifest. For each climate variable, historical baseline and future trends and statistics were analyzed to inform future vulnerability and are presented in Table 10 in this report.

Table 8: Summary of Climate Variables used in This Assessment

Climate Driver	Climate Variable (Examined Seasonally and Annually)
Increasing Temperatures	Maximum Temperature [°C]
	Minimum Temperature [°C]
	Average Temperature [°C]
Shifts in Precipitation (Increase Annually, No trend in Summer)	Total Precipitation [mm]
Drought	Consecutive Dry Days [days]
Extreme precipitation Intensity	1-day maximum precipitation accumulation [mm]
	5-day maximum precipitation accumulation [mm]
Extreme Heat	Days per Month where Max Temperature > 30, 35, 40 [°C]
Ice Storms	Ice Potential [# Freezing Rain Events annually]
Growing Season Conditions	Growing Season Length (frost-free period) [days]
	Growing Season Start Date [date of year]
	Growing Season End Date [date of year]

An ensemble approach was used to generate future climate projections for Peel Region, as documented in Auld *et al.*, (2015). The key purpose for using an ensemble is that it captures the full range of uncertainty associated with General Circulation Models (GCM) that are used as the fundamental input for all other downscaled datasets. The ensemble 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 GCMs from 20 global modeling centres 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 for the 2050s, as it represents the business-as-usual projection of future climate that global observations are currently following (Auld *et al.* 2015).

With its most recent report, the IPCC has become much more confident in the findings about climate change at the global scale, though confidence at the local scale is much more limited. This is due to 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 however, much 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 climate variables used to contextualize more generic processes and factors to Peel have not been ground-truthed. Although they have all been used in previous studies (e.g., Sillmann *et al*., 2013a; 2013b). It is for this reason that in this natural systems vulnerability assessment, climate trends (and the level of confidence associated with those trends) are used to infer potential impacts on a component. Impacts discussed in this report should not be used in approaches that require high degrees of precision or accuracy

3.7. Approach to Characterizing Current and Future Vulnerability to Climate Change

Information identified from both literature review and subject matter expert consultation was used to drive the vulnerability characterization process (Steps 9 and 10 in Figure 4). More specifically, vulnerability indicators which were selected based on the approach described in Section 3.5.2 were used to guide research and mapping to inform the vulnerability of Peel's natural systems. Vulnerability characterization was conducted both qualitatively and quantitatively as part of this assessment (see Figure 5). A literature review of numerous current condition reports was first conducted to identify the current state of natural components throughout Peel Region. From this information, qualitative descriptions, such as "impaired" or "thermally stable" based on vulnerability indicators were collected using P-CRAFT. In addition, data were collected, where available, based on the same vulnerability indicators to be used for mapping (quantitative analyses) in ArcGIS.

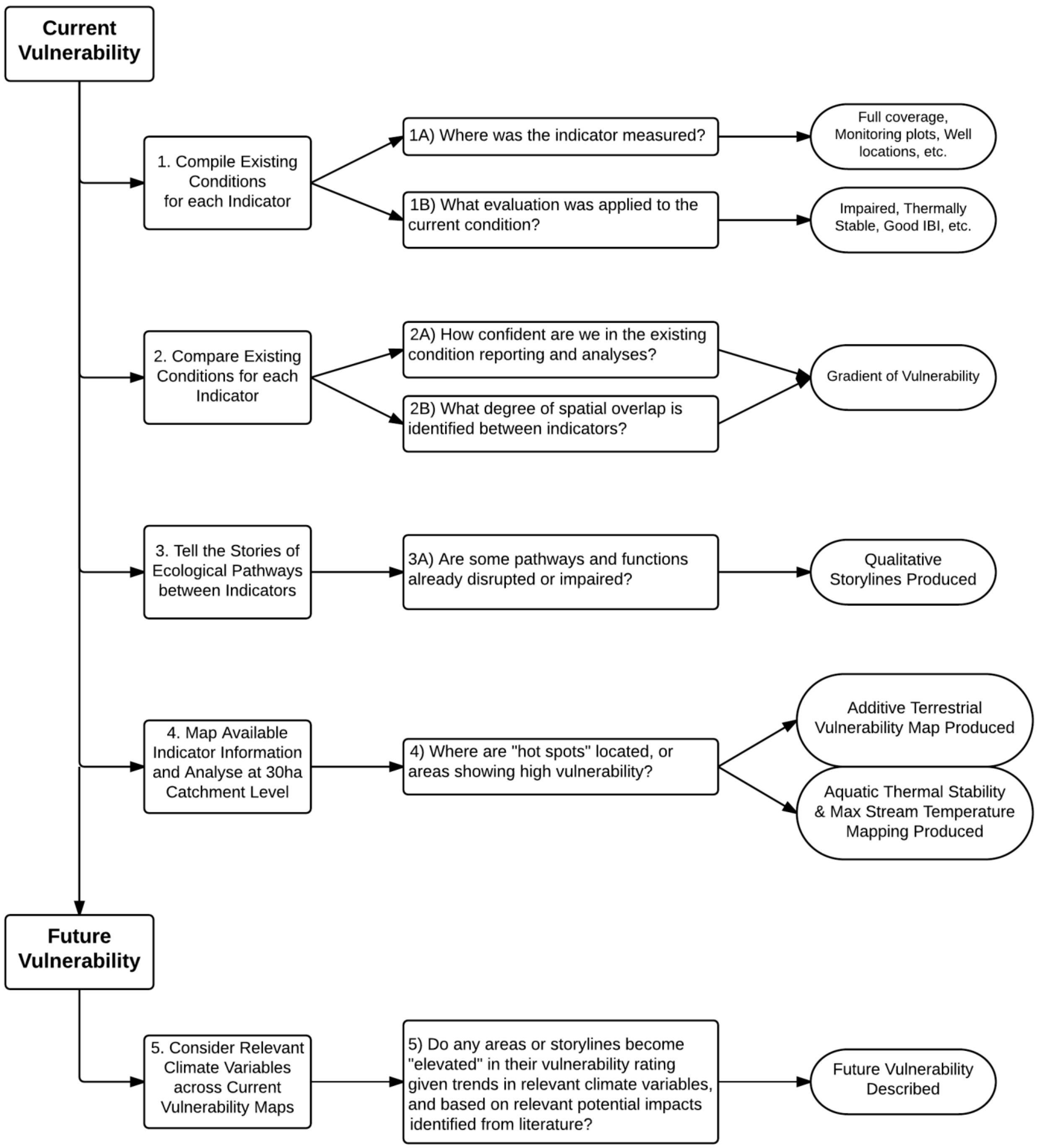


Figure 5: Approach to Characterizing Current and Future Vulnerability to Climate Change

Figure 5 outlines the difference in how information was collected, analyzed and interpreted for ‘current vulnerability’ versus ‘future vulnerability.’ Current vulnerability information is based on available monitoring data, current condition reporting and existing assessments in Peel Region. Future vulnerability has been interpreted based on current vulnerability, the consideration of relevant climate drivers and their directional trends (not magnitude of change), and potential climate impacts to ecological processes as identified from literature. For example, upland terrestrial habitat that is currently degraded due to low pervious (natural) cover and low urban forest canopy is considered relatively vulnerable to heat and drying; further sensitive wildlife using this habitat would be highly exposed to this heat stress and have poor ability to cope assuming habitat connectivity is low and movement to refuge habitat limited. Analyzing the relative amount of pervious (natural) cover and urban forest canopy across the Region illustrates a gradient of current vulnerability (see Figure 5), and this particular area may be assigned a rating of 'moderate vulnerability'. However, with increasing temperatures and particularly extreme heat events becoming more frequent and more extreme, this same area may shift to 'highly vulnerable' in the future.

Following this approach and using all available current condition information, data were 'grouped' and areas were selected to represent those from highly impaired to highly functioning. These areas formed the basis for the selection of focal storyline areas of vulnerability (see Section 6). Figure 6 illustrates how information from a variety of sources was 'grouped' to narrow down locations for detailed 'storylines of vulnerability.'

Information obtained from two modeling case studies were also used to inform vulnerability characterization: one in the West Humber subwatershed (see Section 6.2.2 for full methods and results) and one across Peel Region for streamwater temperature and wetland vulnerability (Chu, 2015; see sections 6.1.2 and 6.1.3 for summary of methods and results for stream temperature and wetlands, respectively).

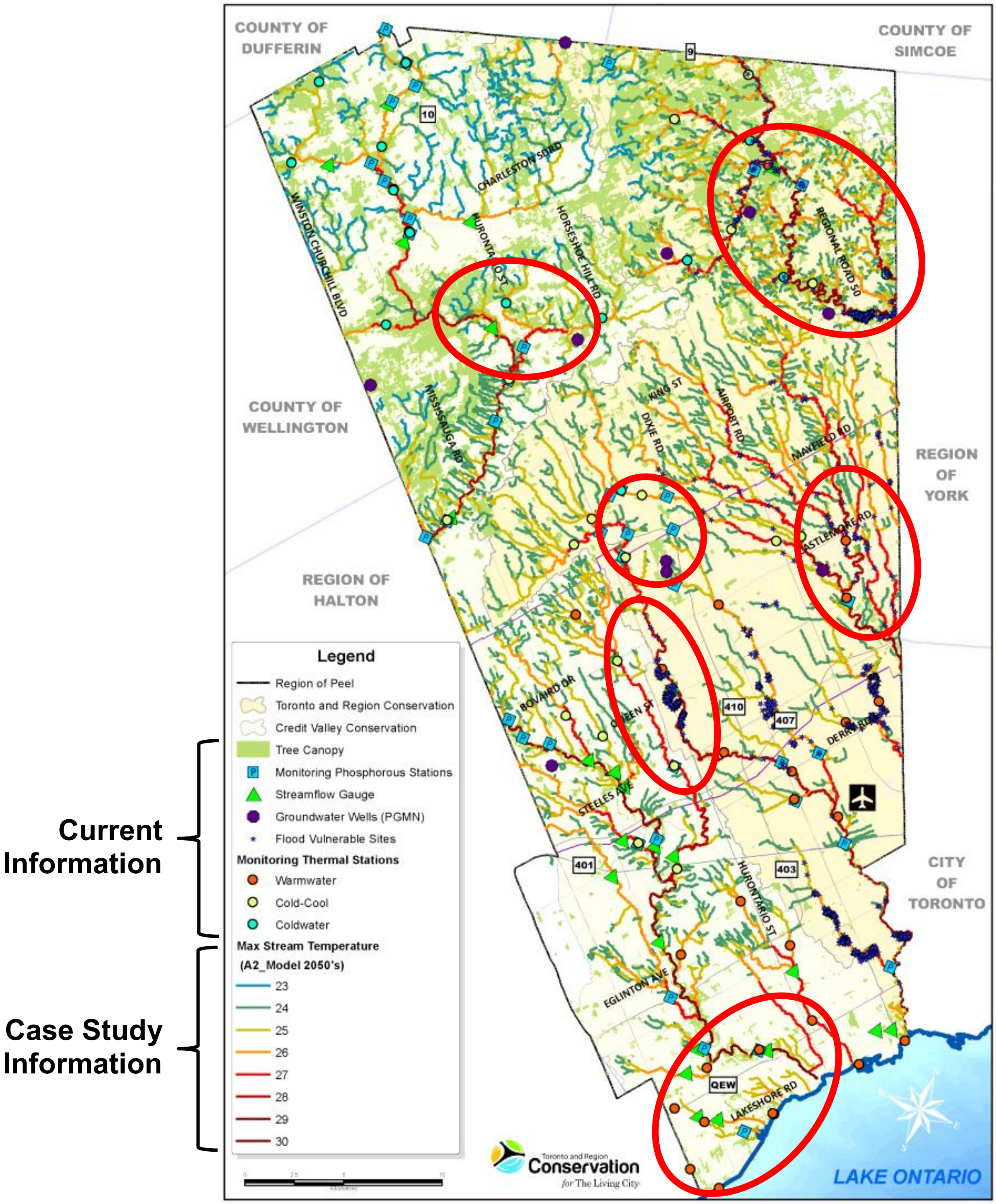


Figure 6: Grouping of Current and Case Study Information to Select Focal Area Storylines of Vulnerability

As an additional step within characterizing the current vulnerability, a GIS analysis was conducted whereby raw data for each vulnerability indicator was assessed. As part of this analysis, Peel Region was divided into spatial units of analysis (‘catchments’) based on surficial drainage patterns. The catchments were derived using the ArcHydro extension for ArcGIS. An average 30ha catchment size was selected for two main reasons. First, it allowed for a representative extrapolation of data without being too large where extrapolation becomes inappropriate. Second, existing studies have similarly employed the use of the average 30ha size to produce integrated planning for ecosystem restoration (e.g., TRCA, 2015d). Thus, this unit formed the basis for defining the dominant condition (defined using the majority of information). The objective of this analysis was to validate current information collected from literature review and to describe the gradient of conditions (and vulnerability) across Peel Region (see Figure 7).

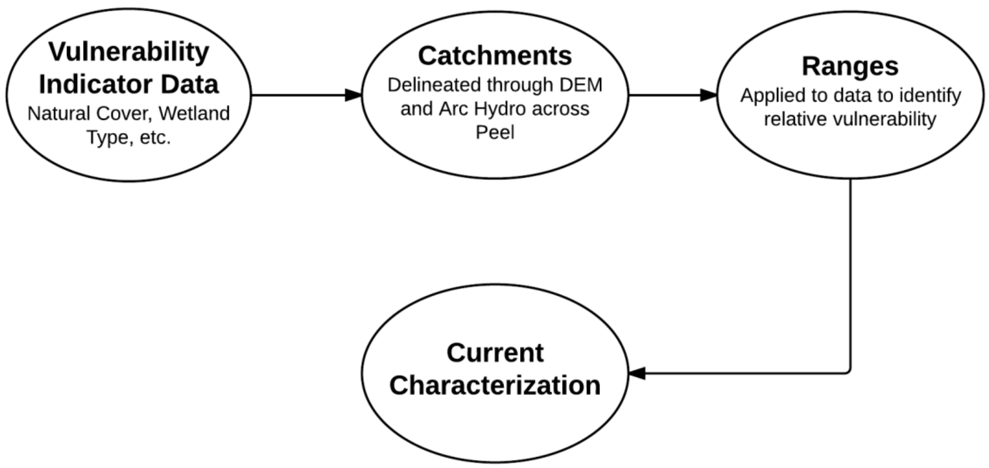


Figure 7: Approach to the GIS Analysis Conducted as Part of the Current Vulnerability Characterization

Notably, no thresholds were used in evaluating the gradient of vulnerability for an indicator. Instead, ranges were used (see vulnerability indicator mapping in section 6) to describe the gradient of vulnerability based on the principle that ‘more is better’ (e.g., more tree canopy is better for shading, more forest cover is better for habitat connectivity, etc.) in reducing vulnerability of the natural system. These ranges are described on the legends of figures provided in this report where GIS analysis has been conducted at the 30ha catchment level[1], and are included with spatial mapping in section 6. The establishment of scientifically-sound, justifiable thresholds was considered out of scope for this assessment, and in fact would require extensive additional literature review, statistical analyses in some cases, and consultation and widespread discussion with experts to determine the sensitivity of a particular indicator in contributing to vulnerability in a given area.

[1] An average 30ha catchment size was selected for representative extrapolation of data and based on precedent through existing studies that have similarly employed its use (TRCA, 2015d)

4. CLIMATE TRENDS IN PEEL REGION

The following describes climate trend information analyzed for Peel Region, from both Auld *et al.*, (2015) and Environment Canada (2015).

4.1. Historical Climate

Temperature

On an annual basis, higher mean temperatures are found in the southern portion of Peel than in the northwest regions (see Figure 8). The same trend also holds when temperatures are considered on a seasonal basis. This trend is attributed primarily to the effects of elevation that increases to the north (due to the presence of the Niagara Escarpment and the Oak Ridges Moraine, or ORM), the presence of Lake Ontario, and intensely urbanized land use in the south. Additionally, the land use in north Peel consists of farmland, natural forests and some grasslands, which tend retain less heat energy than the heavily urbanized areas in the south. Lake Ontario does exhibit a moderating effect at certain times of the year as well; however, this pattern is likely outweighed by other factors previously mentioned (elevation, land use, geographic features) as well might be 'masked' given that temperatures are averaged over the year. These factors exert influence on the geographic trends in all temperature-related variables during the historical period (e.g., mean, maximum and minimum, number of extreme heat days, etc.).

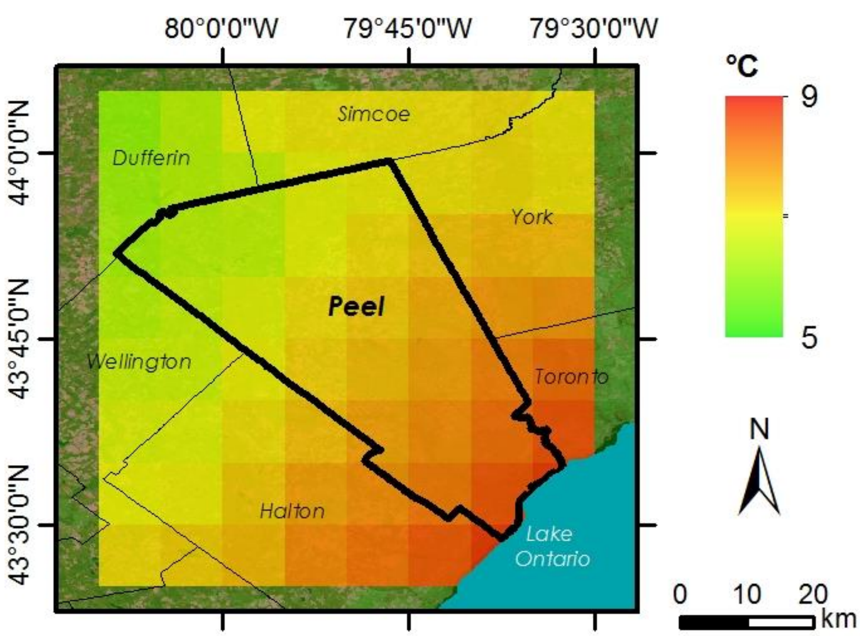


Figure 8: Annual Mean Temperature in Peel Region for the Baseline Period of 1981-2010

Precipitation

The north-western portion of Peel is historically the wettest area within the Region on seasonal and annual bases, with the southern portion receiving the least precipitation. Northwest Peel receives an average total amount of precipitation between 835 mm and 925 mm per year and southern area in Mississauga receives between 794 and 836 mm (see Figure 9). The north-south trend in precipitation is driven primarily by the influence of topographic and elevation features of the ORM, Niagara Escarpment and some regional storm track differences. These differences include, but are not limited to, the Great Lakes influences on summertime convective precipitation, the extent of northern progression of tropical air in winter and transition seasons, springtime and fall positions of frontal zones. These features cause a slight rain shadow effect (reduction of precipitation) delivered to Peel compared to other surrounding areas.

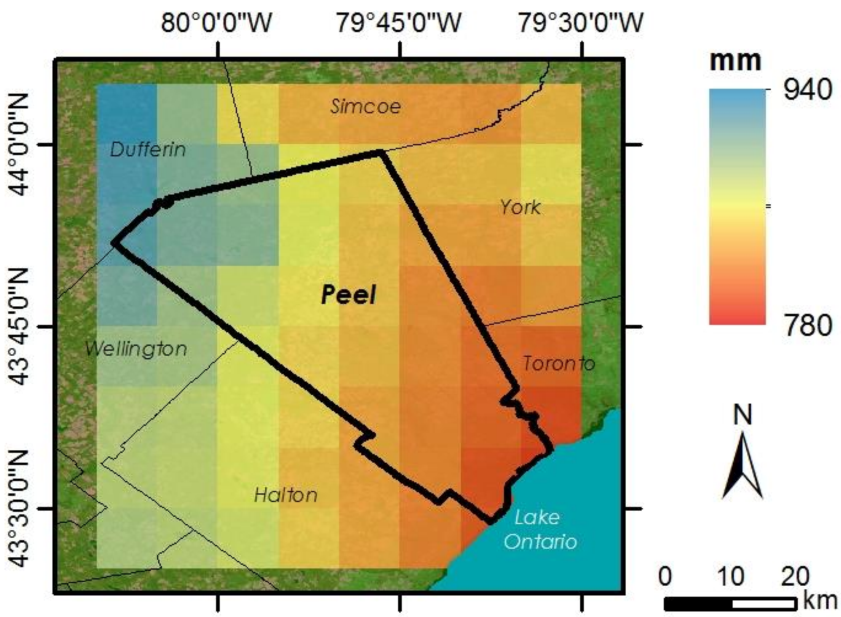


Figure 9: Total Annual Precipitation in Peel Region for the Baseline Period of 1981-2010

Historical and future climate trends are presented using thirty-year periods (or "climate normals") that are most representative of climate conditions (IPCC 2007b). A thirty-year period is typically used to smooth out extremes, and ensure that particularly wet, dry, hot or cold years do not dominate the climate conditions overall (which may occur if only ten years are used as a normal period, for instance). Typically, the middle decade is used to name the climate normal, such as 2041-2070 referred to as the 2050s, 1981-2010 referred to as the 1990s (or baseline period). Baseline climate conditions were obtained from two sources: CANGRD (as presented above in Figures 7 and 8), and from Environment and Climate Change Canada (ECCC) (see Table 9 and Figure 10). In general, these datasets provide very similar historical trends in climate. Auld *et al.*, (2015) presents a comparison between these two sources of historical data and determines that CANGRD (which interpolates station data across Canada) replicates very similar climate trends from 1981 to 2010 compared to the Pearson International Airport climate station for mean annual temperatures and total annual precipitation. More specifically, CANGRD data were used only to characterize the magnitude and certainty in future trends provided by Auld *et al* (2015). However, CANGRD did not provide the range of historic time series that best supported the analysis conducted in this assessment. As a result, information from ECCC's Climate Normals (see Table 9) was used to characterize a particular historical year and provide context for data used in the analysis and characterization of the natural systems in Peel Region. For instance, using ECCC's climate normals, the years when satellite imagery was collected (i.e., 2009 and 2014) were determined to be cooler than a recent 10-year average as well as the entire climate normal period (1981-2010) and as a result, conclusions on land surface temperatures drawn from satellite data could be considered conservative (see Table 9).

Table 9: Historical Climate Normals from Pearson International Airport

Year	Mean Temperature (˚C)	Total Rain (mm)	Total Snow (mm)	Total Precipitation (mm)
1981	7.1	716.3	70.6	790.3
1982	6.8	735.3	131.8	847.4
1983	7.8	712.3	88.3	795.6
1984	7.3	624.0	103.9	717.4
1985	7.2	751.6	167.4	936.2
1986	7.5	873.6	83.0	951.2
1987	8.5	603.6	107.0	710.6
1988	7.8	531.5	74.8	604.0
1989	7.0	555.7	92.2	629.6
1990	8.7	733.3	76.2	815.3
1991	8.9	661.6	110.6	760.4
1992	7.0	865.2	92.8	951.4
1993	7.2	657.5	102.0	750.8
1994	7.3	593.4	141.0	719.8
1995	7.8	820.6	110.4	928.1
1996	7.2	846.8	122.4	969.8
1997	7.6	485.6	143.6	628.6
1998	10.1	621.9	61.5	682.1
1999	9.5	545.7	117.8	661.8
2000	8.3	635.2	135.7	755.7
2001	9.6	611.0	81.6	690.4
2002	9.4	546.6	114.9	661.9
2003	7.9	752.0	129.6	895.6
2004	8.2	643.3	134.9	755.0
2005	9.0	612.2	162.6	766.7
2006	9.7	833.9	32.4	865.7
2007	8.9	478.2	114.1	592.7
2008	8.2	840.9	216.5	1049.6
2009	8.0	810.8	89.0	904.0
2010	9.5	748.0	45.6	787.2
2011	9.1	831.3	131.2	936.8
2012	10.5	683.2	49.2	731.6
2013	8.5	609.4	141.0	733.8

Year	Mean Temperature (˚C)	Total Rain (mm)	Total Snow (mm)	Total Precipitation (mm)
2014	7.4	820.1	122.8	944.8
Climate Average (1981-2010)	8.2	681.6	108.5	785.8
10-Year Average (2003-2012)	8.9	726.8	110.4	831.3

A graphical version of mean temperature and total precipitation is illustrated in Figure 10 for easier reference.

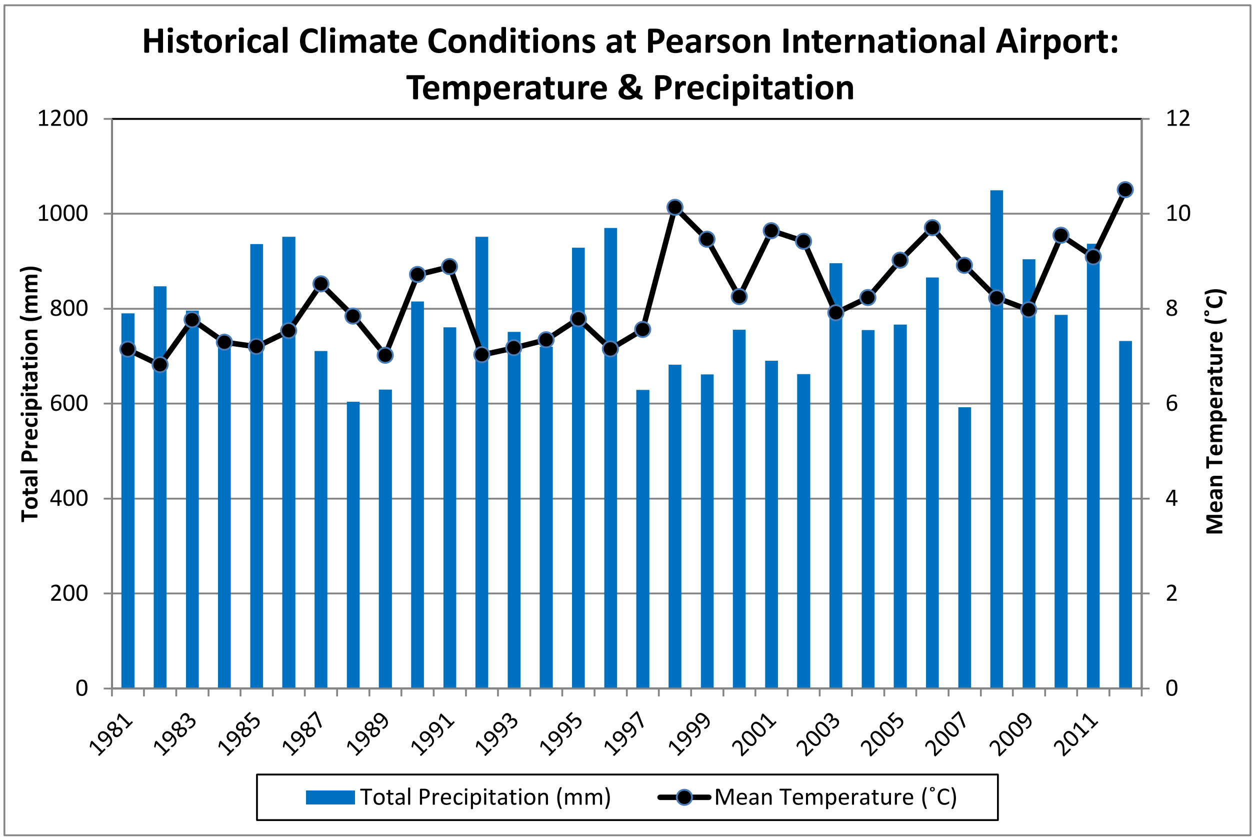


Figure 10: Historical (1981-2010) Annual Average Temperature and Total Annual Precipitation at Pearson International Airport

4.2. Future Climate Trends

The general scientific consensus is 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 Peel Region is 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 (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 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. While the growing season is projected to increase by between approximately 13 and 34 days on average, because of the difficulty of predicting day-to-day variability in climate models (Deser *et al*., 2012), unseasonal frost is still an important climate risk (Holland, T., Smit 2010). Additionally, the increased occurrence of extreme heat events during the summer season may compound issues of lacking moisture.

Future climate trends are summarized in Table 10, and it is evident from the estimates that the uncertainty associated with climate change will make predicting seasonal climate conditions more difficult. RCP8.5 corresponds to the Business-as-Usual (Conventional) Development Scenario used in this Assessment (Auld *et al.*, 2015).

Table 10: Historical (1981-2010) and Future (2041-2070) Projected Values for Climate Variables in Peel Region

Variable [Future Projection Trend Confidence]	Future Trend	Baseline Value (1981-2010)	Future: 2050s (2041-2070) RCP8.5
Mean Temperature (°C)	**[VERY LIKELY]**		
Winter	↑	-4.8	-2.6
Spring	↑	6.1	7.8
Summer	↑	19.3	21.3
Autumn	↑	9.1	11
Annual	↑	7.4	9.4
Average Max. & Min. Temperature (°C)	**[VERY LIKELY]**		
Max. Annual Temperature	↑	12.3	14.2
Max. Winter Temperature	↑	-0.97	0.94
Max. Spring Temperature	↑	11.3	13.2
Max. Summer Temperature	↑	25.1	27.1
Max. Autumn Temperature	↑	13.7	15.7
Min. Annual Temperature	↑	2.5	4.5
Min. Winter Temperature	↑	-8.7	-6.1
Min. Spring Temperature	↑	0.78	2.6
Min. Summer Temperature	↑	13.5	15.5
Min. Autumn Temperature	↑	4.4	6.3
Extreme Heat Event Frequency (days yr^{-1})	**[VERY LIKELY]**		
Days T_{max} >= 30°C	↑	12	26
Days T_{max} >= 35°C	↑	0	2
Extreme Cold Event Frequency (days yr^{-1})	**[VERY LIKELY]**		
Days T_{min} <= -5°C	↓	81	50

Variable	Future Trend	Baseline Value	Future: 2050s
Days T_{min} <= -10°C	↓	44	23
Days T_{min} <= -15°C	↓	19	8
Total Precipitation	**[LIKELY]**		
Winter (mm mo^{-1})	↑	61	71
Spring (mm mo^{-1})	↑	68	78
Summer (mm mo^{-1})	↔	77	78
Autumn (mm mo^{-1})	↑	77	82
Annual (mm yr^{-1})	↑	852	926
Dry Days (days yr^{-1})	**[MORE LIKELY THAN NOT]**		
Total Annual	↔	234	231
Extreme Precipitation	**[LIKELY]**		
Max. 1-day precip. (mm)	↑	37	8%
Max. 5-day precip. (mm)	↑	59.2	10%
95^{th} Percentile precip. Amount (mm)	↑	223	28%
99^{th} Percentile precip. Amount (mm)	↑	79	51%
SDII (mm day^{-1})	↔	6.5	7%
Growing Season	**[LIKELY]**		
Growing Season Start Date (day of year)	↓[3]	124	112
Growing Season End Date (day of year)	↑[4]	292	314
Growing Season Length (days/yr)	↑	169	203
Agriculture Variables	**[VERY LIKELY]**		
Corn Heat Units	↑	3087	4199
Snow and Ice (days/yr)	**[MORE LIKELY THAN NOT]**		
Ice Potential	↔	2.4	1.9
Days <= 0°C	↓	147	96
Days between -2 and 2°C	↓	87	71
Wind Velocity* (m/s)	**[MORE LIKELY THAN NOT]**		
Mean annual	↔	4.5	4.4
Humidity*	**[MORE LIKELY THAN NOT]**		
Mean annual Specific Humidity (kg/kg)[1]	↑	0.0073	0.011
Mean annual relative Humidity (%)[2]	↓	71.3	67.5

Notes:

*Additional details on these particular variables and how they were determined from the CMIP5 ensemble is provided in Auld *et al.*, (2015)

[1]Baseline value provided as an average from the multi-model CMIP5 ensemble (unavailable from historical datasets or CANGRD)

[2]Baseline obtained from Environment Canada historical archive (unavailable from CANGRD)

Variable	Future Trend	Baseline Value	Future: 2050s
[3]Decreasing trend implies a shift towards an earlier start date of the growing season			
[4]Increasing trend implies a shift towards a later end date of the growing season			

5. STUDY LIMITATIONS AND ASSUMPTIONS

Given time and resources available for this project, and the priorities of stakeholders, this assessment was undertaken with a large scope to address all components within the natural systems of Peel Region. This large scope dictated the level of analysis that could feasibly be undertaken to a level of high quality (see Figure 4). For instance, ecosystem services were not the focus of literature review, although were included in key word literature searches. Thus, if a natural systems component's function is lost or impaired, it was assumed that associated ecosystem services are also lost or impaired. Similarly, vulnerability factors identified through literature review are assumed to be equal in the degree to which they contribute to vulnerability (described in Section 3.7). Targeting these factors through adaptation actions is then assumed to be an effective initial starting point for addressing climate change effects. It should be noted that vulnerability indicators are based on the best available data for Peel Region. For instance, organic carbon content in the soil A-horizon layer was collected from 1950s to the 1960s as part of the Peel County soil survey (Hoffman and Richards 1953). Therefore, caveats have been placed on these types of limited information, such as only considering it valid in natural areas and even so, recognizing that conditions have likely changed since the dates of collection.

Furthermore, to undertake the future vulnerability characterization, it was assumed that no interventions, or adaptive management actions, will occur from now until the 2050s and that urbanization will continue conventionally (or business-as-usual). This is in fact a conservative approach in that future vulnerability is not underestimated to the natural systems in Peel Region. It should be noted that all climate trends used in this assessment have been produced in the Peel Climate Trends Report (Auld *et al*. 2015) and any assumptions made in their analysis, including assumptions embedded within the climate models analyzed, have been accepted as part of this assessment.

Detailed analyses were scoped to conditions in the watersheds in Peel Region. Not all vulnerability indicators had data available within the region and as a result, vulnerability characterization analysis was largely qualitative with the exception of the West Humber case study and GIS analyses. As part of analyzing vulnerability indicators in GIS, no thresholds were used in evaluating the gradient of vulnerability for an indicator. This is because there is a lack of known ecological thresholds available from literature. The establishment of scientifically-sound, justifiable thresholds were considered out of scope for this assessment and in fact would require consultation with experts and an additional literature review. Instead, ranges were used to describe the gradient of vulnerability based on the principle that 'more is better' (e.g., more tree canopy is better for shading, more forest cover is better for habitat connectivity, etc.) in reducing vulnerability of the natural system. Additionally, there was significantly more research available for certain impacts and system components than others. For instance, wetlands and natural forests had a far greater abundance of information than some other components, such as bluffs. The Lake Ontario component of the natural systems was initially scoped into this assessment but following literature review was removed from the higher level of vulnerability characterization analysis and instead is included only as a narrative (Box 1). This was because it was concluded Peel Region has limited control over the lake-based processes which govern water quality, such as upwelling and downwelling conditions, and because data and monitoring information was limited for this component. However, analyses were carried out on tributaries draining into Lake Ontario which are described in terms of vulnerability accordingly. The focus has instead been placed on watershed (land-based) management and adaptive actions. The Bluff component was also initially included but was removed from detailed vulnerability characterizations given a lack of information and their limited relevance in Peel Region.

Information described in section 8 of this report identifies a suite of management considerations for agencies conducting adaptation in their programs (i.e., conservation authorities). This set of considerations is not meant to be prescriptive for addressing all impacts and vulnerabilities, but rather it is intended to advance dialogue on adaptation, which is required as adaptation plans are refined during Milestone 3 of the ICLEI adaptation process (ICLEI 2010). It should be cautioned; however, that the level of detail and characterization that has occurred in this report (such as the directionalities identified for potential climate impacts), has been completed based on timelines constrained by Peel Region's adaptation planning process, and is meant to parallel other vulnerability assessments across sectors.

Finally, it is recognized that many other systems and contextual factors contribute to the effects of climate change on natural systems, local community characteristics, economics, government services and programs, infrastructure in the landscape, among many others. It is however, beyond the scope of this report to examine all these systems and their effects on the natural systems in detail. This report is also not a risk assessment that weights the different impacts discussed against one another. This is in accordance with the steps for risk and vulnerability assessment in many guidance documents (Gleeson *et al*. 2011; ICLEI 2010; UK Climate Impacts Programme 2003).

6. VULNERABILITY CHARACTERIZATION RESULTS: CURRENT AND FUTURE ESTIMATES

The following sections characterize natural systems vulnerability (see Figure 4; Steps 9 and 10) under a future climate consisting of 'warmer wetter years' in the 2050s that seasonally have hotter drier summers, on average, but are punctuated by heavy rainfall events. This was selected as it draws from the more confident future climate projections in Peel Region (discussed in Section 4.2), and coincides with when the majority of available ecological data are collected and studied; and the knowledge of processes, tolerances and interactions is highest (i.e., the summer months). Some discussion will venture beyond this climate scenario and touch on other seasons or effects of extreme weather events (e.g. drought, extreme heat or flooding) when understanding and relevance to particular ecological processes or relationships were strong (e.g., summer drought in streams with naturally low baseflow).

Despite the futuristic context, it is important to emphasize that climate impacts are already happening and some ecological shifts won't be experienced gradually, but rather may occur non-linearly and abruptly. Biological and other ecological effects may respond to or may be determined by more by extremes or tolerance thresholds than average conditions. For example, brook trout populations could drastically decline or marginal populations disappear due to a severe drought event that may occur within the next decade, long before the coldwater habitat is predicted to warm up to a predicted summer maximum, which crosses lethal thresholds for this species. Thus, management considerations presented later in Section 8, contain urgency for action today in light of understanding response to future trends and extremes.

The first section (6.1) broadly describes current conditions and future vulnerability across Peel Region for each of the following systems: groundwater, aquatic and terrestrial. Conditions are organized geographically for north (Caledon), middle (Brampton) and southern (Mississauga) areas of Peel. The implications to ecosystem services are also presented (see Figure 4; Step 11), followed by a more integrated discussion on ecosystem services that considers how future urban development may exacerbate and contribute to climate vulnerability.

Moving from broad to specific, a series of eleven focal area storylines (see Figure 11) in Caledon, Brampton and Mississauga are then presented in Section 6.2. Storylines were created to provide additional detail for watershed managers, Conservation Authority staff and ecosystem scientists to better understand, design and develop adaptation actions and performance indicators in the face of climate change. Of interest in this section are both existing impairment issues and areas of high quality as the latter are critical for shaping and increasing resilience under a future climate. The scope of these focal area discussions is largely groundwater and aquatic vulnerabilities or groundwater and terrestrial vulnerabilities; however this reflected the type of available datasets with spatial and temporal continuity and is not intended to lessen the importance of integrating all three systems and make transparent how disruptions in one system can have consequences that transmit through space and time to affect the other two systems. For instance, the Etobicoke Creek headwaters presents a truly integrated storyline as the amount of cross-system information available for this location set it apart from the others. Additionally, the West Humber focal area storyline is different as it is a case of a *quantified* vulnerability assessment using existing groundwater and surface water models. The locations of all focal area storylines are illustrated in Figure 11.

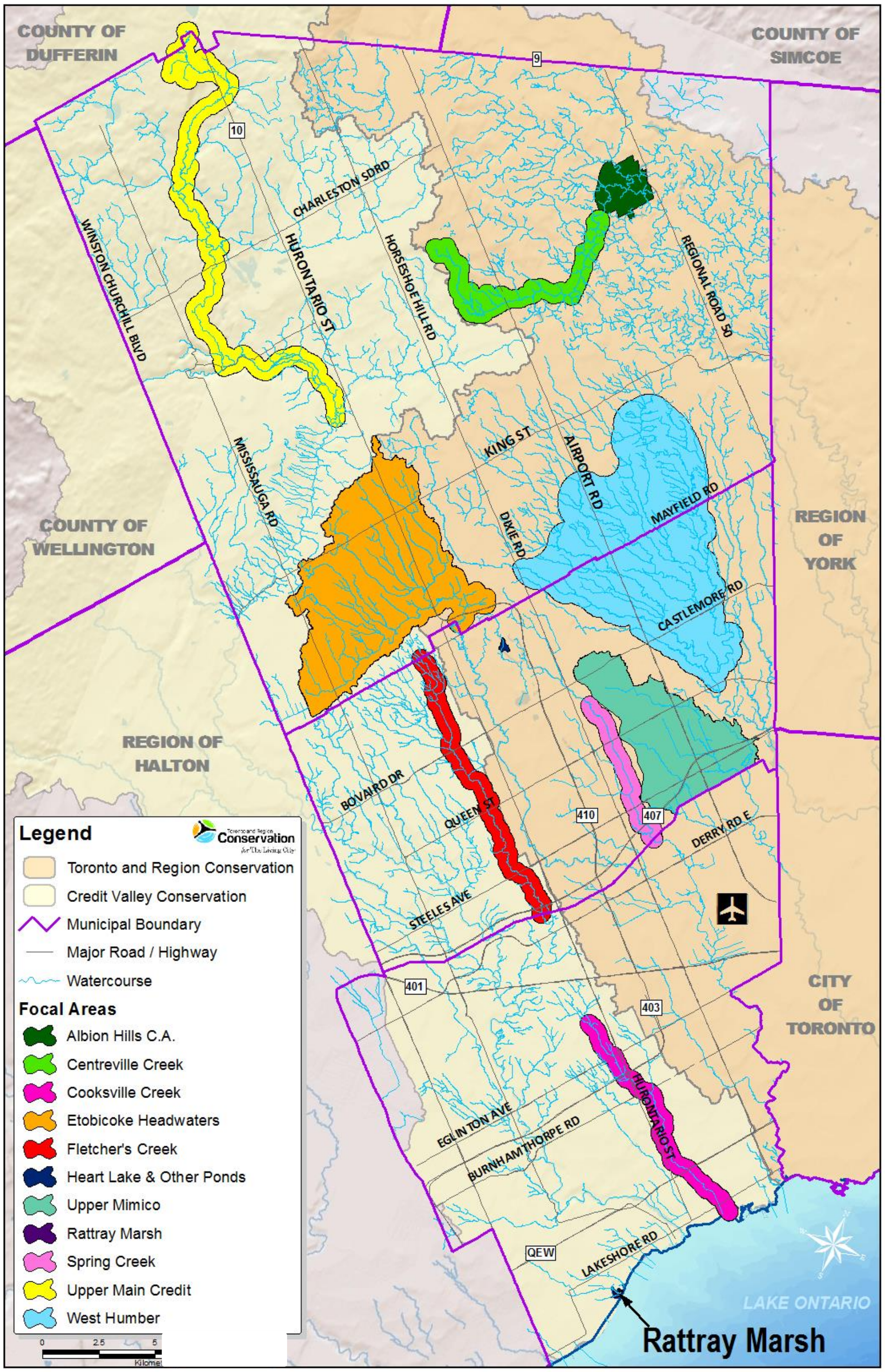


Figure 11: Locations of Focal Area Storylines in Peel Region

6.1. Peel Region Wide Characterization

For each of the following system component descriptions, the relevant vulnerability factors and vulnerability indicators are explicitly outlined, and these guide both *current conditions* and *future vulnerability* characterization. Key findings are summarized for each system in section 7.

6.1.1. *Groundwater System*

Most groundwater comes from precipitation, which gradually percolates into the ground; surface waters that infiltrate into the ground move vertically downward to the water table and flow by gravity, following the path of least resistance (TRCA 2008b). Approximately, 10-20% of precipitation, falling on watersheds in Peel Region, eventually infiltrates and enters aquifers (TRCA 2015b). The groundwater system is comprised of shallow and deep aquifers, which respond to climate differently. Deeper aquifers are unique in the sense that they are naturally buffered from "present" surface influences due to a delay (lag) in the amount of time it takes for waters to infiltrate, recharge and discharge at the surface. For instance, beneath the surface some groundwater flow paths may take 10,000 years to reach Lake Ontario from the same areas of the ORM in north Peel (D. Ford, personal communication, November 3, 2014). However, this lag time response is not clearly understood and it is uncertain if responses of groundwater just haven't happened yet or to what degree confounding effects of anthropogenic impacts of water taking contribute to potential responses. By comparison, surface water flows take approximately two days to travel from north Peel in and around the ORM down to Lake Ontario (D. Ford, personal communication, November 3, 2014). These considerations imply climate drivers have lesser influence on deeper groundwater processes (although local subsurface conditions may cause greater vulnerability).

The following table presents characteristics of Peel's groundwater system, or vulnerability factors, which help determine this system's vulnerability to climate change (see Table 11). Figure 12 illustrates the processes or pathways that may be disrupted in the groundwater system when exposed to changes in precipitation and temperature by the 2050s. As a result of changes to related ecological processes, the ecosystem services that may, in-turn, be affected are listed at the bottom of the diagram.

Table 11: Component, Vulnerability Factors and Vulnerability Indicators Discussed in Peel Region's Groundwater System

Component	Vulnerability Factors	Vulnerability Indicators
• Groundwater	• Area-to-Depth Ratio (Aquifer depth) • Aquifer Maintenance • Water Taking • Water Chemistry	• Groundwater Levels • Recharge • Total Phosphorus

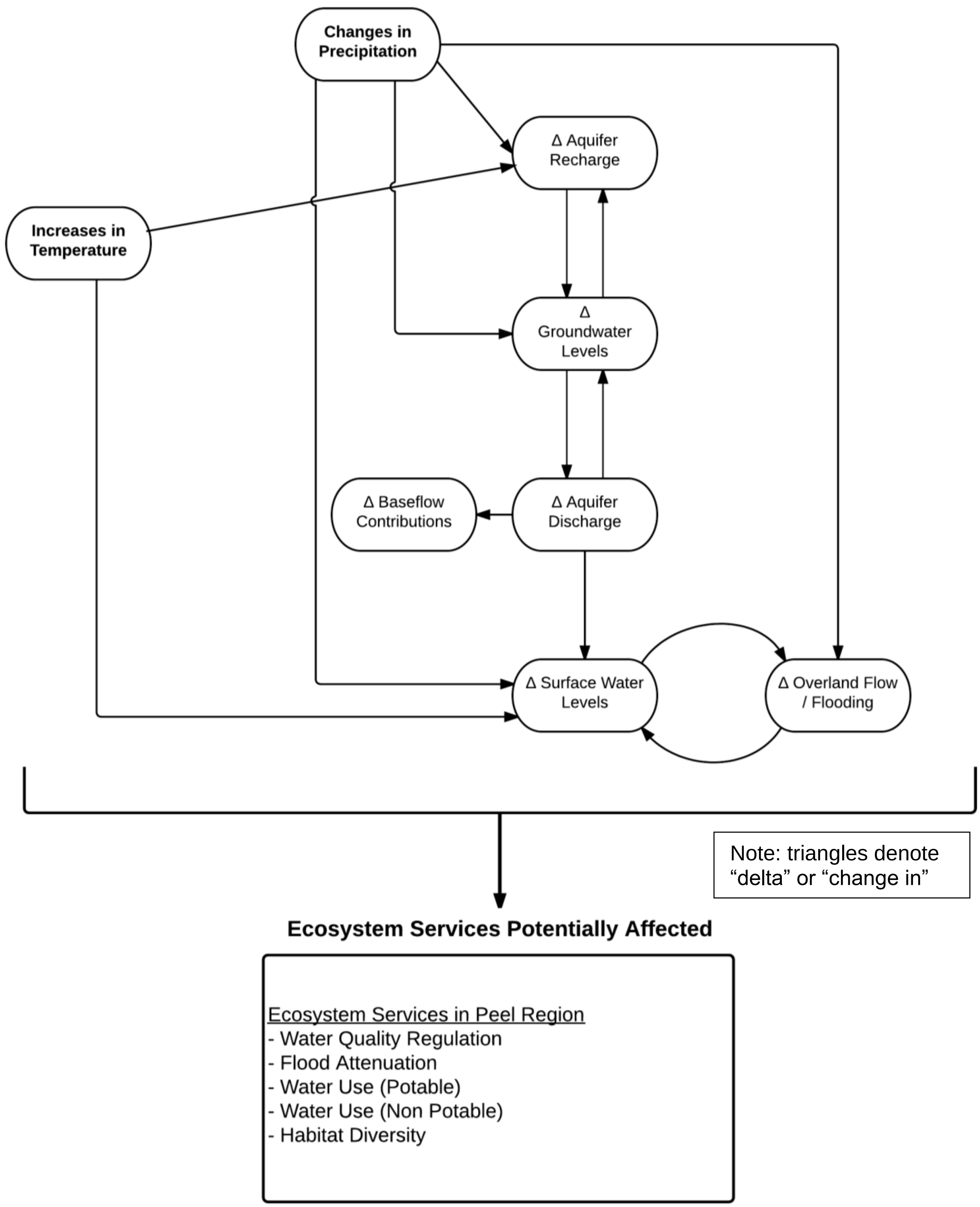


Figure 12: Impact Pathway Diagram Highlighting Climate Change Impacts and their Complex Interactions in the Groundwater System

Current Conditions in Peel's Groundwater System

Aquifer Depths and Distance of Flow Path

The groundwater in Peel, in general, flows from north to south from the Niagara Escarpment and ORM to Lake Ontario, with some local areas moving west to east from the CVC to TRCA watersheds in Caledon (TRCA 2008c). The Niagara Escarpment traverses the north western portion of the Humber watershed in north Peel. Here, the vertical cliffs of exposed rock are covered by ORM sediments, and appear in the landscape as a steep topographic rise approximately 490 metres above sea level (TRCA 2008b; TRCA 2015a). Across much of north Peel, the groundwater system is characterized by the ORM Aquifer Complex, which is a mix of confined and semi-confined aquifers that are not as deep as the underlying regional systems, namely the Thorncliffe and Scarborough Aquifers (TRCA 2008b; TRCA 2010a). Moving further south to the Peel Plain and Halton Till, the soils are dominated by gently sloping, poorly drained clay and clay till soils (TRCA 2008b; TRCA 2015a). The groundwater system in middle Peel, particularly the West Humber subwatershed, is more uniformly *shallow,* have underlying permeable sand deposits of Halton Till (formed during the Mackinaw Interstadial) and support short flow paths of local recharge-discharge to the receiving watercourses (TRCA 2008b). Baseflow in these watercourses tends to be low in the summer season, with large tributaries of the West Humber River often drying up in the summer months which can be indicative of shallow aquifers (TRCA 2008b). Also in middle Peel, but further to the west, the Etobicoke and Mimico Creeks headwaters are fed by groundwater likely discharging from the Oak Ridges Moraine or Equivalent (ORAE) aquifer (TRCA 2010a).

In general, however, there is no consistent trend in aquifer depth or flow path structure from north Peel to south Peel as it depends on historical glacial deposits in sediment to define the aquifer and aquitard systems underlying an area; and these deposits are not uniform. For instance, a modeled cross-section completed in the upper Main Humber River from west to east illustrates numerous relatively deep aquifer systems (e.g., ORM Aquifer Complex, Halton and Newmarket Till) but which vary in absolute depth depending on the presence of Halton Till, ORM Till and Silt deposits (TRCA 2008c). Middle Peel aquifer systems range from shallow to moderate depth associated with Newmarket Till deposits, the ORM Aquifer Complex and more recent deposits (TRCA 2010a). Underlying aquifers in south Peel are defined by the Iroquois shoreline, which is characterized by a longitudinal sandy lens that draws water from the deeper, regional aquifers and discharges to the main rivers as well as sources the tributaries that drains directly into Lake Ontario (e.g. Cooksville Creek, Turtle Creek, Sheridan Creek) (CVC 2011a).

Aquifer Maintenance: Recharge to the Groundwater System

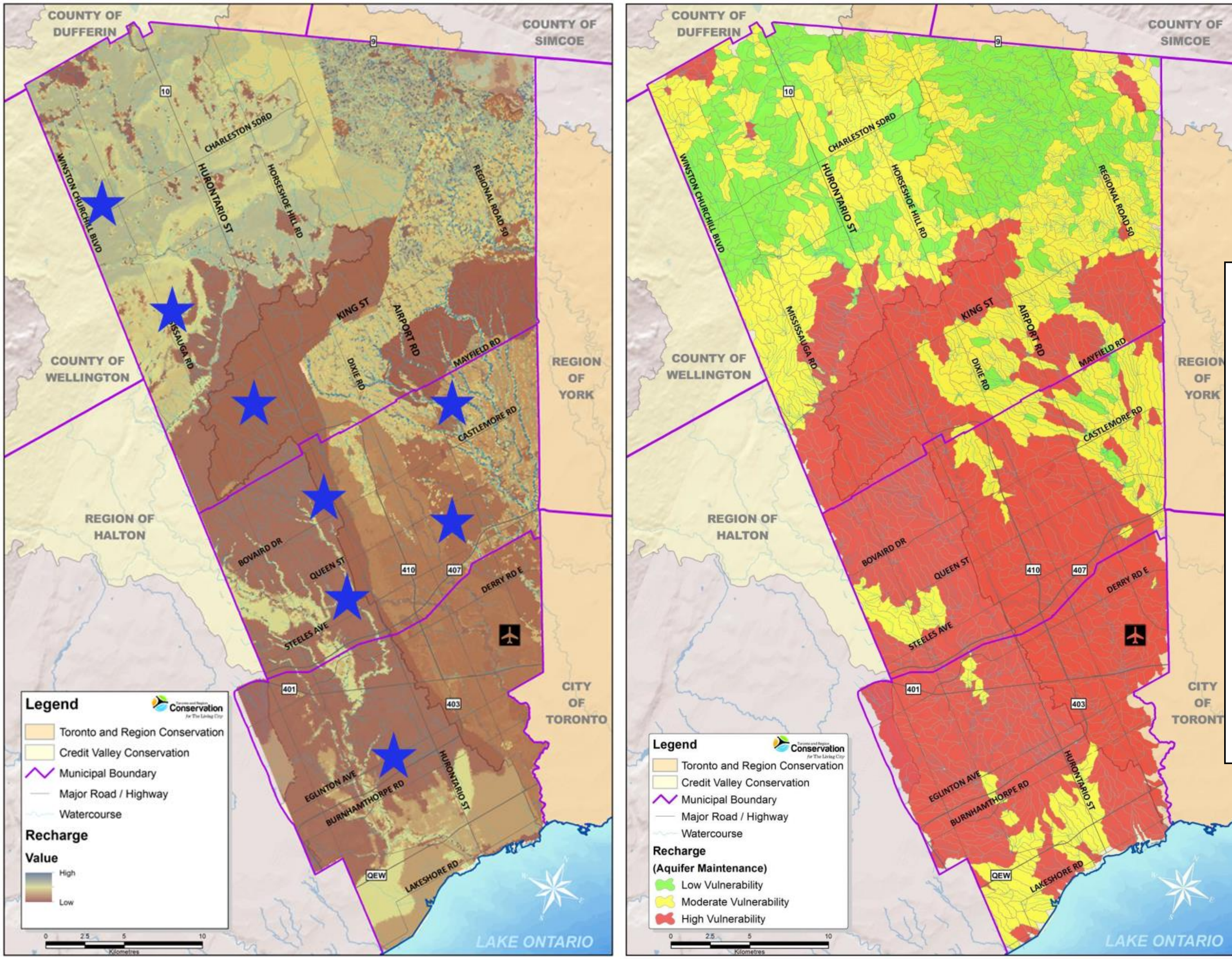
Aquifers are maintained through infiltration of surface waters and precipitation which become recharge. Aquifer maintenance is not necessarily a local process; areas of high recharge may not be supplying water to an aquifer system directly beneath it. Recharge depends upon the geologic formation underlying the surface and the presence of aquitards which may cause water to flow laterally for some distance as opposed to vertically. Recharge areas in Peel Region were modeled using the York-Tier 3 model (Humber watershed), the FE Flow Model (Credit

Watershed), and the West Model (Etobicoke and Mimico watersheds model outputs) and are illustrated in Figure 13. Areas of high recharge are typically found in north Peel and particularly in the northwest portion of the Humber River watershed, where permeable limestone bedrock from the Niagara Escarpment is at or close to surface (TRCA 2008b). Similarly, across north Peel the terrain is hummocky and filled with local depressions where the ORM influence is strong. This increases the capture and retention time of surface waters thereby increasing recharge rates to about 360mm/year, which is a critically important source to the deeper, regional aquifers and to local streams and wetlands through shallow groundwater flow paths that also characterize this area (TRCA 2008d; TRCA 2015a). Moving further south into the rest of Peel, areas are dominated by Halton till deposits (on the Peel Plain) (e.g. West Humber River, Etobicoke Headwaters, Middle Reaches of Credit River and Fletcher's Creek), are generally less than 25 m thick and serve as an aquitard wherever present, limiting recharge rates to 60 to 100 mm/year (TRCA 2008d). An exception is the Brampton Esker located in the Etobicoke Creek watershed (Highway 410 between Mayfield Road and Queen Street) where estimated recharge is close to 380 mm/year (TRCA 2010a).

Water Taking: Stress to Aquifers and Aquatic Surface Features

Groundwater Peel Region is used to supply drinking water for both municipal and private wells in addition to supporting ecosystem functions (TRCA 2015a). Groundwater is an important source of drinking water for approximately 116,000 people in the Credit watershed (although these are not all within Peel) where on average per year 39,600m^3/day of water are removed from the groundwater system (CVC 2013a; CVC 2015c). Other significant groundwater users include golf courses and aggregate extraction operations (TRCA 2008b). In north Peel, the ORM aquifer complex provides municipal water supply in the Town of Caledon (north eastern portion of the Credit River Watershed), in Caledon East and in Palgrave (TRCA 2008d; CVC 2015c). In middle and south Peel, municipal drinking water systems are primarily surface water based, with Lake Ontario as the source (TRCA 2015a).

The 2010 Tier 1 Water Budget Assessment for surface water stress identified several subwatersheds in Peel Region to be 'significantly stressed' as a result of surface water taking: West Humber, the Etobicoke Headwaters, the Etobicoke West Branch and the Upper Mimico (Figure 13). All of these stressed areas are also considered vulnerable only due to natural conditions (i.e. underlying shallow, unconfined aquifers) and/or non-municipal supply water taking as none of these areas rely on groundwater sources for municipal drinking water (TRCA 2015a). Not surprisingly, stress to groundwater in these subwatersheds was not identified by the Water Budget Assessment; the groundwater use for both Etobicoke and Mimico watersheds represents less than 1% of the total recharge, consistent with an overall low level of stress on the groundwater system supporting these watersheds (TRCA 2010a).



Range-based Thresholds applied to characterize the gradient:

Low Vulnerability: Upper third percentile of recharge in Peel (>333mm/yr)

Moderate Vulnerability: Middle third percentile of recharge in Peel (167-333mm/yr)

High Vulnerability: Lower third percentile of recharge in Peel (<167mm/yr)

Figure 13: Modeled Recharge and Areas of Surface Water Stress (illustrated in blue stars) in Peel Region (A) and Vulnerability Characterization of Modeled Recharge at the 30ha Catchment Level (B)

The 2010 Tier 1 Water Budget Assessment for the Credit watershed, and its 25 non-municipal surface water taking permits, identified that moderate surface water stress exists in Fletcher's Creek, Cheltenham to Glen Williams, Norval to Port Credit, and the upper Main Credit River – Melville to Forks of the Credit (CVC 2013a). For these Credit River reaches, maximum monthly water demand was found to be approximately 19% higher than average annual water demand, indicating that many of the non-municipal water users operate on a seasonal basis, and, as a result, their consumptive use is much higher in the summer than in the winter months (CVC 2015c).

Tier 2 Water Budget Assessments (conducted in 2010) were not required in TRCA watersheds within Peel (indicating no municipal supply associated with surface or groundwater stress). Tier 2 Water Budget Assessments were required in the Credit River watershed; however, areas flagged for groundwater stress related to municipal water supply, particularly in the summer months, were not located in Peel Region. There is concern, however, that water taking demands and/or urban development outside of Peel may have broader reaching impacts on the groundwater system within Peel, particularly watercourses and wetlands in the upper Credit River watershed that rely on groundwater or baseflow (CVC 2013a). Tier 3 studies done on the Credit watershed in Halton and Orangeville demonstrate important implications in affecting baseflows downstream in Peel. Existing or planned groundwater supply wells in Orangeville and Mono are not able to meet their allocated quantity of water or planned quantity of water because the municipal demands result in measurable and unacceptable impacts to other water uses under the existing climate and land use in the area (CVC 2015c). For coldwater streams, an unacceptable impact is defined by a circumstance where baseflow is reduced by 20% of the existing monthly baseflow (CVC 2015c). The Towns of Orangeville and Mono have never historically had problems meeting required pumping rates, even during periods of higher water demand. The identified concerns do not indicate a problem associated with current municipal wells and their current pumping rates; rather, they reflect a need to manage the drinking water resources in the Local Areas to protect against future problems (CVC 2015c).

Groundwater Level Stability and Sensitivity to Climate Drivers

As recharge processes unfold, groundwater levels become highest in northwestern Peel, where levels range upwards around 470 metres above sea level in the Credit River watershed across the TRCA divide. From north to south, groundwater levels generally become lower (to around 40 metres above sea level) in the lower West Humber subwatershed (TRCA 2008b). Provincial groundwater monitoring network (PGMN) wells indicate that annual average groundwater levels in 2011 in Peel Region were consistent with long term records. Specifically, the well in Caledon is considered stable, within a given year, and shows an increasing trend in inter-annual water levels likely due to a latent response in earlier climate conditions (CVC 2013a). Groundwater levels underlying Etobicoke Creek appear to be rebounding in the vicinity of the Brampton Esker in response to cessation of dewatering associated with aggregate extraction, which could pose implications for the design of subsurface infrastructure, and lead to increased baseflow in the West Branch of Etobicoke Creek (TRCA 2015b; TRCA 2010a; TRCA 2014a). Rising trends in groundwater levels are also apparent in the Humber River watershed, but the cause of this trend in the watershed is not yet understood. Areas immediately to the west of Peel Region have reported unstable annual groundwater levels that are strongly influenced by seasonal climate events (CVC 2013a). Generally speaking, the stable inter-annual water level conditions in Peel and latent response are consistent with a low climate-sensitivity status being applied to the groundwater system. However, closer verification of which aquifers are measured through the PGMN (shallow or deep) and information on seasonal response to climate events would help clarify the gradient of resiliency through the groundwater system.

Water Chemistry in the Groundwater System

Water chemistry in Peel's groundwater system is generally considered to be of good quality; however, local impacts are known and observed around particular features such as landfill sites or naturally elevated iron, manganese and hardness in the deeper groundwater systems like Thorncliffe and Scarborough Aquifers outside of Peel (TRCA 2008d; TRCA 2015a). In north Peel, six drinking water supply wells exist to service the communities of Caledon East and Palgrave. Water chemistry sampling that occurs under the Safe Drinking Water Act identified that in 2008; only one water quality parameter was detected above the Ontario Drinking Water Quality Criteria in either the raw or treated water (two occurrences of total coliform bacteria in raw groundwater sampling). Total phosphorus in the groundwater has low mobility, and groundwater sampling from PGMN wells has mostly yielded stable and low concentrations below 50µg/L (TRCA 2015a). Nitrogen and nitrogen compounds, which are commonly associated with human and natural influences (e.g., septic systems, fertilizer applications, agricultural activities, large populations of waterfowl in wetlands), were found to be generally less than 1mg/L in Peel. All wells are considered stable in their nitrogen concentrations over time with the exception of W-330 located in a subdivision of Caledon East, which is likely influenced by local application of lawn fertilizers and has a concentration less than 3mg/L (TRCA 2015a).

Future Vulnerability in Peel's Groundwater System

The manner in which climate change manifests in the groundwater system could lead to different and cascading impacts. For instance, the influence of increasing temperatures and changes in precipitation may directly impact surface conditions (e.g., soil moisture) and as a result influence the amount of water attenuating and infiltrating into the subsurface, or it may lead to changes in aquifer water levels if they are shallow and unconfined, which ultimately could impact hydrologic connections between the groundwater and surface features within the aquatic and terrestrial system components.

Aquifer Depth: Vulnerability to Climate-Driven Surface Impacts

As inferred from evidence in the previous section, the overall deeper groundwater system appears to have a degree of natural buffering to climate drivers, although some uncertainty exists in how long impacts may take to be exhibited in groundwater levels and to what degree anthropogenic impacts such as water taking influence the system. This concept is further explored in this section through a discussion of hydrological and ecological processes, starting with lag time for water to recharge and discharge. This lag time, while not fully understood, varies depending on the aquifer depth from the surface (Bovolo *et al.*, 2009; Dove-Thompson *et al*., 2011; Environment Yukon - Water Resources Branch, 2011; Green *et al*., 2011). Shallow and/or exposed aquifers, like those found in the West Humber, are considered those less than 15 metres in depth (see section 2.1.1) (D. Ford, personal communication 2015), although some literature identifies impacts being exhibited in shallow systems up to 100m beneath the surface (i.e. Bovolo *et al.*, 2009). Specifically, a shallower aquifer is more susceptible to contaminant loadings from the surface since it is faster to respond (Bruce *et al*. 2008; Environment Canada 2013). Deeper aquifers that are thicker, and/or have a dense protective layer such as a till overlying them, typically have very long lag times and are generally less vulnerable (e.g., Scarborough Aquifer which is 30m thick and one of the deepest in Peel Region is considered less vulnerable) (TRCA 2010a). It is suspected that in general groundwater temperatures will follow the average annual air temperatures in Peel Region (Don Ford, personal communication 2015), which are projected to increase by the 2050s. Other impacts from climate change in the groundwater system are less certain. For instance, depending on aquifer depth and patterns of the freeze-thaw cycle into the 2050s, impacts may differ depending on water table levels (Doll 2009; Jyrkama and Sykes 2007b).

Vulnerability of the Recharge Process and Implications to Water Chemistry at the Surface

Long-term average groundwater recharge (aquifer maintenance) is essentially a measure of the 'renewable' groundwater resources in Peel Region (Doll 2009). With increasing temperatures by the 2050s expected in Peel Region, aquifer maintenance through recharge may be an opportunity if the spring recharge window widens due to soils thawing long before leaf-out (and evapotranspiration drives the water budget). Numerous studies cite increasing precipitation, particularly in later winter and early spring, as a climate driver that will change aquifer recharge rates (i.e., Allen *et al*. 2004; AquaResource Inc. & EBNFLO Environmental, 2010; Doll, 2009; Eckhardt & Ulbrich, 2003; Green *et al.*, 2011; Mishra & Singh, 2010). Climate change will likely result in increased recharge rates and a shifting spring melt from spring towards winter, allowing more water to infiltrate and possibly become recharge; although this assumes that soil thaw rates will also shift into late winter and/or the extent of soil freezing is reduced with the warmer winter weather (Jyrkama and Sykes 2007a; Green *et al*. 2011). North Peel, where hummocky terrains with higher grades exist, is an important area of high recharge for regional aquifer systems and may provide an advantage. Areas containing meadows, shrublands and grasslands within the urban envelope (central and south Peel) provide some opportunity for recharge opportunities as well (Collins *et al*., 2012; Staudinger *et al*., 2012). Where recharge is limited, there is little contribution to aquifer water levels or storage volumes, but these natural components can protect the groundwater system from surface contamination (water chemistry) which may be important should road salt application increase with warmer winter temperatures fluctuating around freezing as is projected (TRCA 2008b; Goderniaux *et al*. 2009; Winter 1999); from this secondary or indirect perspective, the deeper aquifers are again less vulnerable. Increasing temperatures, particularly throughout the winter and spring seasons, may also impact water chemistry of shallow groundwater systems and particularly those features which receive groundwater discharge at the surface. More about attenuation and flooding, soil saturation and infiltration/recharge processes will be discussed in the Aquatic and Terrestrial System sections (6.1.2 and 6.1.3, respectively).

Vulnerability to Groundwater Levels due to Variable Recharge Rates

Increasingly variable recharge rates may ultimately cause changes in some regional groundwater levels, depending upon soil conditions and the amount of precipitation falling in the spring season when recharge occurs (TRCA 2008b; Goderniaux *et al*. 2009; Winter 1999). For instance, if less recharge occurs due to lesser precipitation in the spring, groundwater levels may be reduced in shallow systems that rely and respond more on surface influences (TRCA 2010a; Tomalty and Komorowski 2011). In addition, groundwater levels in Erin (west of Peel) that exhibit unstable annual groundwater levels will likely be more heavily influenced by seasonal climate events, which indicate that groundwater support at the surface is more vulnerable to drying and may affect the baseflow of streams flowing into Caledon and down into Brampton.

Compounding Vulnerabilities of Anthropogenic Water Taking and Variations in Recharge

Climate-related changes to groundwater have been relatively small compared with non-climate drivers (i.e. water taking) in certain aquifers like those that are shallow and/or unconfined (Green *et al*. 2011; Allen *et al*. 2004). This may change in the future, where groundwater support at the surface may be impacted due to climate drivers like shifting precipitation patterns. This is particularly important in areas of Peel where shallow unconfined aquifers underlie the surface or urban land cover lies above the groundwater system. For instance, changes in timing of baseflow (which already occur due to urbanized areas in Peel) to surface water features may become increasingly variable, and dependent upon the frequency, duration and magnitude of precipitation events throughout the year (AquaResource Inc. and EBNFLO Environmental 2010; Dove-Thompson *et al*. 2011; Tomalty and Komorowski 2011). This, in turn, may disrupt aquatic habitat diversity at the surface due to warming of surface waters as a result of less groundwater support (baseflow) under periods of little rain and drought. This baseflow is needed to assimilate heat loading from direct solar radiation at the surface, but will depend on when precipitation is delivered in the future and how much facilitates the recharge-discharge processes.

Implications to Ecosystem Services in the Groundwater System

The underlying groundwater system in Peel Region is vital for maintaining watershed health and resiliency, including providing a constant cold, clean source of water to the surface, supporting habitat and providing potable and non-potable water for local residents. Climate change is expected to disrupt the delivery of at least 2 of these ecosystem services: water quality regulation and supporting habitat diversity. Water quality regulation at the surface may be disrupted as a result of intermittent, or increasingly variable, groundwater discharge and/or baseflow to streams that may arise due to inadequate precipitation in the summer season.

While potable water use is not expected to be disrupted significantly, non-potable water use may contribute to compounding vulnerabilities at the surface due to higher water use in local areas that already exhibit current levels of stress (e.g., Fletcher's Creek, Cheltenham to Glen Williams, the West Humber and the Etobicoke Headwaters). Finally, aquatic habitat diversity is likely to be disrupted due to warming of surface waters as a result of less groundwater support (baseflow) in the summer season needed to assimilate heat loading from direct solar radiation.

6.1.2. *Aquatic System*

The following section is largely a discussion of climate sensitive conditions within and affecting rivers, streams and valley corridors as these components reflect the majority of available monitoring data, information and understanding for the aquatic system in Peel Region. An overview of inland lakes and ponds is provided but is limited by the age and type of data (not necessarily climate relevant). Heart Lake is the waterbody that has been most widely characterized, which is fully detailed as a storyline focal area (Section 6.2.1). As discussed in Section 4, the Lake Ontario shoreline and nearshore area were taken out of scope with respect to detailed characterization; a narrative is provided to touch on the 'hot issue' of algal blooms (see Box 1) and the *Peel Region Water Infrastructure Vulnerability Assessment* (in progress) will include the shoreline and nearshore area from a water quality perspective. The discussion of wetland conditions and vulnerability, including riparian wetlands, is presented in the Terrestrial System (Section 6.1.3), and is also described as part of key findings in section 7.

Table 12 presents local characteristics or vulnerability factors of Peel's aquatic system that help determine this system's relative vulnerability to climate change. Figure 14 illustrates some of the processes or pathways that may be disrupted in the aquatic system when exposed to increased temperature and precipitation by the 2050s: a hotter, drier summer on average. It should be noted that this figure 14 is not meant to be comprehensive but rather illustrative of the complexity that climate conditions can cause in cascading impacts or changes in aquatic ecosystems. As a result of changes to ecological processes, the ecosystem services that may, in-turn, be affected are listed at the bottom of the diagram.

Table 12: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Peel Region's Aquatic System

Components	Vulnerability Factors	Vulnerability Indicators
• Rivers, Streams and Valley Corridors • In-land Lakes and Ponds	• Thermal Gradient/Regime • Flow Variation • Degree of Connectivity (Hydrologic) • Water Chemistry • Community Range • Pervious Cover • Urban Forest Canopy	• Water Temperature • Baseflow • Total Phosphorus • Natural Cover • Urban Forest Canopy

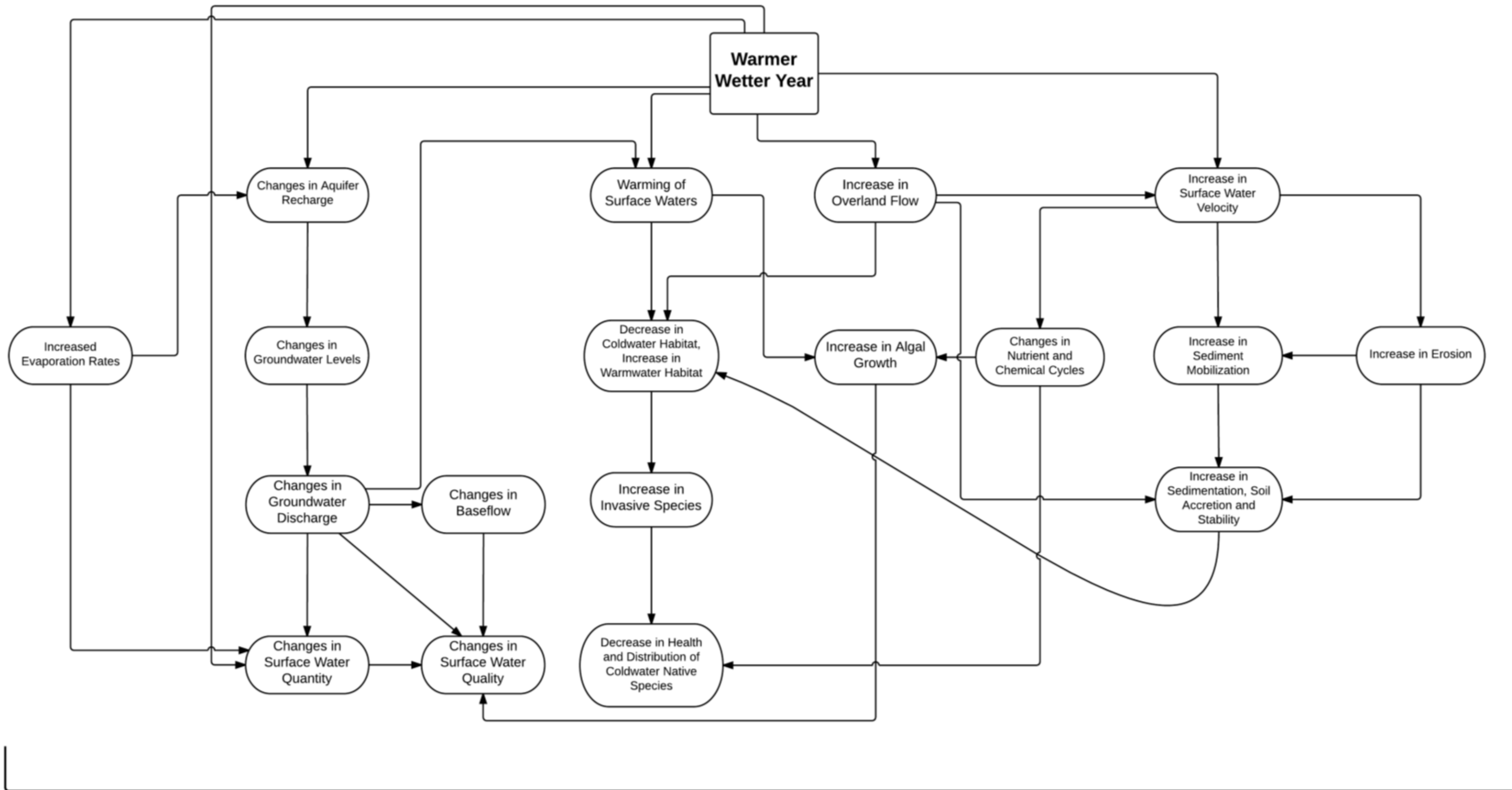
Box 1: Algal Blooms, Warmer Winters and Lake Ontario

Several ecosystem services along the Lake Ontario shoreline may be affected by a changing climate. While it is difficult to predict the end result of changes in the complex interactions in both the living and non-living components of this ecosystem, several potential changes, related to invasive species, and water quality, may influence adversely recreational and water use services along the Lake Ontario shores.

Degraded water quality from high nutrient levels in the nearshore areas of the lake is already an issue of increasing concern in neighboring jurisdictions. The levels of nutrients in the nearshore can be influenced in several ways, including inputs from rivers and physical conditions in the lake, both of which are influenced by temperature. Phosphorus (P), a key nutrient affecting water quality (by promoting the growth of algae), is delivered from the landscape to the lake via the rivers that drain them. Storms and snow melt events are responsible for much of the P washed from the land to rivers. Increasing winter temperatures and increasing storm event intensity, both potential effects of climate change, may therefore increase the amount of P transported by melt events and storms to the lake nearshore and may ultimately increase the frequency or severity of algal blooms. Additionally, the direct effect of increasing the water temperature of river and nearshore waters may promote more rapid growth of nuisance and harmful algae, exacerbating the impact of P supplied by rivers.

Climate change may also affect how P is processed by the invasive zebra and quagga mussels that now inhabit many of the nearshore regions of the lake. These mussels filter P from the water, depositing it at the lake bottom, where it fuels the growth of nuisance algae (such as Cladophora). Increasing temperatures may increase the rate at which mussels filter, thereby increasing the amount of P deposited at the lake bottom and increasing the amount of nuisance algae that can be supported.

The above changes, interacting with other phenomena that may be affected by climate change, such as lake circulation patterns and water levels, add further dimensions of complexity and uncertainty in our ability to predict the net effects to nearshore water quality and consequent changes in the lake nearshore. However, several lines of evidence suggest that climate change may exacerbate degraded water quality with periods of impairment and ultimately impact recreational activity and potentially water use.



Ecosystem Services Potentially Affected

<u>Ecosystem Services</u>
- Water Quality Regulation
- Air Quality Regulation
- Regulation of Urban Heat Island
- Regulation of Erosion (soil, sediment)
- Flood Attenuation
- Moderation of Rate of Spread/Establishment of Invasive Species
- Recreational Benefits (hiking, cycling, bird-watching, angling, etc.)
- Water Use (Potable)
- Habitat Diversity

Figure 14: Impact Pathway Diagram Highlighting Climate Change Impacts and their Complex Interactions in the Aquatic System

Current Conditions in Peel's Aquatic System

Generally the rivers and streams within Peel Region start as groundwater fed systems which typically form as small cold water habitats in the headwaters; as the rivers flow down through the watershed, and gain volume as tributaries converge, the rivers begin to warm. Some first order streams are also found along the escarpment outside of Peel and are intermittent, picking up groundwater further downstream as they flow in Peel. Current conditions of the watersheds within Peel Region have illustrated that there are still areas of high ecological function that support the majority of the remaining aquatic species abundance and diversity (CVC, 2007; TRCA, 2007, 2015a). There are two endangered fish species within the Humber and Credit River watersheds: Redside Dace (*Clinostomus elongatus*) and American Eel (*Anguilla rostrata)* as well as one dragonfly, Rapids Clubtail (*Gomphus quadricolor)* (Committee on the Status of Endangered Wildlife in Canada, 2007, 2008, 2012).

There are also areas of lower aquatic ecological function that have been significantly degraded and fragmented over time, particularly in the lower portions of the watersheds in the highly urban areas. These impacted reaches typically exhibit lower overall species abundance and diversity, have the lowest stream health scores (Index of Biotic Integrity [IBI]), and have generalist (tolerant) species that dominate the aquatic community (TRCA, 2015a).

Thermal Gradient: Warming in Rivers and Streams & Species Tolerance

There are three thermal habitat regimes found across the four watersheds in Peel Region: coldwater, cool (or mixed) water and warmwater. Aquatic monitoring stations in both CVC (23) and TRCA (32) watersheds collect stream temperature data; CVC has developed summer targets for the 3 thermal habitats largely based on biological tolerance of fish. This assessment used CVC's Absolute Maximum Summer Water Temperature targets (see Table 13) which is the greatest water temperature recorded from June to September and provides a measure of short-term temperature stress experienced by aquatic organisms (CVC 2013a). Figure 2 in Appendix G maps these spatially, where available, throughout the Credit River watershed in Peel. The acute, short-term stress target was used to analyze stream temperature monitoring data and determine where sensitive fish species, such as Brook Trout (*Salvelinus fontinalis*) or Redside Dace, are potentially exposed to the upper range of temperatures, including sub-optimal and lethal conditions; unless they are able to freely move to and from pockets of thermal refuge (e.g. deep pools).

Table 13: Absolute Maximum Summer Water Temperature Targets for Thermal Regimes

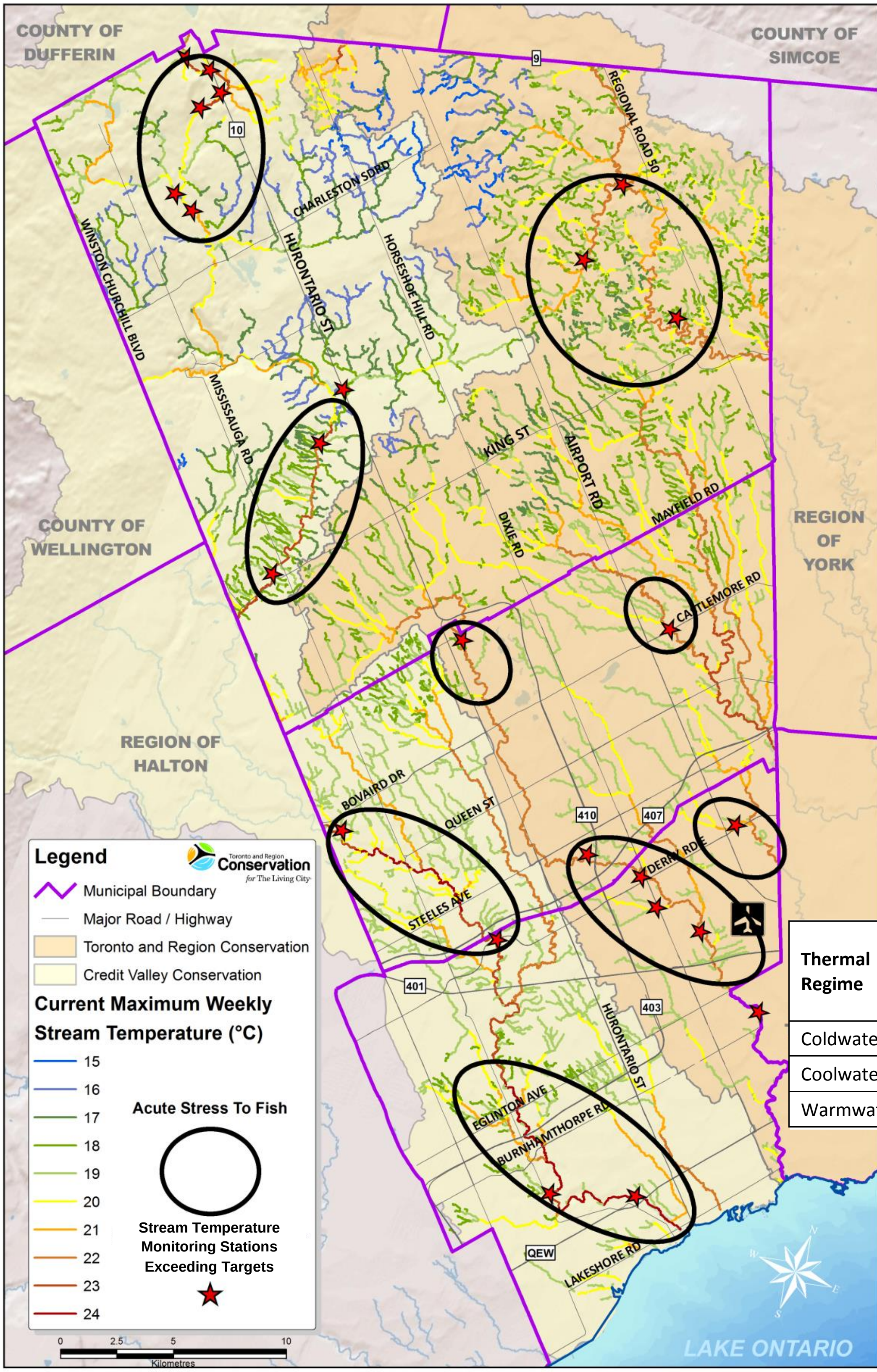
Thermal Regime	Thermal Targets (0°C)		
	Coldwater	Mixed (Cool)	Warmwater
Absolute Maximum Summer Water Temperature	26	28	30

Using both TRCA and CVC maximum summer stream temperature values for similar climatic years (2011 and 2013 - average air temperature and close-to-average precipitation as rain; see Table 9), nine areas of acute thermal stress appear throughout Peel, and not just in highly urban areas where land surface temperatures can be higher than 36°C in mid-afternoon (see spatial mapping of land surface temperatures in section 6.1.3). Thermal “hot spots” in 2011 or 2013 occur in several reaches of the main stem of the Credit River, west branch of the Etobicoke Creek and main branch of Centreville Creek as it flows into the main stem of the Upper Humber River. Generally, tributaries appear less impacted but they are also less represented in the data sets due to monitoring station locations. A take-home message from this analysis is thermal stress was measured in a ‘normal’ climate year; in a hotter and drier than average year (e.g., 2012) stream conditions would likely be even warmer (stream temperature data not available for TRCA watersheds in 2012 to conduct this additional test).

These stream temperature targets were also used to consider empirical modelled outputs of Maximum Weekly Average Stream Temperature (MWAT), a metric linked to fish distributions and quantify the hottest and potentially biologically limiting conditions for biota in streams (C Chu 2015). The Chu (2015) study looked at streams in Peel Region and used a ratio of projected change in air temperature and precipitation based on the A2 scenario in the previous generation of IPCC modeling (CMIP3 in 2007). Specifically, it was assumed that a 10% increase in precipitation is needed to offset increases in evapotranspiration associated with 1˚C of warming. Thus, low ratios of temperature-to-precipitation calculated for a particular area imply low vulnerability, and vice versa. The model considers air temperature, baseflow support to streams (which provide thermal cooling if present in sufficient quantity), slope of the stream and the stream order.

Chu’s (2015) stream temperature modelling results (see Figure 15[2]) show highest thermal values for MWAT (22°C - 24°C) in reaches spatially consistent with the acute thermal stress areas, suggesting high likelihood of biologically limiting conditions occurring for aquatic biota in these same ‘hot spots’ (note, modelling uses data from a broader set of climate years but appears to underestimate maximum summer temperature values and overestimates extent of coldwater habitat, at least in Peel Region; potential explanation is the model does not consider the effects of urbanization, water taking or stream regulation). Research into thermal tolerance of Brook Trout, informed by field observations of fish occupation, indicate this coldwater species is rarely found in streams with 60 day mean temperatures above 21.0°C; lethal conditions are above 24°C for more than 24hrs (Wherly *et al*., 2007). The TRCA aquatic monitoring station in Centreville Creek (HU33), located just downstream of an on-line pond in Albion Hills Conservation Area in the Upper Humber River catchment, was the only TRCA coldwater habitat station in Peel to fail this 60 day test; as validation, no Brook Trout have been collected at this station since regional monitoring began in 2001 to present (see Section 6.2.3 for more discussion). This analysis was not available for the Credit River.

[2] Station data from 2011 for Credit, Humber, and Etobicoke Watersheds, and 2013 for Mimico Watershed



Thermal Regime	Absolute Max Summer Water Temperature Targets (˚C)
Coldwater	26
Coolwater	28
Warmwater	30

Figure 15: Current Maximum Weekly Average Stream Temperature (MWAT) across Peel Region and Areas of Acute Thermal Stress to Fish

Flow Variation: Total Annual Flow and Baseflow

Total annual streamflow provides guidance on the state of the overall hydrologic regime and flags trends (such as increasing flows) that may have impacts to stream habitat or produce phenological disruptions for aquatic species adapted to certain cycles (e.g., high water levels associated with spring spawning migrations or inundated habitat). Flow patterns vary across spatial habitats and reflect the underlying geo-physical stream processes that give rise to evolutionary adapted biota. For example, small, intermittent headwater streams experience huge ranges in seasonal and event-based flow conditions while first order permanent, coldwater streams are generally quite stable in both flow volume and thermal conditions; the latter supporting fish with narrow thermal tolerances and/or require reaches with ice-free flow year round for winter egg survival. Accordingly, different stream forms, functions and communities have greater or lesser adaptive capacity to changes in natural flow variation. It is this theme that the following section will explore with respect to current stream conditions across Peel Region.

Streamflow variation is based on stream gauge data that largely reflect main stem or otherwise permanently flowing, higher order streams where instrumentation can be properly installed. Extrapolation is made, as necessary, to smaller tributaries and intermittent or seasonal streams where data are not well represented. Both total annual flow and seasonal low flow are discussed.

Variability in annual streamflow in the Credit River Watershed is pronounced over the monitoring period (7 gauges, all longer than 10 years; one, located in Cataract, since 1916 to present), however, time series analysis indicates there are few statistically significant trends in flow variation through time (CVC 2013a; CVC 2012b). This implies the overall flow regime, at the watershed scale, is not highly altered and there is an existing tolerance or resiliency to natural and sometimes large fluctuations. There are some notable exceptions to this trend at the subwatershed or reach scale, which are discussed in more detail as part of the Upper Main Credit and Tributaries and Cooksville Creek focal area storylines (see section 6.2.3).

The following description of annual streamflow variation in the Peel portion of the Humber River is adapted from the *Humber River Scenario Modelling and Analysis Report* (TRCA 2008d). The surface water hydrology regime in the Humber River watershed is highly variable over the monitoring period (3 gauges in the Main Humber and 1 in the West Humber that have long enough time series to establish a baseline period). Geology, topography, and land use vary significantly between catchments resulting in a diversity of surface water flow regimes with widely differing baseflow and surface run off contributions. A substantial portion of the watershed in Peel remains rural or natural, sustaining relatively natural, dynamically stable surface flow regimes in northern areas, although development is expanding rapidly in places like Caledon East and Bolton, with the latter having to implement flood management measures (see section 6.2.3 for more on conditions in Bolton and downstream effects).

Further to the south, ongoing development in Brampton has begun to alter the West Humber flow regime in lower reaches where surface run off already makes up a large portion of the total surface flow regime due to the less pervious, clayey surface soils and underlying geology limiting infiltration and recharge. The last streamflow assessment for the West Humber was undertaken in the mid-2000s (using TRCA ortho-imagery 2002 land cover) and although no appreciable upward trends in total annual flow volumes were identified, this may shift as Official Plan build-out is completed.

Historical streamflow data analysis showed that mean annual streamflow in both the Etobicoke and Mimico watersheds has increased over the past 40 years (27% increase in Mimico Creek and 44% increase in Etobicoke Creek), and the increase has been accelerating for the past 10 years (with a 60% increase measured over this time period) (TRCA 2010a).

Although baseflow is groundwater that discharges to the stream year round, considering the seasonal conditions is critical; summer low flows can determine survival of both young and adult fish as thermal stress can become limiting and winter low flows protect eggs of some fish species from ice formation and freezing. Monitoring these flow conditions is also important to ensure that minimum flows are maintained to support water takings and the assimilation of stormwater and wastewater discharges. There are many different indices that are available to measure low flow and determine if impacts are likely. Over the years, different indices have been used to report baseflow conditions in Peel watersheds; deciding if one index or methodology is better than another is beyond the scope of this assessment. The following sections describe how baseflow in the various watersheds across Peel have responded over time and/or to specific climatic years.

Approximately half of the Credit River's average flow comes from groundwater and during periods of drought, groundwater becomes the primary source of water to streams in the Credit River watershed (CVC 2013a). Since the construction of the Island Lake Reservoir to augment low flows, low water conditions have been rare in the Credit River (largely represents understanding at the subcatchment scale) which is reflected in CVC's *Integrated Watershed Monitoring Program: Ten-Year Review (1999 – 2008) Technical Report Draft* (CVC 2012b) that indicated lowest average summer month flow values for the Upper Credit River gauge stations (Melville and Cataract), for the ten-year period (1999-2008), are well above the range of values established for the historical period of available streamflow records (by 33% and 62% respectively). Historically, "it appears" that low water conditions have been relatively infrequent in the Credit, with droughts occurring ten times over the course of 21 years (1994, 1995, 1998, 1999, 2001, 2002, 2003, 2007, 2012 and 2015), with low water levels throughout that period of record observed in 2007 and 2015 at West Credit River and Silver Creek. A more rigorous examination of the data will be required to fully understand low water levels through time. However, the following consideration of inter-annual climate and low flows suggests a regulating relationship does exist, and that streams are vulnerable when exposed to drier and hotter than average conditions (e.g., low baseflow component from groundwater). It is noted that the influence of any increased water taking during hotter, drier years may also play into this relationship; water taking records were not reviewed in this assessment.

As described earlier in this section, the year 2011 was wetter than normal but average temperature. Under this climate, the summer low flow measured at the Cataract gauge (within Caledon area) exceeded the minimum flow requirements as calculated using the Tessman method, implying sufficient streamflow at this station to support ecological function (CVC 2013a). The Tessman method is intended as a first order estimation of ecological flow requirements. However, in 2012, a drier and hotter year than average (see Table 9), the Credit River Watershed was raised to a level 1 low water condition where residents were asked to voluntarily reduce water use by 10 percent (CVC 2013a). This request was in keeping with the *Ontario Low Water Response*[3] which uses the Lowest Average Summer Mean Flows (LASMF) as a streamflow threshold value to identify low water conditions requiring a legislative response. Low water conditions are identified when monthly mean flows fall below 100% of the LASMF during the spring (April to June), and below 70% of this threshold value in all the other seasons (July to March*).* Moving ahead to 2013, a drier than 'normal year' but with average temperatures, the monthly mean flows at three gauge stations in the Upper Credit were analyzed as part of a *Watershed Health Bulletin* series issued by CVC (CVC 2014b; CVC 2014a; CVC 2014c): Shaw's Creek (captures flow through upper west corner of Caledon), Glenn Williams gauge (captures flows draining parts of Caledon), and East Credit River Gauge (within Caledon) were all above historical minimums or 95th percentile flows (Q95 in the record from 2001 to 2012) and all exceeded provincial streamflow threshold (LASMF) values for low water conditions. No "low water alerts" were issued for 2013 in the Credit River watershed.

In terms of TRCA watersheds within Peel, groundwater discharge accounts for the majority of total flow volume in the upper Humber River due to the relatively high recharge rates as discussed in section 6.1.1 of this report; only about one third of total flow in the West Humber arrives as baseflow (see section 6.2.3; and TRCA, 2008b). Past reporting in this watershed has used the low flow index 7Q20 as a guide to determine if baseflows are going below extremes of low water when, presumably, potential for thermal stress to biota would be highest. The 7Q20 is the discharge having a 20-year return period derived from a frequency analysis of the lowest average flow for seven consecutive days in a year (Pryce 2004; James 1995).

Using the median of the mean daily flow rate in the spring-summer months, neither the Main Humber (0.810 $m^3 s$) nor the West Humber (0.047 $m^3 s$) dropped below their respective 7Q20s (0.584 $m^3 s$ and 0.001 $m^3 s$) for the period of 1997 – 2003. This series of years represent a range of climate conditions, including consecutive years of hotter and drier than average conditions (i.e., 2001 to 2003). Similar to the long-term monitoring for the Credit River, this analysis and was conducted at the catchment scale and suggests that processes governing groundwater discharge and support baseflow are, on average, not highly sensitive to climate variation experienced to date; however, at the stream reach scale and where groundwater is shallow, stream vulnerability appears to increase as specific areas in the West Humber (north of Mayfield Rd) have been reported as dry during summer months (see Section 6.2.2 for deeper examination of the West Humber River). No municipal supply water taking affects this catchment but the West Humber, along with four other areas in Peel, have been identified as "moderately" or "significantly stressed" from non-municipal supply water taking activities (see

[3] http://www.mnr.gov.on.ca/en/Business/Water/Publication/MNR_E002322P.html

discussion on Tier 1 Water Budget Assessment in Section 6.1.1); this likely plays a role in stream vulnerability to drying.

Unlike the Credit or Humber Rivers, mean summer baseflow in Etobicoke Creek has been increasing by 1.3% per year since 1967; larger increasing trends have been observed during the most recent 10 year period (1997 to 2006) (TRCA 2010b). Some of the increase in baseflow may be attributed to the rising groundwater levels in the Brampton Esker area coincident with the cessation of quarry activities, as discussed in the Groundwater System (section 6.1.1) but also urbanization (e.g., leaky pipes or pipes that wick shallow groundwater directly to streams). In contrast, mean summer baseflows in Mimico Creek have decreased by 0.3% per year since 1966, but increased by 2.5% per year in the last 10 years, possibly associated with urbanization. Although half the years in the recent 10 year period had normal or in excess of normal annual precipitation which suggests that this system may be quite sensitive to the distribution of precipitation over the year (TRCA 2010b); perhaps analyzing flow data in relatively dry years would reveal a correlation with lowest baseflows and provide greater understanding of climate sensitivities (such analysis was not part of this assessment).

Again, at the stream reach scale, two low order streams in Etobicoke Creek were classified as “highly vulnerable” in the watershed plan update (TRC, 2010b) as water users could potentially take more than 25% of measured baseflow and these streams were observed as dry during 2007 field measurements (Etobicoke Headwaters and Tributary 4 in Spring Creek); 2007 was a very dry year but with average air temperatures (see Table 9).

In summary, summer baseflows within the main channels and some larger tributaries of the four watersheds in Peel Region are, on average, not an issue from a low flow response perspective across variable climate years, however, specific stream reaches are experiencing water and/or acute thermal stress in the Main Credit River, West Humber tributaries, Etobicoke Creek Headwaters and West Branch and Upper Mimico tributaries (note, section 6.2.3 discusses water and thermal stress in Fletcher’s Creek, part of the Credit watershed). This suggests that current amounts of baseflow, at the reach scale, are not sufficient to buffer thermal loading from direct radiant heating and/or warmed surface run off (e.g., from on-line ponds/reservoirs in the north and/or urban drainage in the south). This also suggests that using current low flow thresholds as a management tool, such as 7Q20 or LASMF, may not adequately prevent thermal impacts to aquatic organisms that are scale dependent. The consideration of whether current baseflow adequately maintains hydrologic and hydraulic connectivity through the stream network will be explored in the next section.

Hydrologic Connectivity: Baseflow to Aquatic Features

When water depths in a stream declines sufficiently, or go dry, the connectivity between habitat sites is reduced, or lost. This can be highly impactful should aquatic organisms become stranded in sub-optimal habitat or not have the mobility to leave a dried stream bed (e.g., eggs or benthic invertebrates). When stream drying is within the natural flow variation, species occupying this habitat are generally adapted to the no-water period, and display survival traits or behaviours, providing it does last too long (e.g., mussel species will burrow into moist sediments). Natural cycles of stream drying and aquatic community response are not well studied in Peel watersheds, however, aquatic connectivity is also impacted by the construction of in-stream structures that prevent or impede fish passage during summer low flows, and this has been reasonably well assessed and reported.

Generally speaking, the degree of connectivity through the aquatic system in Peel Region is fragmented for both riverine ecology and human recreation (Planning and Engineering Initiatives Ltd, 2005; TRCA 2010c) (MNR and CVC 2002). This has been caused largely by human-made dams and weirs constructed over time for flood control, grade control, power, irrigation and aesthetic purposes; perched culverts are also prevalent and present issues for fish movement (MNR and TRCA 2005; CVC 2009a). Although the physical structures themselves are not influenced by climate, the amount and temperature of baseflow between barriers can be sensitive to precipitation patterns and/or air temperature (as discussed earlier) and could limit fish survival, favouring the thermally tolerant and/or agile jumpers/swimmers. Increased precipitation also results in increased total flow, which can decrease permeability in areas that are constricted in the aquatic system. Dams and ponds can also alter river hydrology upstream and downstream, affecting water quality, quantity as well as aquatic ecology (CVC 2009a). On the other hand, physiography across Peel's landscape, such as the Niagara Escarpment that bisects the Credit River watershed, can limit connectivity of species as well.

To confirm whether or not an in-stream structure presents a barrier to all or some fish movement, field verification during summer baseflow periods is required. A field-based in-stream barrier assessment has been completed for Etobicoke and Mimico Creeks. Less is known about the Humber River and Credit River beyond locations of large dam structures and, for the Humber River, ortho-photography interpretation that provides a rough estimate of potential barriers to fish passage.

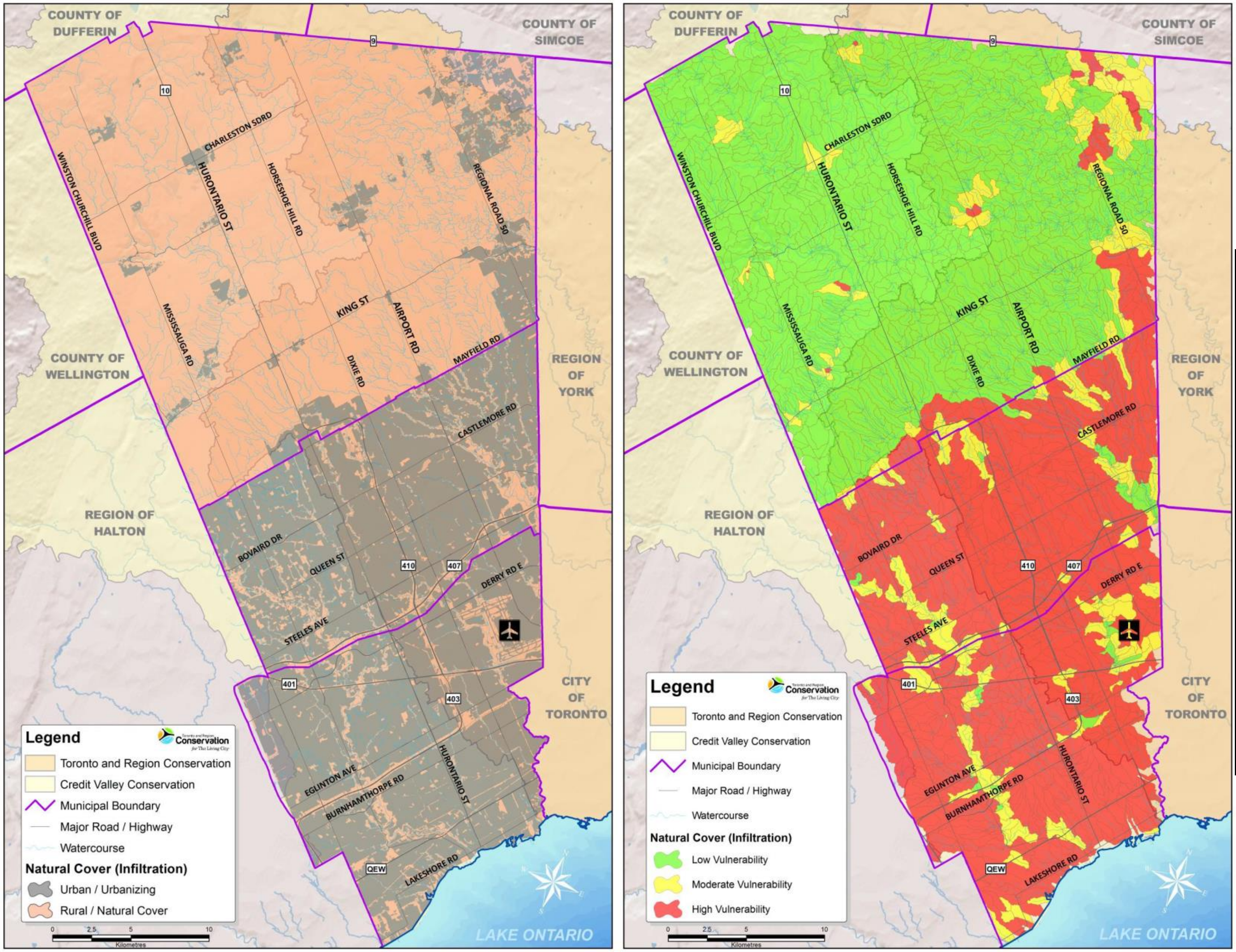
The Etobicoke Creek in-stream barrier assessment confirmed there are a total of 304 barriers to fish passage within 150 km of watercourse. Of those 304 barriers, 179 barriers prevent the passage of non-jumping species, and 125 barriers prevent the passage of jumping species (TRCA 2010b). The issue of habitat fragmentation is greatest in Little Etobicoke Creek and Spring Creek; while there are lengthy portions of the Etobicoke Creek West Branch that remain open with few anthropogenic barriers (TRCA 2010b). The Mimico Creek in-stream barrier assessment confirmed the presence of 271 barriers to fish passage along 57.2 km of watercourse. Of those 271 barriers, 145 barriers prevent the passage of non-jumping species, and 126 barriers prevent the passage of jumping species (TRCA 2010b).

As reported in the *Humber River Fisheries Management Plan* (MNR and TRCA 2005), over 110 in-stream barriers such as dams or weirs have been identified throughout the watershed (survey did not include the West Humber River) though many more exist. Preliminary investigations have identified 1,201 potential in-stream barriers and stream crossings across the entire watershed that could be limiting the movement of fish and other aquatic species (MNR and TRCA 2005). From this initial inventory, in-stream structures include four dams, four ponds, seven weirs, 1,100 road crossings, 25 railroad crossings and six trail crossings. An additional 61 structures have not yet been formally classified. It is likely that many of the road, railroad and trail crossings do not actually prevent fish passage, but formal barrier assessments are required to confirm which ones are barriers, either partial or complete, and to set priorities for mitigation. The specific portion of in-stream barriers, actual or potential, within Peel Region was not calculated. Various methods for mitigating barriers have been applied at major dams in Toronto and Woodbridge which facilitate overall passage of fish into watercourses that flow through Peel Region; two smaller dams, one in Palgrave and the other Bolton have also been mitigated.

According to the *Credit River Fisheries Management Plan* (MNR and CVC 2002), an accurate inventory of the ponds (associated with dams/weirs) in the Credit watershed has not been done, except in the West Credit subwatershed (outside of Peel Region boundary) where over 300 ponds were identified. However, in 2005 CVC developed a detailed inventory of 37 major dams, and has identified just over 500 on-line ponds assumed to have dams. Culvert inventories are in progress, except for some Subwatershed Study inventories (e.g., Barriers on Cooksville have been classified on a sliding scale of passage depending on season/flow). Although some of the larger dams and ponds across the watershed are easily identified and accepted as permanent features, they require active management and pose great potential risks and opportunities for rehabilitation. The larger dams within Peel Region include: Streetsville Dam, Norval Dam, Belfountain Dam, and un-named dam on East Credit River; there is also the South Dam associated with Island Lake (reservoir) just north of Peel that is close enough to influence temperatures and baseflows in the main Upper Credit as it flows through north Caledon. Through implementation of the Credit River FMP, fishways have been constructed at 2 of the major dams (Streetsville and Norval). Furthermore, in 2005, CVC undertook a Dam Assessment Study (PEIL Consulting, 2005) to inventory in greater detail the number of dams throughout the Credit and to create a method for identifying high priority dams for management. A total of approximately 550 dams were identified in the Credit River watershed (CVC 2009a). A set of criteria for each minor dam was used to develop a method of ranking based on: (1) impoundment size, (2) stream order, (3) physiography-based fish community type and (4) stream discharge/recharge status. From this work, CVC is currently creating a GIS-based tool to prioritize dam mitigation in the Credit River watershed based on available information such as ortho-photo interpreted inventories, the distance of stream between upstream and downstream dams, pond area and fisheries management communities. It is anticipated that this tool will be finalized in April of 2017.

Pervious Cover: Stream Condition and Flooding

The more paved surface area there is (or less pervious cover), the less opportunity for attenuation and infiltration, and as a result, more over land flow is generated to rivers and streams; the greater the impervious condition of the catchment the greater the controlling influence precipitation has on watercourse form and function (Center for Watershed Protection 2003). As part of this study, the distribution of natural cover was used as an indicator of pervious cover to identify areas of current high, medium and low vulnerability as it relates to infiltration mechanisms and the potential for overland flow or flooding (see Figure 16) and also see section 6.1.3 Terrestrial System for more discussion on soil, slope and vegetation properties that govern infiltration and attenuation processes and regulate runoff and flooding).



Range-based Thresholds applied to characterize the gradient:

Low Vulnerability: Upper third percentile of natural cover in Peel

Moderate Vulnerability: Middle third percentile of natural cover in Peel

High Vulnerability: Lower third percentile of natural cover in Peel

Figure 16: Ortho-Interpreted Natural Cover (A) and Vulnerability Characterization of Natural Cover (Infiltration) at the 30ha Catchment Level (B)

This GIS analysis reveals general spatial patterns for where higher run off volumes may be experienced by rivers and streams (i.e. lowest amounts of natural cover), however data delineating current in-stream geomorphological conditions (e.g., channel erosion, widening or depositional areas) were not available in sufficient or consistent coverage across Peel watersheds to spatially verify effects of 'higher run off' areas, thus the following section focuses on the relationship between higher run off and areas of acute thermal stress.

Typically there is more paved surface area present within the southern half of Peel Region, as urban expansion is generally occurring from south to north (CVC 2007a; TRCA 2007). The West Humber is particularly deficient in pervious green space in the southern half (TRCA 2008c), and similarly, about 88% of the Mimico Creek watershed and 63% of the Etobicoke Creek watershed are designated as urban (TRCA ortho-imagery 2002), resulting in a high degree of impervious cover (TRCA 2010a). These descriptions of where paved surfaces dominate are spatially consistent with Figure 16 and where current areas are highly vulnerable to generating more run off (low natural cover; low infiltration). The small pockets of urban development in the northern half of Peel (Caledon, Palgrave and Bolton) also reveal the pattern on low natural cover and associated high vulnerability.

Bringing this information to bear on where acute thermal stress is currently experienced (Figure 16), all impacted locations, except the two in the upper half of the Credit River, are found in catchments dominated by low natural cover/high vulnerability. Despite the amount of natural cover, in most cases, being relatively higher along the valley-stream corridor, summer thermal stress is not surprising when mid-afternoon land surface temperatures in June are factored-in and a summer rainstorm may flow over ground 29°C – 36°C or hotter. A closer look at why the Upper Credit River monitoring stations are measuring elevated temperatures, despite highest range in natural cover/low vulnerability and much lower land surface temperatures (<25°C) is described in the Upper Main Credit to Cheltenham storyline (see section 6.2.3).

When the rainfall is intense enough and of sufficient duration in a given area, soils, if present, become saturated and associated infiltration or attenuation processes are overwhelmed; in simple terms, this is a riverine flooding[4] scenario. Flood Vulnerable Structures (FVS), Flood Damage Centres (FDC) and Special Policy Areas (SPA) are all present in Peel Region (see Figure 16). Each term is defined below:

Flood Vulnerable Structure (TRCA 2014b): Sub-area within the regulatory storm floodplain containing structures and/or roads for which a single, comprehensive flood remediation approach may be viable.

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[4] The inundation of areas adjacent to a shoreline or a watercourse and not ordinarily covered by water that is beyond bankfull discharge (TRCA 2014b) [Additional details are provided in Appendix A - Glossary]

Flood Damage Centre (CVC 2009c): A cluster of buildings that are prone to flooding. There are a total of 22 flood damage centers (more than 600 buildings) within the Credit River and its tributaries. These flood damage centres are areas where buildings and other structures have been established within the floodplain prior to establishment of floodplain protection area. Each damage centre has a different level of concern depending on the number of buildings within the flood plain and the amount (and depth) of flooding which may occur. For example, the depth of flooding expected in one damage centre may be in the order of centimeters, while another may expect several metres. Given that the majority of the watershed population lives in the lower watershed, the majority of the flood damage centres are located here.

Special Policy Area (TRCA 2014b): An area within a community that has historically existed in the floodplain where site-specific policies, approved by both Ministries of Natural Resources and Forestry and Municipal Affairs and Housing, are intended to provide for the continued viability of existing uses (which are generally on a small scale) and address the significant social and economic hardships to the community that would results from strict adherence to provincial policies concerning development.

These FVSs, FDCs and SPAs represent riverine flooding that place people, property and infrastructure directly at risk; and are generally found in older urban areas that were built before flood plain regulation was in effect and, in many cases, transformed multi-functional, flood-adapted streams into single-purpose, mal-adaptive and hardened conveyance channels that are under-capacity to service the range of surface flows experienced today. Also, the pattern of natural cover distribution is as expected, that is, catchments with the lowest range of natural cover (or higher impervious cover) are coincident with the majority of current flood vulnerable areas. Notably, these areas likely also place additional stress on wildlife as well, given the modification that has occurred to natural habitat and vegetation along valley corridors.

A review of flooding in the Credit River indicated that even though there was no significant trend in the number of flooding incidents, the timing of the maximum daily water level has become increasingly variable, possibly as a result of climate change (CVC 2013a). The same report revealed in the early to mid-1900s, maximum daily water levels most often occurred in spring. Increasingly from the mid-1900’s forward maximum daily water levels are occurring during winter and fall. This shift in timing of maximum water levels may result in increased risk of winter or fall flooding.

Generally speaking, large scale flood events are actually not a primary concern for the greater ecology of river and valley corridors, lakes or their resident communities. A healthy stream (e.g., not disconnected from its natural floodplain, not narrowed or urbanized, etc.) is expected to erode and deposit sediments over low, bankfull and flood stages in order to re-create and maintain habitats (MNR and CVC 2002). Periodic flooding is a natural process and part of a healthy aquatic system dynamic and, all things being equal; resilience to this perturbation is high[5]. River systems in Peel that accommodate and cope well with natural riverine flooding do so in the presence of wide floodplain areas extending beyond the banks of watercourses, which is common in newer urban and natural areas (TRCA 2015b). Where wetlands and small streams are still abundant and distributed (e.g., in the northern portions of Peel), they help reduce the frequency of threatening events by stabilizing water levels, absorbing flow when it is abundant and replenishing water during periods of droughts (TRCA 2007).

Native aquatic species have evolved to take advantage of natural fluctuations in surface water flow, adapting to historic variations in rainfall/runoff characteristics; fish spawning, rearing, and migration typically occur in the spring or fall, which coincides with flood events or higher baseflows and runoff volumes (TRCA 2015e). Although this relationship is recognized, the effects of flooding on the ecology of aquatic communities in Peel Region have not specifically been studied. It is however, known that most of the energy in small natural streams comes from external, or allochthonous, sources (i.e. nutrients, leaves, and twigs, etc.) from the nearby floodplain/riparian habitats, during flooding events (Hynes 1975). As well the components of a river's natural flood regime (magnitude, frequency, duration and timing of high flows) interact with the channel to maintain greater habitat and species diversity as well as ecosystem productivity (Poff 2002; Peters *et al.* 2015). Likewise, the current role of flooding as a mechanism for invasive species expansion/movement (aquatic plants and fish) across Peel has not been estimated.

In addition to natural cover amount and flood vulnerability, SWM also plays a large role in the state of urban hydrology, and for many of the older urban centres across Peel Region, current levels of SWM practices are not adequate to achieve overall quantity targets (TRCA 2010a) and urban flooding becomes the greater risk. Focal area storylines for Fletcher's Creek and Cooksville Creek (section 6.2.3) explore some or all of these themes in more detail. Focal area storylines are in-progress for Etobicoke Creek West Branch and Spring Creek, both of which will also include more discussion of urban hydrology issues.

In Figure 17, Special Policy Areas in Peel Region are illustrated in black circles. Data were unavailable for structures in the Credit Watershed in Brampton and Caledon. Notably, hydrology and existing floodplain mapping in the Etobicoke Creek Watershed is currently being updated by the TRCA and as a result some existing flood vulnerable structures may change (and some flood vulnerable structures may be added).

[5] http://www.americanrivers.org/

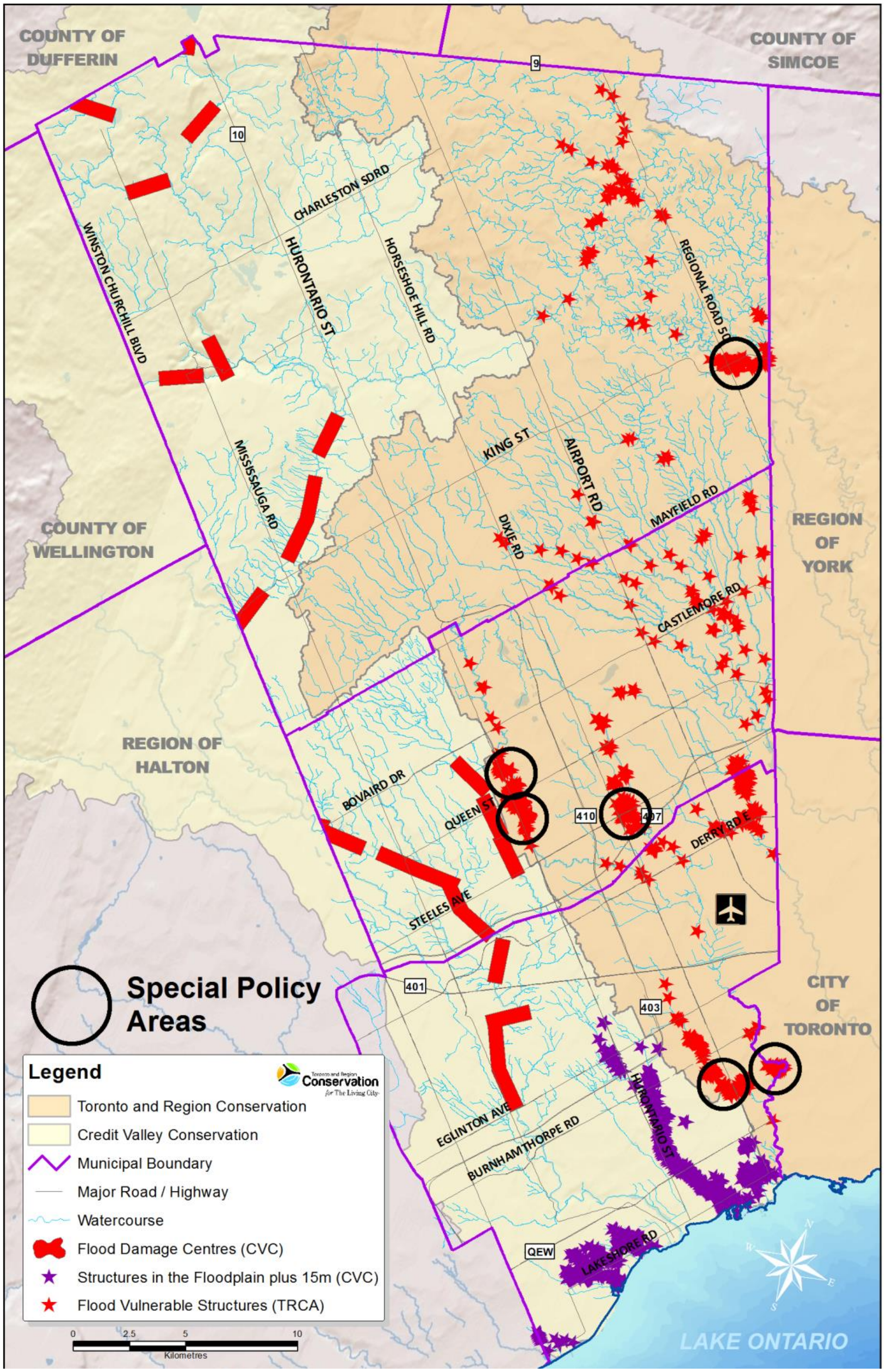


Figure 17: Locations of Flood Vulnerable Structures (TRCA), Structures in the Floodplain plus a 15 metre Buffer (CVC), and Flood Damage Centres that illustrate Clusters of Buildings Vulnerable to Flooding (CVC)

Water Chemistry: Total Phosphorus Levels in Rivers and Streams

Total Phosphorus is a nutrient compound that stimulates plant and algae growth. At elevated concentrations, phosphorus can have negative effects on receiving waters, such as eutrophication. This can cause intense algal blooms, decreases in ecologically sensitive species, increases in tolerant species, and anoxia resulting in fish kills (CVC 2012b; TRCA 2015b). A significant positive relationship was found between median total phosphorus concentrations (along with other contaminants) and urban land cover (TRCA 2015b)

Based on 10 years of monitoring data, the water chemistry in the Credit River watershed varies from good to poor with low water quality stations generally receiving much of their water from Water Pollution Control Plants (WPCP) and urban runoff, which have higher concentrations of contaminants (CVC 2012b). Although there is concern about the impacts of phosphorus, total phosphorus trends are showing a statistically significant *improvement* in the upper Credit and have remained *stable* in the middle and lower portions of the watershed. The mean values were 0.044 mg/L, 0.036 mg/L and 0.046 mg/L from the lower, middle, and upper watershed, respectively (CVC 2012b) which are still all above the Provincial Water Quality Objective (PWQO) of 0.03mg/L (MOE 1994).

Historically, nutrients, metals, chlorides and bacteria counts were elevated in Fletcher's Creek where Redside Dace currently seem to be in decline; a trend thought to be primarily related to loadings from urban runoff (MNR & CVC, 2002; COSEWIC 2013). Water chemistry has not improved over time in the tributary and recent sampling in 2011 determined a Water Quality Index (WQI) rating of "poor" (CCME 2001). In comparison, all other 2011 monitoring stations in the Credit River ranged from 'good' to 'marginal' (CVC 2013a). A more detailed examination of Fletcher's Creek is provided in section 6.2.3. The majority of marginal WQI scores (which considers Total Phosphorus amongst 9 other parameters) were located in the southern, urban portion the Credit watershed, but also in the upper Main Credit River where water quality may be affected by urban runoff and the Orangeville WPCP (CVC 2013a); this location is also where acute thermal stress was measured in 2011.

Based on 2013 WQI scores, the overall Humber River watershed was rated "Good", Etobicoke Creek was "Fair", while the Mimico Creek was rated as "Very Poor" (TRCA 2011c). Total phosphorus concentrations were high in 2013 for the upper and mid Etobicoke Creek, Mimico Creek, and the mid Humber River; phosphorus had an almost significant inverse relationship with precipitation ($p<0.07$). More specifically, four water quality stations upper tributaries of Etobicoke Creek exhibited elevated median values of total phosphorus. This 2013 analysis concluded that nonpoint sources of contamination from urbanization, such as sediment, nutrients and chemicals, continue to be the largest contributor to poor water quality conditions within TRCA's jurisdiction. At the subwatershed scale, earlier reports have noted total phosphorus issues in Centreville Creek during wet weather flow (see section 6.2.3 for more details).

Inadequate SWM is a major reason why older and more urban watersheds in Peel clearly have water chemistry and quality issues (including excess phosphorus). Approximately 21% of the developed areas in the Etobicoke Creek watershed have water quality treatment and only 2% represents an Enhanced level of treatment (TRCA 2010a) as defined in the Ministry of the Environment's *Stormwater Management Planning and Design Manual* (MOE 2003). In comparison, about 8% of the urbanized areas in the Mimico Creek watershed have quality treatment and only 0.2% of the developed areas provide an Enhanced level of quality treatment. Levels of nutrients and metals have been maintained or decreased over the past decade but it will still be a challenge to meet 2025 targets for total phosphorus, chloride and bacteria in the Etobicoke and Mimico watersheds.

When considering tributary loadings to Lake Ontario, the recently approved updated source protection assessment reports (TRCA 2015a; CVC 2015c) recognize that the Niagara River accounts for 80 percent of the flow entering Lake Ontario. Accordingly, the Niagara River is the largest single source of materials entering the lake and has a dominating influence on the chemistry of the entire lake. However, contaminants from other watercourses can influence near shore water quality along the Peel Region shoreline of Lake Ontario following major storm events. For example, the *CVC Lake Ontario Integrated Shoreline Study* (Aquafor Beech Limited and Shoreplan Engineering Limited 2011) identified the Credit River contributes more than two times the combined total phosphorus load of the Clarkson and Lakeview Wastewater Treatment Plants to Lake Ontario; and contributes 86% suspended solids and 66% of the nitrates entering the lake from within the study area (i.e., shoreline extent that includes CVC owned lands in the Lorne Park, Port Credit and Clarkson neighbourhoods). It is important to note, though, that this is likely in part because the Credit River outflow carries with it the discharge of three additional wastewater treatment plants in the watershed from upstream of Peel Region (Orangeville, Acton and Georgetown). Contaminant-laden storm events typically occur in the summer months and during periods of snow melt or rainfall induced runoff during frozen ground periods over winter. Mixing and circulations patterns in the lake will, in turn, determine whether or not water quality issues will persist in the near shore and at what spatial distribution (TRCA 2015a).

Inland Lakes and Ponds

There are roughly 2,300 water bodies located within the Region that are classified as lakes, ponds, industrial ponds, reservoirs, marshes, and drainage/stormwater management ponds. (Peel Data Centre 2015) (See Table 14); however, information was only found for a few inland lakes and ponds. Data sets associated with these varied in comprehension and detail and did not consistently report on the vulnerability indicators of interest: thermal gradient, water levels and total phosphorus concentrations. Considering this data limitation, current conditions are summarized for only a few water bodies: Heart Lake, Tea Pot Lake, Professor's Lake and Albion Pond. These descriptions are framed according to origins of the water body (natural or artificial) and whether they are on-line or off-line.

The importance of knowing if a lake or pond is well connected to a local watercourse (on-line) or isolated on the landscape (off-line) relates to the potential for accumulation and retaining of sediment, nutrients (i.e., total phosphorus) and other contaminants. Highly dependent on the land use context, an off-line or poorly connected inland lake that receives moderate to high nutrient loading from the surrounding catchment likely also has a slow rate of flushing, preventing the transport of (excess) nutrients downstream (TRCA 2002). The probability increases for such a lake or pond to experience intense cycles of algal blooms (sometimes toxic), exacerbating bottom-water anoxia and increasing fish mortality (Nurnberg *et al.*, 2003).

Numerous inland lakes and ponds in Peel Region, particularly in Brampton and Caledon where urban development is occurring, are the result of historical or active aggregation extraction. For example, in CVC's *Caledon Creek and Credit River Subwatershed Study – Phase III Implementation Report*, aggregate extraction is listed as one of three main land uses in Melville to Forks of the Credit and Caledon Creek subwatersheds (Blackport Hydrogeologic, CVC, Environmental Water Resources Group, Water Systems Analysts 2001). Further impacts associated with aggregate extraction are discussed in section 6.1.4.

Heart Lake is a naturally occurring kettle lake located in the Heart Lake Conservation Area (HLCA) within the upper Etobicoke Creek watershed; it receives limited surface water drainage and unquantified groundwater inputs (TRCA 2010a). Heart Lake is 17.5 ha in size and has an average depth between five and six metres, but a maximum depth of approximately 10 m. Concerns about excessive nutrients, particularly total phosphorus, leading to blue-green algal blooms have been reported over many years (TRCA 2006b; TRCA 1998). No water temperature data were found but a warmwater fish community was reported in the recent past (TRCA 2006b). More discussion on Heart Lake and the surrounding conservation area is included as part of the focus area storyline in section 6.2.1.

Tea Pot Lake is also a naturally occurring kettle lake within the HLCA and is 0.7 ha in size, but at its centre is 12.6 m deep. It is off-line (no surface water inflows or outflows) and sustained predominantly by groundwater originating from a deep aquifer system (TRCA 2006b). It is classified as 'meromictic' because it lacks any vertical turnover in water stratification on a seasonal basis. Water quality issues have not specifically been reported for this lake, but information was generally sparse. No water temperature data were found but a warmwater fish community was reported in the recent past (TRCA 2006b).

Professor's Lake is an artificial feature located in the most northern extent of Mimico Creek watershed. It was a former gravel/sand pit and small municipal dump that was transformed into a recreational lake-oriented community in the 1980s by Amex Developments. The lake is spring-fed, off-line and is reportedly 12 m at its deepest, with a municipally maintained beach area[6]. The beach is monitored by Peel Region for bacteria and temperature (standards at this location have historically been identified as an issue); however, few beach closures were reported in 2012-2014[7]. No total phosphorus data for the Lake was found, and it has been anecdotally reported to have a warmwater fish community present.

[6] http://www.thestar.com/life/2010/08/13/urban_oasis_brings_cottage_life_to_city.html

[7] https://www.peelregion.ca/health/beach/enbeach.asp

Albion Pond – An artificially dug pond that is on-line with Centreville Creek, located within the Albion Hills Conservation Area in the Upper Humber Watershed; this feature has known thermal issues cited (MNR and TRCA 2005) but the latest park Master Plan is directing the decommissioning of the existing dam and restoration of the natural stream channel, which may proceed as early as 2016. Further discussion on the pond and thermal impacts is included in the focal area storyline in section 6.2.1.

A smattering of physical habitat data does exist for some of the ponds and lakes in Peel Region. For example, bathymetric information, and qualitative descriptions of cover and/or substrate, and/or wetland evaluation information, has been collected for Fairy Lake (west of Peel), Island Lake (just north of Peel), Lake Aquitaine and Wabakayne (SWM Ponds) and Ken Whillans (gravel pit); many of these ponds and lakes have been identified as an issue in relation to their impacts on riverine ecology (MNR and CVC 2002).

Privately owned lakes also exist in Peel Region, including parts of Caledon Lake and Innis Lake; anecdotal information on fish community, lake use and physical descriptions can be found but more comprehensive inventories need to be made if an estimation of current (or future) vulnerability to climate drivers can be discussed.

Table 14: Inland Lakes and Ponds in Peel Region

Municipality	Name	Conservation Authority Jurisdiction	Type	Area (ha)
Caledon	Caledon Lake	CVC on-line	Lake	37.3
Caledon	Cressview Lakes	CVC	Pond	1.2
Caledon	Cressview Lakes	CVC	Pond	1.3
Caledon	Cressview Lakes	CVC	Lake	7.5
Caledon	Cressview Lakes	CVC	Lake	2.6
Caledon	Cressview Lakes	CVC	Pond	1.8
Caledon	Cressview Lakes	CVC	Pond	0.4
Caledon	Dufferin Lake	CVC	Lake	3.4
Caledon	Gibson Lake	TRCA	Lake	20.2
Caledon	Green Lake	CVC	Lake	13.7
Caledon	Innis Lake	TRCA – on-line	Lake	8.1
Caledon	Ken Whillans Pond #1	CVC	Pond	8.0
Caledon	Ken Whillans Pond #2	CVC	Pond	2.6
Caledon	Mill Pond	CVC	Pond	1.8
Caledon	Salt Creek	TRCA	Pond	0.3
Caledon	Salt Creek	TRCA	Pond	0.04
Caledon	Warnock Lake	CVC	Lake	8.1
Caledon	Widgett Lake	TRCA	Lake	3.3
Caledon	Caledon Pits	CVC	Industrial Pond	48.3
Caledon	Unnamed	CVC	Industrial	18.2
Caledon	Caledon Pits	CVC	Industrial Pond	37.1
Caledon	Caledon Pits	CVC	Industrial	21.3
Caledon	Caledon Pits	CVC	Industrial Pond	2.5
Caledon	Caledon Pits	CVC	Industrial Pond	1.4
Caledon	Caledon Pits	CVC	Industrial Pond	0.19

Caledon	Caledon Pits	CVC	Industrial Pond	0.15
Caledon	Caledon Pits	CVC	Industrial Pond	0.7
Caledon	Caledon Pits	CVC	Industrial Pond	5.7
Caledon	Caledon Pits	CVC	Industrial Pond	17.3
Caledon	Caledon Pits	CVC	Industrial Pond	10.3
Caledon	Caledon Pits	CVC	Industrial Pond	10.6
Caledon	Caledon Pits	CVC	Industrial Pond	31.0
Caledon	Caledon Pits	CVC	Industrial Pond	14.9
Caledon	Caledon Pits	CVC	Industrial Pond	0.9
Caledon	Caledon Pits	CVC	Industrial Pond	0.7
Caledon	Caledon Pits	CVC	Industrial Pond	2.3
Caledon	Caledon Pits	CVC	Industrial Pond	1.3
Brampton	Claireville Reservoir	TRCA – on-line	Reservoir	33.7
Brampton	Heart Lake	TRCA – on-line, limited	Lake	20.5
Brampton	Loafer's Lake	TRCA	SWMP	0.5
Brampton	Major Oaks Pond	TRCA	Lake	2.5
Brampton	Unnamed	TRCA	Pond	0.6
Brampton	Norton Place Lake	TRCA	Lake	2.1
Brampton	Parr Lake North	TRCA	Pond	2.0
Brampton	Parr Lake South	TRCA	Pond	1.3
Brampton	Professor's Lake	TRCA – off-line	Lake	26.4
Brampton	White Spruce Valley	TRCA	SWMP	1.7
Brampton	White Spruce Valley North	TRCA	SWMP	1.0
Mississauga	Lake Aquitaine (SWM pond)	CVC	Lake	4.2
Mississauga	Rattray Marsh	CVC – on-line	Marsh	4.3
Mississauga	Lake Wabukayne (SWM pond)	CVC	Pond	1.8

Future Vulnerability in Peel's Aquatic System

From the above descriptions of current conditions, the aquatic system flowing through Peel Region already displays measurable impacts related to urbanization and resource use, with the most widely reported being elevated stream temperatures and nutrient concentrations. Issues with flooding are localized but reflect impacts to the broader hydrologic cycle linked closely to the conversion of pervious natural cover to impervious paved surfaces; specifically, the processes of infiltration, attenuation and run off, during small and extreme events alike, are affected. Habitat fragmentation by in-stream structures and ponds is also a concern throughout Peel watersheds. From this inventory of impacts, it is inferred that water temperature, nutrient concentrations (primarily total phosphorus) and flows are all governed by processes that are sensitive to human activity and, in cases of hydrology and stream habitat, altered to a point that intrinsic adaptive mechanisms are failing (e.g. flood attenuation) and known biological thresholds are being crossed (e.g. stream temperature). These same processes are also responsive (sensitive) to climate. Thus, the collision between business-as-usual urbanization and climate change will serve to amplify and exacerbate existing impacts to the aquatic system and likely disrupt ecosystem service delivery. Furthermore, additional stressors will add to this cumulative effective, such as increased water taking to meet population growth requirements, waste disposal, aggregate and agricultural practices. For example, in demonstration of these cumulative impacts the aggregated fish IBI and brook trout data on the Credit River already shows a statistically significant decline since 1999 (CVC 2013a). With this understanding of numerous stressors, the following sections describe future vulnerability of the aquatic system under the 2050s climate scenario of increasing temperature and precipitation.

Thermal Gradient: Warming of Rivers, Streams, Inland Lakes and Ponds

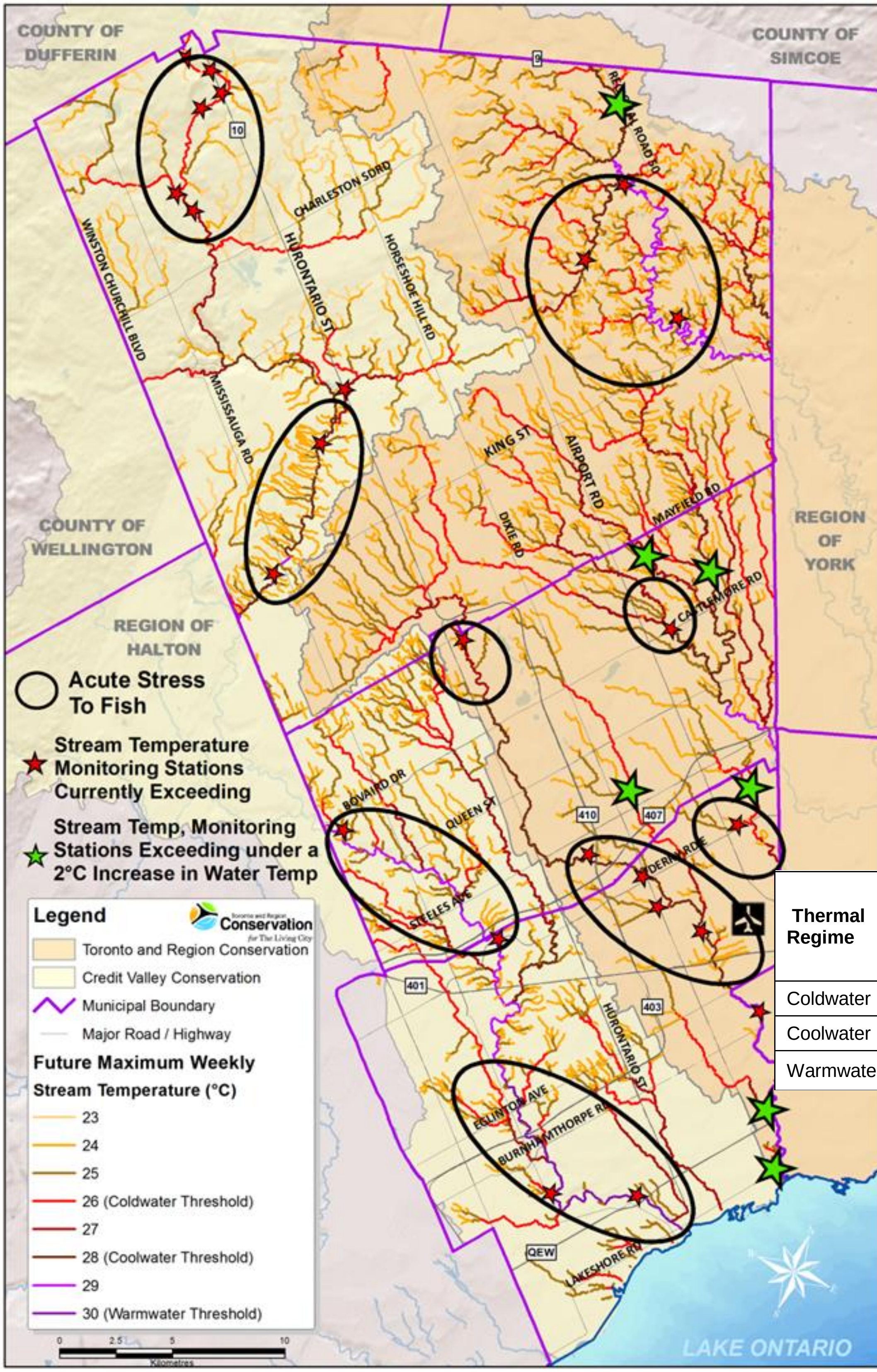
Studies indicate surface water temperatures of the Great Lakes, inland lakes and streams are rising (O'Reilly *et al*. 2015; Sharma *et al*. 2007), water levels are in decline and the composition of aquatic communities in streams and wetlands are shifting (Chu 2015; Warren *et al*. 2012; van Vliet *et al*. 2013). A study monitoring fish since the mid-1950s (Casselman 2007) demonstrates that climate change is already dramatically altering temperature and water resources, affecting aquatic environments and habitats, fish, community structure, fish resources, and fisheries. For example, 2˚C of warming (which is what is projected for Peel) is extrapolated to decrease fish recruitment by 2.4 times for lake trout (a coldwater species) and increase recruitment by 6 times for smallmouth bass (a warmwater species) (Casselman 2007). Changes in aquatic system thermal properties also alter nutrient and contaminant pathways, as well as chemical cycles affecting aquatic life (Wisconsin Initiative on Climate Change Impacts 2011). Based on the case study by Chu (2015) on assessing the vulnerability of stream temperatures in Peel Region to climate change, future vulnerability will increase as regional patterns of warming exist across the study area that predict a rise in stream MWAT from 18 – 24°C (current baseline) to 20 – 30°C in the 2050s A2 scenario (generally equivalent to 2050 RCP 8.5) (see Figure 18). Given measured stream temperatures in Peel Region are currently higher than the model predicts for baseline (discussed in previous section) and some reaches already exceed thermal targets, it is the predicted trend of *further* warming, rather than absolute values, that we infer our streams are highly vulnerable to increasing air temperatures. More broadly, the study predicts MWAT of Lake Ontario basin streams to rise up to 2 – 4°C under the A2 scenario by 2050s, which is considered low vulnerability relative to degree of warming predicted for streams in the other Great Lakes basins (Chu 2015).

The previous section spatially defined where stream reaches currently exceed summer maximum thermal targets. Using the Chu study as a guide, a conservative 2°C was added to current summer maximum stream temperatures to gauge the potential expansion of future stream conditions that would expose aquatic organisms to acute thermal stress in TRCA watersheds (see Figure 18). Through this analysis, seven more monitoring stations would measure acute thermal stress as air temperatures increase, the vast majority of them in urban and future build-out areas. In Figure 18, station data are from 2011 for Humber, Credit and Etobicoke Watersheds, and 2013 for Mimico Watershed.

In terms of amount of coldwater habitat, there is general agreement in the literature and between models that the presence of high groundwater discharge makes streams more resilient to warming (Chu, 2015; Kurylyk *et al.*, 2014; Snyder *et al.*, 2015). There is less agreement around whether the buffering capacity of groundwater (in strong discharge areas) is sufficient to counter anticipated increases in air temperature (direct solar radiation) and subsequent increased rates of evaporation; the latter working to reduce overall assimilative capacity of streams by reducing stream (or lake) volume during critical, and perhaps extended, summer low flow periods.

Earlier models suggest that climate change will lead to a significant loss of Brook Trout (cold water) habitat, sustaining greatest reductions occurring in their southern range (Flebbe *et al*. 2006; Meisner 1990); Chu (2015) predicted 23% of coldwater streams in Lake Ontario basin may warm to coolwater by 2080 under the A2 scenario but with the overall pattern of having cold, cool and warmwater still available to biota; Snyder *et al*. (2015) found predictions of Brook Trout future habitat loss were far less pessimistic than those determined from earlier models, however, the recent model did reveal spatial variation in thermal sensitivity resulting in a patchy distribution of thermal suitable habitat which has implications to ensuring high connectivity through a stream system.

In areas like Peel Region, it becomes harder to clearly discern what thermal models are saying about the magnitude of temperature change in streams or lakes that heavily rely on groundwater discharge, as they do not consistently differentiate shallow from deep groundwater sources or consider effects of water taking and urban impacts to infiltration and/or recharge processes. Additionally, few models incorporate field observations of fish presence, correlated to time exposed to higher water temperatures, but those that do tend to predict greater losses in coldwater habitat (Wherly *et al.,* 2007). Finally, the use of short-term (seasonal) changes in air temperature applied in models operating at large scales while ignoring changes at finer spatial scales, such as streambed heat fluxes due to subsurface warming, is also problematic (Kurylyk *et al*. 2015; Snyder *et al*. 2015). Despite these differing approaches, models are overall predicting shallow groundwater will warm in response to climate change and in turn warm surface waters; however, the timing and magnitude of subsurface warming depends on several factors that will vary across the landscape, including rate of surface warming, subsurface thermal properties and aquifer depth (Kurylyk *et al*. 2015).



Thermal Regime	Absolute Max Summer Water Temperature Targets (˚C)
Coldwater	26
Coolwater	28
Warmwater	30

Figure 18: Future Maximum Weekly Average Stream Temperature (MWAT) across Peel Region

In the report by Chu (2015), inland lake vulnerability was also assessed; lakes with greater warming of surface waters were interpreted as more vulnerable to climate change as these changes can have chemical and biological consequences, similar to rivers and streams, particularly increase in primary productivity. Lakes within the Lake Ontario basin were classified as *highly vulnerable* using maximum lake surface (0 – 2m) temperature as an indicator. Lakes in the southern basin (including Peel Region) are more vulnerable than lakes in the northern basin; average surface water temperatures may warm by 3 – 6°C under the 2050s A2 scenario.

Flow Variation: Baseflow

As described in earlier sections of this report, it is not just atmospheric warming alone that will drive changes in the aquatic ecosystem, but also the concomitant changing nature of precipitation, which may alter timing and lower intensity of the spring freshet, extend duration of summer low flow conditions, increase event-based streamflow volumes and flood frequency; all of which is plausible given precipitation trends predicted for Peel Region.

Our current monitoring of flows in Peel Region generally indicates during “normal” or wetter and cooler years, minimum low flow thresholds are not crossed. Anecdotal evidence also exists for some areas, where shallow groundwater systems dominate, that streams dry up during very dry climate years and local water taking activities are known to happen (i.e., in the Etobicoke Creek and West Humber); the intersection of these factors set a context of higher sensitivity to stream drying. Under our climate scenario of hotter summers with extended dry periods, the frequency and/or extent of sensitive stream drying may increase on a seasonal basis. Even the general climate resiliency of deep aquifers to maintain baseflow to streams (and other aquatic features) maybe more challenged by significant human activities such as increased water taking associated with urban expansion and population growth, which is discussed in Section 6.1.4.

By understanding potential disruptions to groundwater processes and supply, implications to the aquatic system can be further explored, including potential benefits. Summer recharge is not significant process given evapotranspiration processes are dominant and may even increase under future climate (person. Comm. Don Ford, 2014), the ‘game changer’ is what may happen in the winter as temperatures rise. Currently, no appreciable winter recharge occurs due to consistently frozen ground conditions. However, warmer winters may prevent soil freezing (or at least provide windows of thaw) and winter recharge could become significant, which implies reduced or no snow pack/melt and consequences to river and stream ecology (discussed lower down in this section, under *Implications to Ecosystem Services*). The opportunity, however, is aquifer storage may maximize over time and perhaps provide higher steady discharge rates to surface features during periods of prolonged summer drought. Overall, increasingly variable recharge rates may cause changes in groundwater levels and supply to surface, depending upon soil conditions and timing (TRCA 2008d; Goderniaux *et al*. 2009; Winter 1999).

Whether baseflows are disrupted or not, there may still be less surface water overall in the aquatic system during extended dry and hotter summer months; the processes “to blame” are increased evaporation and evapotranspiration rates associated with increased radiation and air temperature, decreasing humidity and increasing wind speed (Abtew and Melesse 2013; United

States Environmental Protection Agency, n.d.).. This direct loss of water would likely be greatest in streams and ponds where there is little urban forest canopy and cover to provide shade and regulate thermal processes. Evaporative loss from natural water features is not monitored in Peel, and thus an analysis is not supported within this assessment, however vulnerability indicator mapping in Figures 26 and 27 in section 6.1.3 provide a good illustration of the spatial distribution of natural cover and urban forest canopy, respectively.

The additional concern for streams and rivers is becoming *even more* fragmented than current conditions should summer low flows decrease sufficiently to cause an increase the number of impassable in-stream structures. Despite this line of logical thinking, it is noted that climate change impacts to aquatic habitat connectivity are not well studied (Chu 2014) but maintaining access to critical habitats for different life stages and refugia for sensitive species is an ecological imperative.

Overall, climate change may reduce the amount of water reaching the surface as baseflow. Periods of lesser rain or longer droughts in the summer - climate conditions that are within predicted future trends for Peel Region - may cause further reduction in baseflow to stream reaches that currently come close to or dip below minimum summer low flow thresholds; natural conditions and/or anthropogenic impacts contribute to these low flow conditions, notably in the West Humber, Etobicoke Creek Headwaters.

In the previous section characterizing current vulnerability of the aquatic system, the winter season was not specifically discussed. This reflects the lack of current focus on winter hydrology and stream dynamics in Peel Region as our winters, to date, are far less biologically and ecologically “active” compared to the other seasons; and no seasonal-equivalent monitoring data exists for streams or lakes through the winter months in Peel Region. While literature is gaining on winter lake-based processes, most studies are not available for watercourses and inland lakes and ponds in Peel Region, and TRCA has just recently initiated winter-based temperature monitoring of rivers. The main data set that can be found is for “ice-in” and “ice-out” dates related to lake ice cover. Equivalent data sets are not available for Peel streams but a question that is now being asked is what might happen to stream ice formation or break-up and consequences to stream hydrology, hydraulics and overall geomorphic processes (bedload movement, erosive forces, etc.) if there is more ‘unfrozen’ water in the system. The matter of in-stream processes are particularly concerning if there is no or intermittent ice cover, no live vegetation stabilizing stream banks and soils are undergoing frequent ‘freeze-thaw’ cycles that make them more prone to erosion – we will need to very seriously consider year-round stormwater management and how different that might look from current best practice. Implications to fish survival and other organisms that are adapted to over-wintering in stream environments that are relatively low-energy (and few food resources) is also of growing speculation and concern.

The literature is producing more information on winter hydrology and climate change for northern regions, with consistent projections, including: winter hydrological regime of freshwater bodies is strongly affected by changes in temperature and precipitation projected for the next century; overall trends point to later freeze-up in lakes and earlier freeze-up in rivers while break-up (of ice) occurred earlier in both rivers and lakes; while the future ice season will be significantly shorter and less severe than the present period, mid-winter thaw events will significantly increase leading to unstable winter season; an increase in winter discharges; higher winter discharges are expected to have an important geomorphological impact mostly because they may occur under ice-cover conditions (Boyer *et al.* 2010; Gebre 2014).

The current data deficiencies around characterizing winter hydrology/hydraulic conditions and associated geomorphological, ecological and biological relationships are significant research and management gaps. These gaps limit our ability to assess and adapt to the seasonal climate changes that are predicted to shift the most (i.e. increased average winter temperature, increase maximum winter temperature, decreased minimum winter temperature).

Hydrologic Connectivity: Where it is needed

In light of the above discussion, managing streams for hydrologic connectivity is necessary. A recent analysis conducted by the TRCA suggests that these connections are not necessarily equal and that priority stream reaches can and should be managed first. This work was conducted as part of the TRCA *Valley and Stream Crossings Guidelines* (TRCA 2015e) and identified priority stream segments in the Etobicoke and Mimico watersheds (see Figure 19). These priority ratings do not represent vulnerability, but rather priority for maintenance or restoration to contribute to aquatic connectivity for species in the future; and improving connectivity is a key adaptation measure to build ecosystem resiliency (Heller and Zavaleta 2009).

The quality of each watercourse segment was determined by taking into account the structure of the segment and the fish communities that it supports. Segments that are long, thermally stable, surrounded by natural cover, and support rare or sensitive fish species are considered as segments that require high level of effort in terms of crossings to maintain, and if possible enhance aquatic connectivity function. Existing available GIS data on watercourses (2013), natural cover (2013), land use (2013), and field collected in-stream barrier data were used for the aquatic regional connectivity analysis. Figure 19 illustrates priority stream segments, where those in blue are *higher priority* for facilitating aquatic connectivity and those in red are of a *lower priority* (TRCA 2015e). The importance of each segment for maintaining regional connectivity was assessed with the functional connectivity index, Probability of Connectivity (PC) with the program Conefor V2.6. This index accounts for the probability that an organism can travel from one segment to another and offers improved performance over distance based metrics in dendritic networks and allows for the inclusion on complete barriers to fish passage upstream (e.g., dams). Modeling Information was not available for the Humber Watershed in the TRCA jurisdiction. Notably, CVC has undertaken an alternative approach to modeling for the Credit Watershed where dams are prioritized for fish passage based on factors such as length of available habitat upstream.

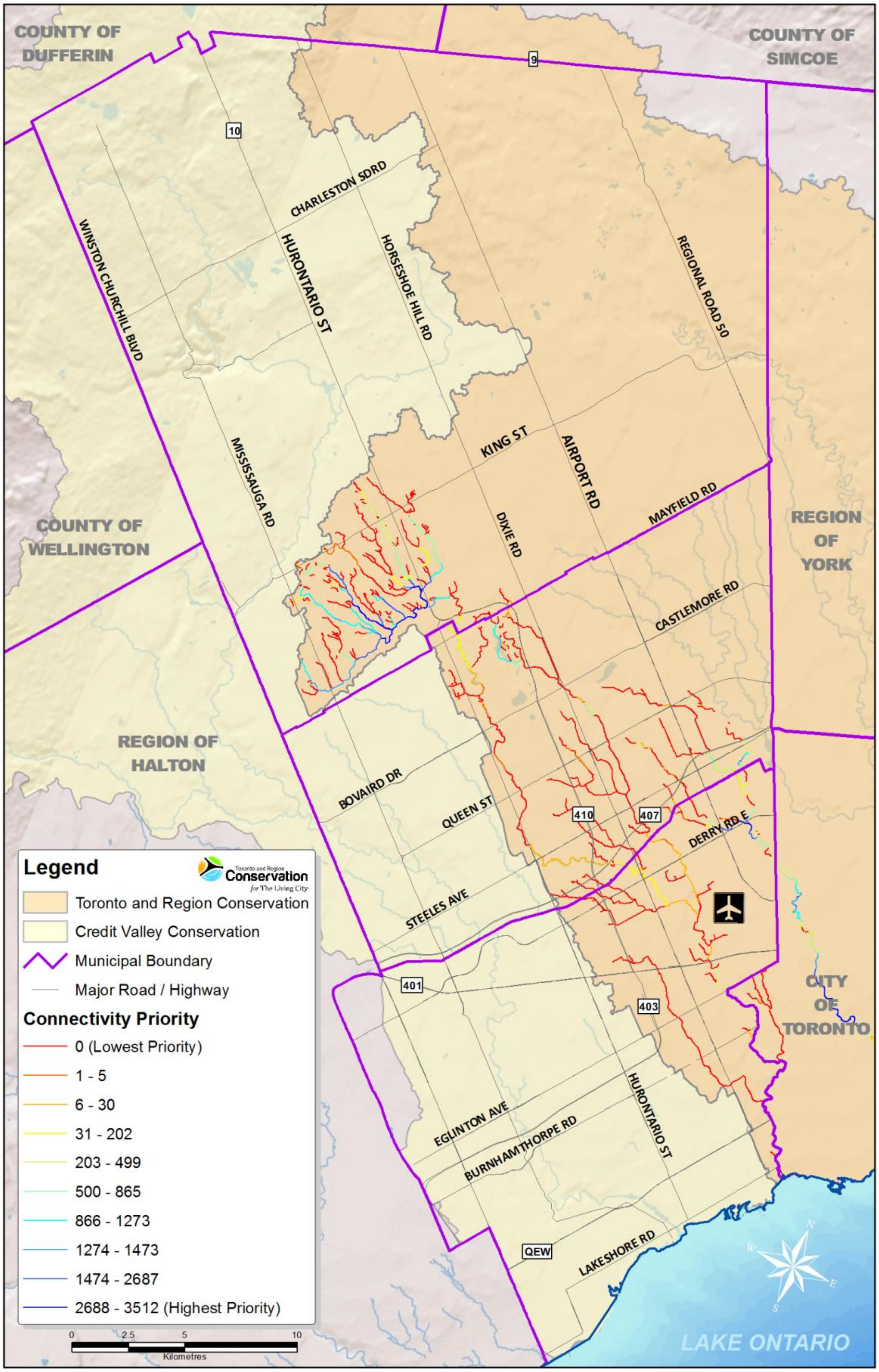


Figure 19: Aquatic Connectivity Modeling in the Etobicoke and Mimico Watersheds in Peel Region.

Pervious Cover and Water Chemistry: Flooding and Total Phosphorus in Rivers, Streams & Inland Lakes

Although climate change alone is not anticipated to reduce the amount of pervious or natural cover (factor in urbanization and that is a different story), it may certainly cause soils to become dry and hard-packed, as well as alter biochemistry thereby reducing vegetation health and diversity (see section 6.1.3 for more detailed discussion on soil quality and process disruption). Trying to infiltrate or even attenuate extreme precipitation into such a medium may effectively (though temporarily) replicate the problem of impervious surfaces. The overall result is more runoff generation and increased flood risk to downstream areas should severe rain events follow an extended drought period.

As discussed previously under 'Pervious Cover: Current Conditions' on page 74, the current riverine (and urban) flooding in parts of Peel Region was not identified as a dominant ecosystem stressor, however, the changing nature of flood events associated with climate change (potential increase in intensity and frequency) may exert strong negative pressures on rivers and streams over the long term (Poff *et al*. 2002; United States Environmental Protection Agency, n.d.). This would affect both aquatic habitats and communities, and in some cases allow for the introduction and expansion of species - plant and fish, native and invasive – between basins and/or along shorelines (F. J. Warren and Lemmen 2014; Wisconsin Initiative on Climate Change Impacts 2011).The spread of water borne pathogens could also be facilitated.

The issue is flood waters can be powerful enough to mobilize much of the river bed (Power *et al*. 2008) and sweep large quantities of biomass from the land into aquatic environments. The vulnerable components are where the material eventually accumulates: inland lakes, ponds and perhaps low-grade streams or pools (depositional areas). Once the growing season starts, all this nutrient laden material is food for primary producers, including algae. If flood conditions are experienced more often, either because of more frequent extreme rain events, or an effective reduction in 'pervious cover', or a combination of both, it is possible that lake and some stream habitats will, in time, become nutrient enriched to a point where anoxic conditions become common/cyclic and resident fish species cannot survive. Note: the predicted warming of surface waters only serves to optimize growing conditions of algae and thermal stress fish and other aquatic organisms.

It was mentioned earlier in the current conditions section for Aquatic Systems that flow records in the Credit River suggest there is an increased risk of winter flooding and that climate change may be the dominant cause (CVC 2013a). In other words, it matters to lakes and streams if future winter precipitation is delivered as more rain than snow. For instance, the winter of 2012 was relatively warm, and the following June/July there was a noticeable increase in the occurrence of algal blooms in stream channels within the Credit River (pers. Comm. A. Singh, 2014). A study from the Mediterranean, where winters are naturally warm, cladophora blooms (a type of filamentous algae that are problematic in our waters) are larger if floods during the preceding winter attained or exceeded ''bankfull discharge'' (Power *et al*. 2008).

As warmer, rainier winters result in less snow pack, there is concern that the spring freshet may come earlier and/or be less intense (Magnuson *et al*. 2000; Jyrkama and Sykes 2007b; Green *et al*. 2011; Tomalty and Komorowski 2011); implications are to timing of aquatic life-history events (phenology) that would de-couple if timing of freshet is disrupted (e.g. fish spawning migrations) (Warren *et al*. 2012) and the flushing of stream sediment, associated with strong freshets, may be less effective, allowing accumulated nutrients and contaminants to remain within the stream environment well into the growing season (pers. Comm. G. Bowen 2015). The latter outcome, and not actual flooding, may be the mechanism responsible for more frequent and intense algal blooms experienced in recent years.

To summarize, we may be progressing towards a tipping point where a system's adaptive capacity is lost. That there are already watercourses and bodies in Peel subject to elevated phosphorus concentrations, particularly during wet weather, indicates loadings are still an issue in the watersheds and the aquatic system is vulnerable when it rains. The effects of more precipitation as extreme rainfall in the future will only serve to increase that vulnerability.

Implications to Ecosystem Services

The aquatic system in Peel Region delivers numerous ecosystem services to the region's residents, with the strongest relationships to: thermal regulation, water quality regulation, flood regulation/attenuation, erosion regulation, water supply provisioning, habitat supporting and recreational opportunities (refer back to Table 3 for full list of ecosystem services). The preceding sections on current and future vulnerability discussed impacts and pathways of effects, directional changes in future vulnerability, interspersed with dialogue about ecosystem services. Although the types of available data structured much of the analysis, common themes around water temperature and water quality impairments emerged that implied the following ecosystem services are being disrupted across Peel:

- Thermal Regulation of water temperatures in streams and lakes
- Water Quality Regulation of total phosphorus and other nutrients that limit algal growth
- Recreational Opportunities from both an angling and general enjoyment of outdoor spaces

Ecosystem Services that are being disrupted more in the Groundwater System and/or Terrestrial System but subsequently may expose the Aquatic System to impacts are:

- Water Supply Provision as baseflow to surface features
- Flood Regulation/Attenuation

The cumulative impact of all the above disruptions appears to be converging and negatively impacting the following, broader service:

- Supporting Habitat for fish and other aquatic organisms, including endangered fish species and a native coldwater species often used as an indicator of watershed health.

6.1.3. *Terrestrial System*

Of the 1,253km^2 total area in Peel Region, approximately 42.4% is currently classified as urban or urbanizing, 27.1% is rural or agricultural land, and just over 30% is natural cover (Greater Municipality of Peel, 2012, All rights reserved). The natural cover area is comprised of approximately 12.9% natural forest, 12.6% meadows, 4.1% wetlands, and 0.9% beach, bluff or aquatic components. The spatial distribution of this land cover composition varies substantially from lower to north Peel (see Figure 20) (Greater Municipality of Peel 2012).

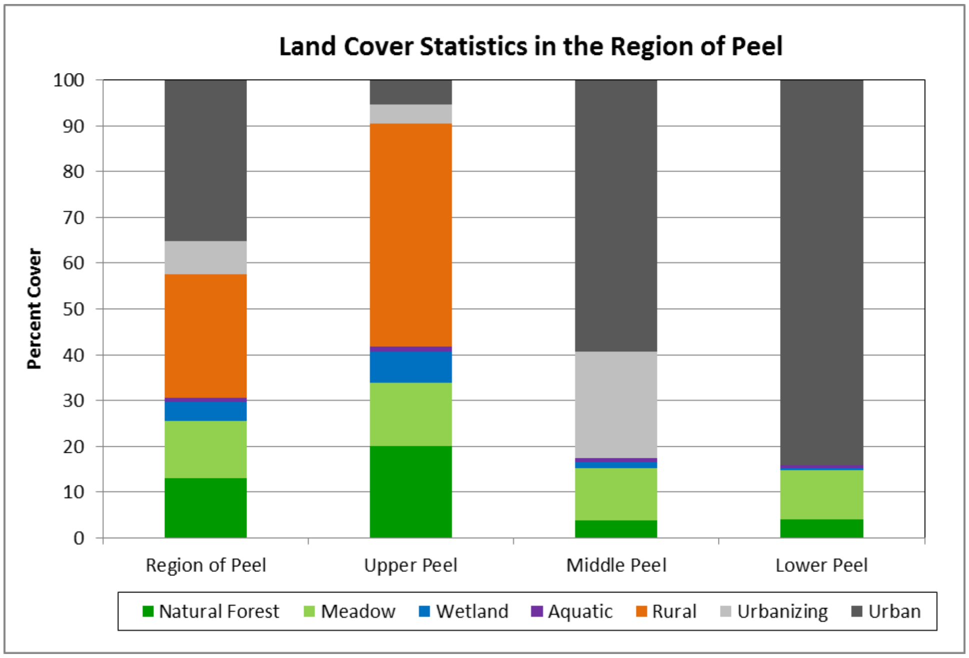


Figure 20: Current Land Cover in Peel Region

The vulnerability of the terrestrial system to climate change is complex, and there are numerous physical, chemical and biological factors at play that may interact, compound stress responses and create uneven distributions of vulnerability. The following sections examine what those complex interactions might ultimately yield. Table 15 summarizes the terrestrial system components (bluffs were determined out of scope, see section 5.0), the vulnerability factors and indicators used in characterizing vulnerability to climate change.

Table 15: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Peel Region's Terrestrial System

Components	Vulnerability Factors	Vulnerability Indicators
• Meadows, Grasslands, Shrublands • Natural Forests • Urban Forests • Wetlands	• Pervious Cover • Degree of Connectivity (Habitat & Hydrologic) • Topography and Grade • Soil Quality • Urban Forest Canopy • Thermal Gradient • Community Range	• Natural Cover: Forest Cover & Wetland Cover • Wetland Type • Habitat Patch Quality • Soil Drainage • Soil Organic Carbon in A-Horizon Layer • Urban Forest Canopy • Land surface temperature • Climate-Sensitive Native Vegetation

In total, eight vulnerability indicators were identified for the terrestrial system that contained sufficient monitoring, satellite imagery or ecological land classification data to map and analyze using ArcGIS. As described in Section 3, a 30ha catchment vulnerability characterization was conducted on each vulnerability indicator. Given the complexity of the terrestrial system, and the amount of available data, an additive or cumulative mapping exercise was conducted to characterize the gradient in terrestrial system vulnerability to climate change in Peel Region (see Figure 21). In other words, if a particular area is considered vulnerable to an indicator (e.g., having poorly drained soils or climate-sensitive vegetation), it received a count of one. Areas receiving five or more counts (i.e., flags for being vulnerable to numerous indicators) were rated to be highly vulnerable. This implies that the area is vulnerable to at least five (any five) of the vulnerability indicators relevant to the terrestrial system listed in Table 15. In contrast, low vulnerable areas were only flagged for three or fewer vulnerability indicators. There was equal weighting applied to the indicators, so Figure 21 does not suggest which indicator(s) might be driving an increase in vulnerability.

Based on Figure 21, approximately 55% of the terrestrial system in Peel Region is currently considered 'highly' vulnerable to the effects of air temperature and summer dry periods. There is a distinct gradient in the cumulative vulnerability of the terrestrial system from north to south. Low vulnerable areas are only found north of Mayfield Road, and most high vulnerable areas are found in middle and south Peel. This trend is the result of significant stresses associated with the current level and type of urbanization. However, local conditions (e.g., shoreline cooling of land surface temperatures in south Peel, and conservation area or natural forest influences on habitat quality in HLCA) do create exceptions. Figure 22 illustrates the processes or pathways that may be disrupted in the terrestrial system when exposed to warmer, wetter conditions in the year by the 2050s. As a result of changes to ecological processes, the ecosystem services that may, in-turn, be affected are listed at the bottom of the diagram.

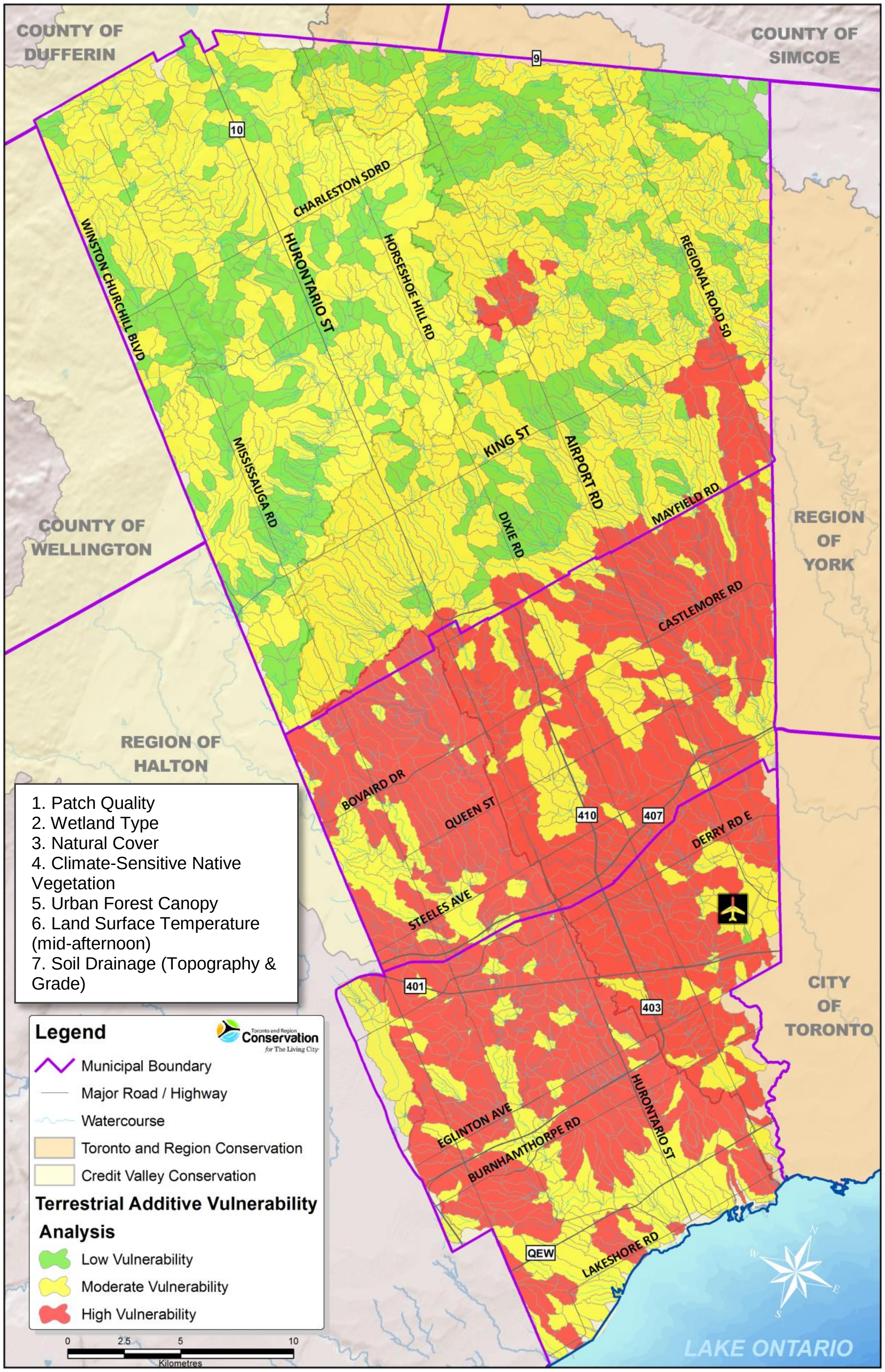
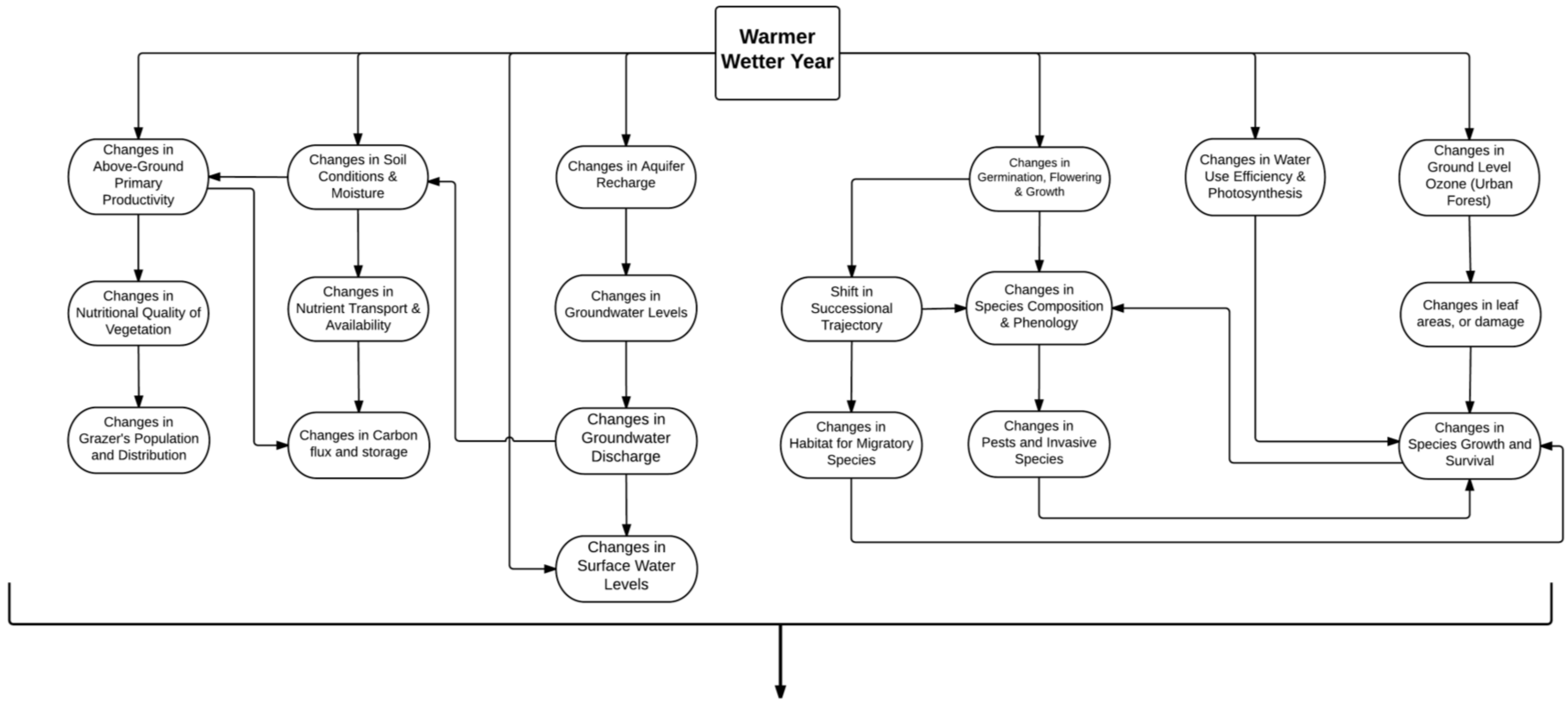


Figure 21: Additive Terrestrial System Vulnerability in Peel Region



Ecosystem Services Potentially Affected

Ecosystem Services
- Water Quality Regulation
- Air Quality Regulation
- Regulation of Urban Heat Island
- Regulation of Erosion (soil, sediment)
- Moderation of Extreme Wind Damage
- Flood Attenuation
- Moderation of Rate of Spread/Establishment of Invasive Species
- Energy Use and Conservation
- Recreational Benefits (hiking, cycling, bird-watching, angling, etc.)
- Habitat Diversity

Figure 22: Impact Pathway Diagram Highlighting Climate Change Impacts and Complex Interactions in the Terrestrial System

Current Conditions in Peel's Terrestrial System

Pervious Cover and Existing Disruptions to Hydrology

The preceding section on the Aquatic System introduced the topic of hydrologic alteration linked to low pervious or natural cover on the landscape. This is also, and equally, a Terrestrial System discussion. A healthy and functioning terrestrial system thrives under natural (non-disrupted) hydrologic conditions. A lack of pervious cover can significantly impact terrestrial system components by reducing infiltration and redirecting surface flow causing soil erosion and/or excess water ponding in some locations while not enough in others. This, in turn, can impact growing conditions and damage or kill sensitive vegetation. It can also disrupt or prevent breeding for species adapted to the natural hydrology – for example amphibian life cycles synchronized with hydroperiods of seasonal ponds or wetlands (see Box 5).

The lower third of Peel Region (City of Mississauga) has been substantially built out; approximately 84% of this area is urban based on policy areas (TRCA ortho-imagery 2013). It should be noted; however, that these numbers may differ from other analyses conducted at a more refined or local scale (e.g., municipal urban forest studies that factor in each individual backyard tree). Numbers used as part of this vulnerability assessment are based on ortho-imagery collected in 2013 and policy area classifications to ensure consistency across Peel Region as a whole. The remaining lands within lower Peel are mainly meadows (10.8%) and some limited patches of natural forest (3.9%). The high percent urban land use, combined with insufficient SWM, has contributed to extreme hydrological alteration in the Cooksville Creek catchment where 309 flood vulnerable structures exist (pers. Comm. N. Gupta, September 24, 2015; CVC 2013a).

In middle Peel (City of Brampton), land cover is changing rapidly, with approximately 59% urban, over 23% urbanizing, and the remaining pervious cover made up of meadows (11.3%), limited patches of natural forest (3.9%) and few wetlands (1.4%) (TRCA ortho-imagery, 2013). The portions of the Etobicoke and Mimico watersheds in middle Peel are described as having little natural cover remaining as a result of anthropogenic activities (TRCA 2010a), with the majority of what is left found along valley–stream corridors (TRCA 2013b; TRCA 2013d) or as small woodlands (Hoy and Hall 2013). There are also many flood vulnerable structures in middle Peel (Figure 17).

Land cover in north Peel (Town of Caledon) is only 5.4% urban and 4.1% urbanizing, with the remainder made up of rural (49%) and natural cover: natural forest (20.1%), meadows (13.9%), and wetlands (6.6%) (TRCA ortho-imagery 2013). Looking east-west, there is slightly more natural forest cover in the upper Humber River watershed than in the Upper Credit River watershed (CVC 2013a; TRCA 2013c). There are relatively fewer flood vulnerable structures in north Peel (Figure 17).

Box 2: Where Have All The White Spruce Gone?

White spruce (*Picea glauca*) is a coniferous tree species that is found in a wide range of soil and climatic conditions associated with northern coniferous forests and boreal forests from Newfoundland and Labrador in the east to Alaska in the west (Figure 2.1). In Ontario, they extend all the way up to the tree line in northern Ontario and down to southern Ontario, including Peel Region. According to Peel's Urban Forest Strategy, this tree species is commonly found in commercial and industrial areas (TRCA *et al*. 2011). As of 2011, almost 10% of Brampton's urban forest was made of White Spruce and almost 3% of Mississauga's (TRCA *et al*. 2011). Similar data were unavailable for all of Caledon; but White Spruce is commonly planted in these areas as well as part of tree planting. This tree species is also an important part of the pulp and paper industry in Ontario and provides food and habitat for a wide range of species, including deer, porcupines, red squirrels, shrews, grouse, and chickadees. This narrative will focus on White spruce; however, a study conducted in 2009 for CVC examines which tree species will 'win', 'lose' or 'stay' under climate change in the Credit watershed (see Malcolm *et al*. 2009).

Figure 2.1: White Spruce and its natural species range in Canada (University of Guelph 2012)

How does White Spruce Respond to Climate Change?
In the northern limit of its distribution range, white spruce is found to be tolerant to extreme conditions associated with temperatures, precipitation, sunlight, and soil fertility. However, the southern limit seems to prefer a mean July temperature of approximately 24˚C and mean annual precipitation of 380-510mm (United States Forestry Services, n.d.). In southern Ontario, under warmer summers, longer growing season, and more frequent extremes such as extended dry periods, white spruce is expected to face considerable challenges in adapting to new norms. It is predicted that white spruce will shift its range northward, thereby moving out of southern Ontario**.** In some parts, white spruce has already shifted 200km north from 1997-2006 relative to its occupied range 1961-1990. This shift is projected to quadruple by 2050s to approximately 800km north (Gray and Hamann 2012).

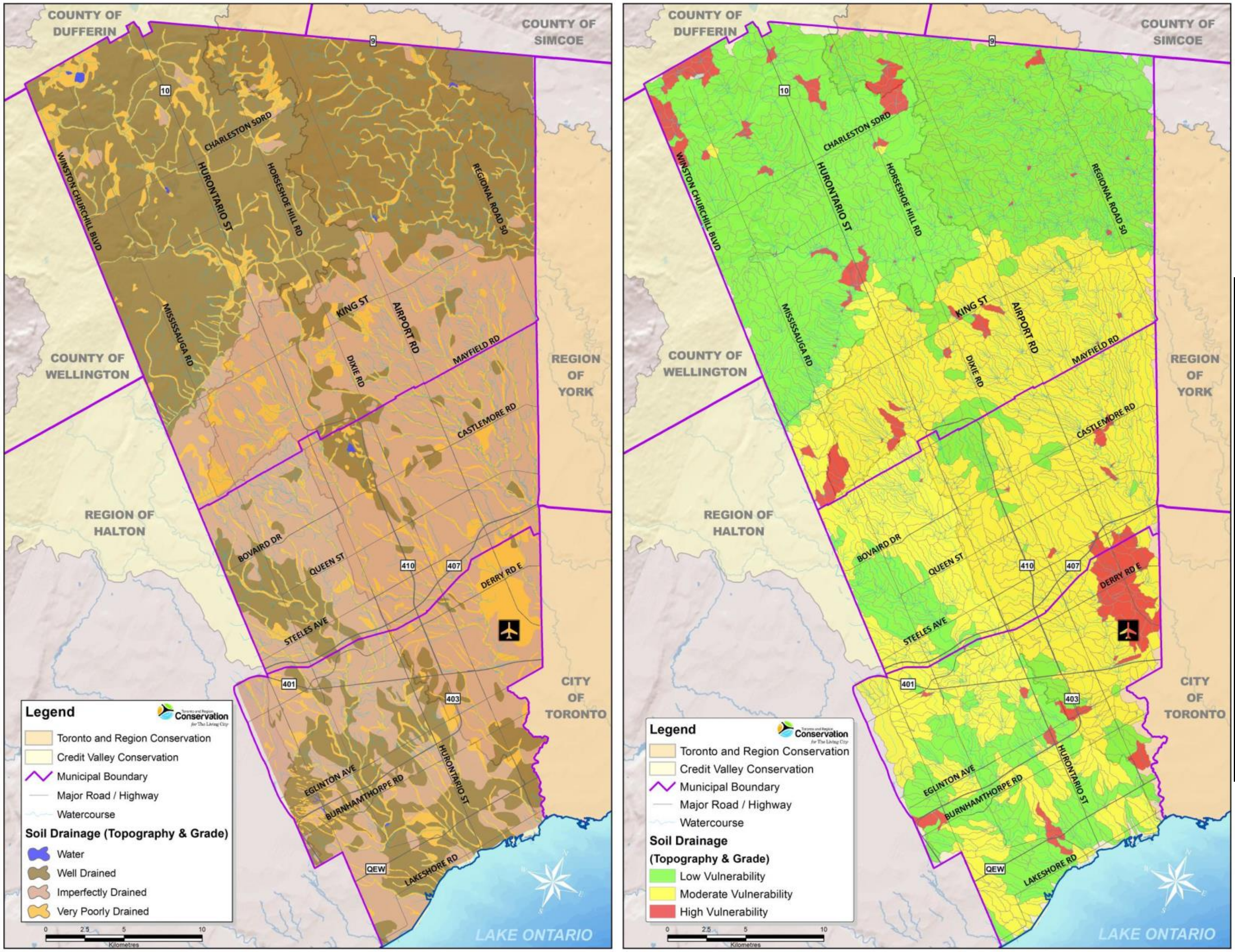
The predicted increase in temperature, especially when combined with extended summer dry periods, is likely going to induce heat and moisture stress in vegetation communities as measured by slower tree growth. A study in the interior of Alaska found, with increasing summer temperature, white spruce growth rate slowed significantly in contrast to western Alaska, where trees were growing more rapidly (Juday *et al*., 2015). This is because white spruce thrives within an optimal temperature range. The long term average temperature for interior Alaska was already at the high end of that optimal range; the warming crossed a threshold tolerance. Increasing temperature beyond a certain range resulted in reduced growth and even mortality.

Climate change favours some species more than others, influencing the competitive interactions between species. Rapid shifts in environmental conditions may mean increased competition from some southern species that are expanding their range northward as well as already established, aggressive and fast-growing species. All combined, this will compromise the ability of northern species like white spruce to use resources (e.g. light, nutrients) as efficiently and persist in the current landscape. Compounding this impact, increasing concentration of CO_2 in the atmosphere has been found to enhance the fast growing species, which reduces the adaptive capacity of slow growers like white spruce.

Topography and Grade: Surface Runoff Volumes

Peel Region has a number of different topographies, grades and soils which leads to a high diversity of vegetation types and natural components. For instance, the vegetation makeup and species dominance of forests on the escarpment is different than those found on the south slope. Specifically, cooler and wetter climate along with soil conditions lead to less vigorous growing conditions found on the escarpment, leading to species such as cedar, hemlock and yellow birch (Puric-Mladenovic *et al*. 2013). It is also the topography, grade and climate conditions that drive what wetlands exist in the region and where they are found. Where wetlands are formed, biogeochemical cycling and the degree of saturation from standing water influences what soil types are formed (e.g., hydric soils, mineral soils) (Daigneault, Nichols, and Hall 2012). The topography and grade also contributes to surface volume runoff, and in fact, when compounded with low pervious cover and low soil drainage, may lead to high amounts of flooding in the natural system.

Physiography and surficial geology in Peel Region were formed by the glacial forces of the Wisconsin glacial episode and its postglacial lakes. Underneath glacial sediments are the relatively flat-lying Paleozoic rocks that underlie not just Peel, but also southern Ontario and Lake Ontario (Puric-Mladenovic *et al*. 2013). In Peel, the Niagara escarpment dissects the region into two more or less distinct physiographic areas: (1) the ORM found in north Peel (top of Peel moving south until the Etobicoke Headwaters) and (2) the Peel Plain and South Slope in middle and south Peel (Etobicoke Headwaters moving south until Lake Ontario shoreline). North Peel and the ORM Area contains steep, irregular topography up to 305 m.a.s.l. (Puric-Mladenovic *et al*. 2013; Hoffman and Richards 1953) whereas the Peel Plain and South Slope are more or less gradually sloping towards Lake Ontario at 76masl, with some very flat regions such as the West Humber. Soil drainage was selected as a representative vulnerability indicator, which is qualitatively described in the Peel County Soils Survey (Hoffman and Richards 1953) based on the topography, grade and soil type underlying a given area (see Figure 23 for a map of Peel's soil drainage). In north Peel and along the ORM, soils tends to be well drained with soil types such as Pontypool Sandy Loam (well drained), Caledon Loam (well drained), Listowell Loam (imperfectly drained), and some muck (very poorly drained) (Hoffman & Richards, 1953). This is in contrast to areas in in middle and south Peel in the South Slope and Peel Plain where soils are predominantly rated 'imperfectly drained' as a result of low slopes, and mild topography. However, not all areas in the Peel Plain and South Slope are imperfectly drained: some variation does exist. For instance, Heart Lake Conservation Area contains well drained soils under its natural forested areas but very poorly drained muck soils in some locations likely associated with wetlands as well. Other exceptions include the Mimico watershed in south Peel where the majority is poorly drained, and some soils along the shoreline of Lake Ontario which tends to be more sandy (e.g., Fox Sand) and rated as well drained.



Thresholds assigned based on Qualitative Descriptions:

Low Vulnerability: Well Drained Soils

Moderate Vulnerability: Imperfectly Drained Soils

High Vulnerability: Poorly Drained Soils, Very Poorly Drained Soils

Figure 23: Soil Drainage Rating (A) and Vulnerability Characterization of Soil Drainage (Topography & Grade) at the 30ha Catchment Level (B)

Habitat Connectivity and Existing Edge Effect to Terrestrial Components

Habitat connectivity for terrestrial species is a highly important vulnerability factor in Peel Region, particularly in understanding the extent to which terrestrial species may experience 'edge' effects due to landscape influences (i.e., urban surfaces surrounding a wetland) and their ability to seek out new habitat which contains better moisture availability and/or nutrients. Higher habitat connectivity also provides numerous other benefits such as (adapted from MNRF 2010):

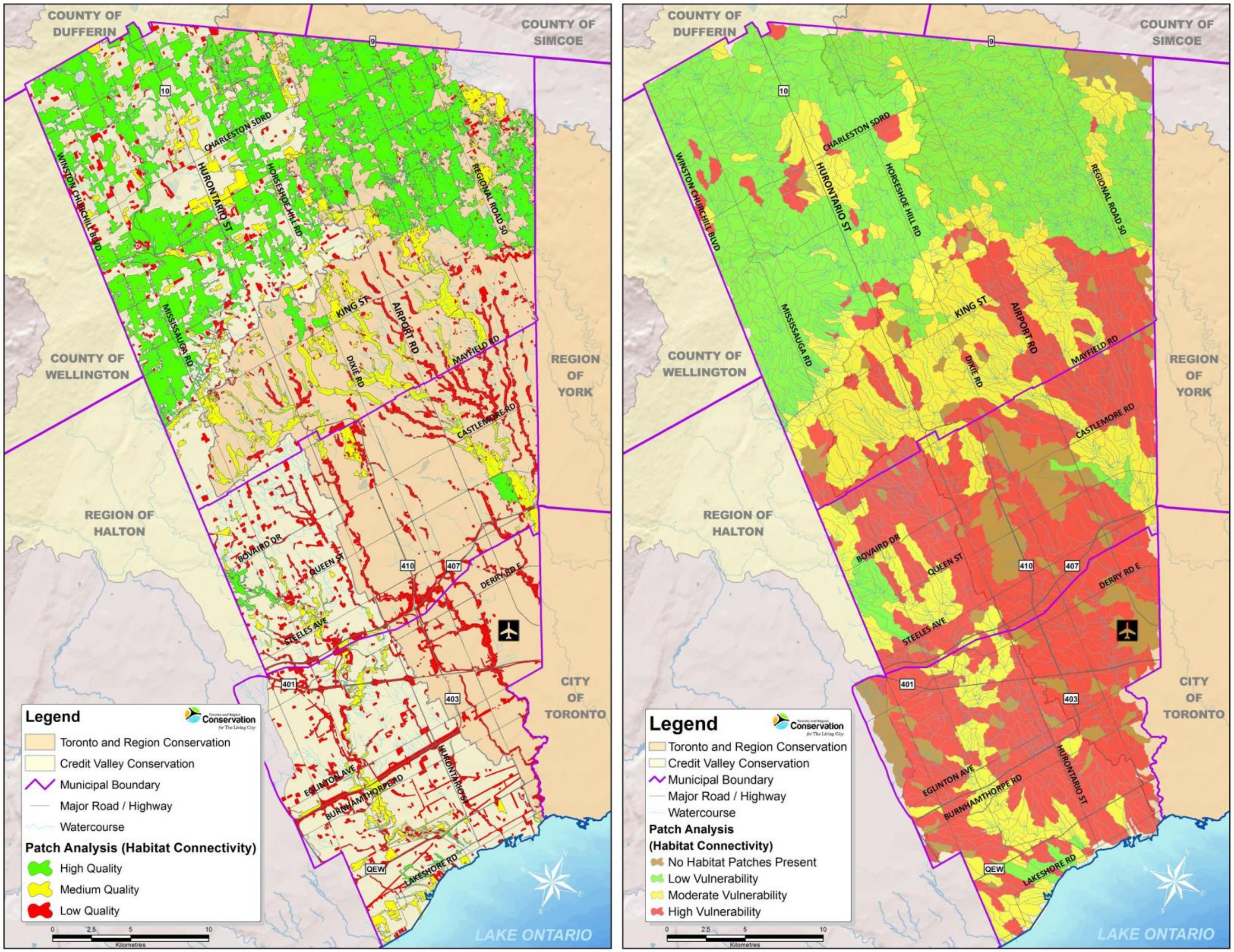
- Enhancing, or making the movement of species among areas used for feeding, shelter or resting less dangerous;
- Facilitating seasonal movements required to complete life cycles for some wildlife (e.g., amphibians, which overwinter in woodlands but migrate to breeding ponds in the spring);
- Enabling dispersal of juveniles to other habitats in the landscape where better habitat conditions may exist;
- Allowing for gene flow to maintain resilience and the ability of wildlife populations to adapt to climate change; and
- Permitting the recolonization of an area after local extinctions.

In fact, in a comprehensive literature review of ecosystem management in the face of climate change, increasing and/or enhancing habitat connectivity was identified as one of, if not the most important and effective adaptation action to undertake to maintain and improve species diversity of our ecosystems (Heller and Zavaleta, 2009).

In Peel Region, an analysis was conducted on habitat patches using both TRCA L-ranking information and CVC qualitative descriptions of patch quality, which characterize quality based on the size, shape and matrix influence (CVC 2011c; CVC 2015a; CVC 2015b). Based on communication with CVC, these are comparable with the analysis conducted by TRCA's Terrestrial Natural Heritage System Strategy (see TRCA, 2007 for more details). Figure 24 illustrates a map of habitat patch quality evaluated by both TRCA and CVC in their respective jurisdictions, and a vulnerability characterization across Peel. In north Peel, habitat patch quality is largely characterized as being high quality and well-connected north of the Etobicoke Headwaters and West Humber subwatershed (TRCA 2008c; TRCA 2007). Notably, some areas where higher urban cover is present, or rural areas where limited habitat patches are present, are considered moderate to low quality (e.g., in the upper main Credit in Caledon).

Furthermore, the wetland coverage of north Peel is considered well connected and highest among all other areas in Peel. Comparatively, the upper Credit naturally contains much larger wetland complexes, or connected areas, than the upper Humber, whereas in the Upper Humber wetlands are smaller, still connected, but more frequently 'peppered' throughout the subwatershed (see Figure 25 for a map of wetland cover; where data were obtained from ELC information in 2013).

In the Etobicoke Headwaters and West Humber, as well as further south into the middle and lower portions of Peel, habitat connectivity (a rating based on habitat patch size, shape and matrix influence) is rated mostly between low to medium quality, with only some local areas being rated as high quality (e.g., main credit river at the Lake Ontario shoreline, an area between Steeles Avenue and Bovaird Drive in the west of Brampton, and in Claireville conservation area) (TRCA, 2007). In general; however, habitat connectivity is much lower quality than that of north Peel, contains habitat patches of irregular or smaller shapes with adverse matrix influences such as urban edge effects, and is of concern. In particular east-to-west connectivity is described as poor in middle Peel, though in the CVC jurisdiction the Niagara Escarpment does provide some east-west connectivity (Hoy and Hall 2013). However, opportunity for connectivity enhancement does exist. For instance, the main Credit River valley is rated as moderate quality and is one of the few remaining corridors from Lake Ontario (south Peel) to north Peel. Wetlands found in middle and south Peel are very small in size, and/or are disconnected (see Figure 25). For example, although there are a number of coastal wetlands in south Peel (Rattray Marsh, Meadowvale Swamp, Creditview Marsh, and Winston Churchill Marsh), they are spatially separate from each other (Ngaio Hotte, Kennedy, and Lantz 2009a) and have been described as "degraded" and small in extent relative to wetland complexes located in northern portions of the Credit River watershed (CVC 2012b).



Range-based Thresholds Applied to Characterize the Gradient in Peel based on Patch Quality (TRCA's L-Ranks, CVC's qualitative descriptions):

Low Vulnerability: TRCA: L1, L2 and CVC: High Quality

Moderate Vulnerability: TRCA: L3 and CVC: Medium Quality

High Vulnerability: TRCA: L4, L5 and CVC: Low Quality

Figure 24: Habitat Patch Quality (Size, Quality and Extent) (A) and Vulnerability Characterization of Habitat Patch Quality (Habitat Connectivity) at the 30ha Catchment Level (B)

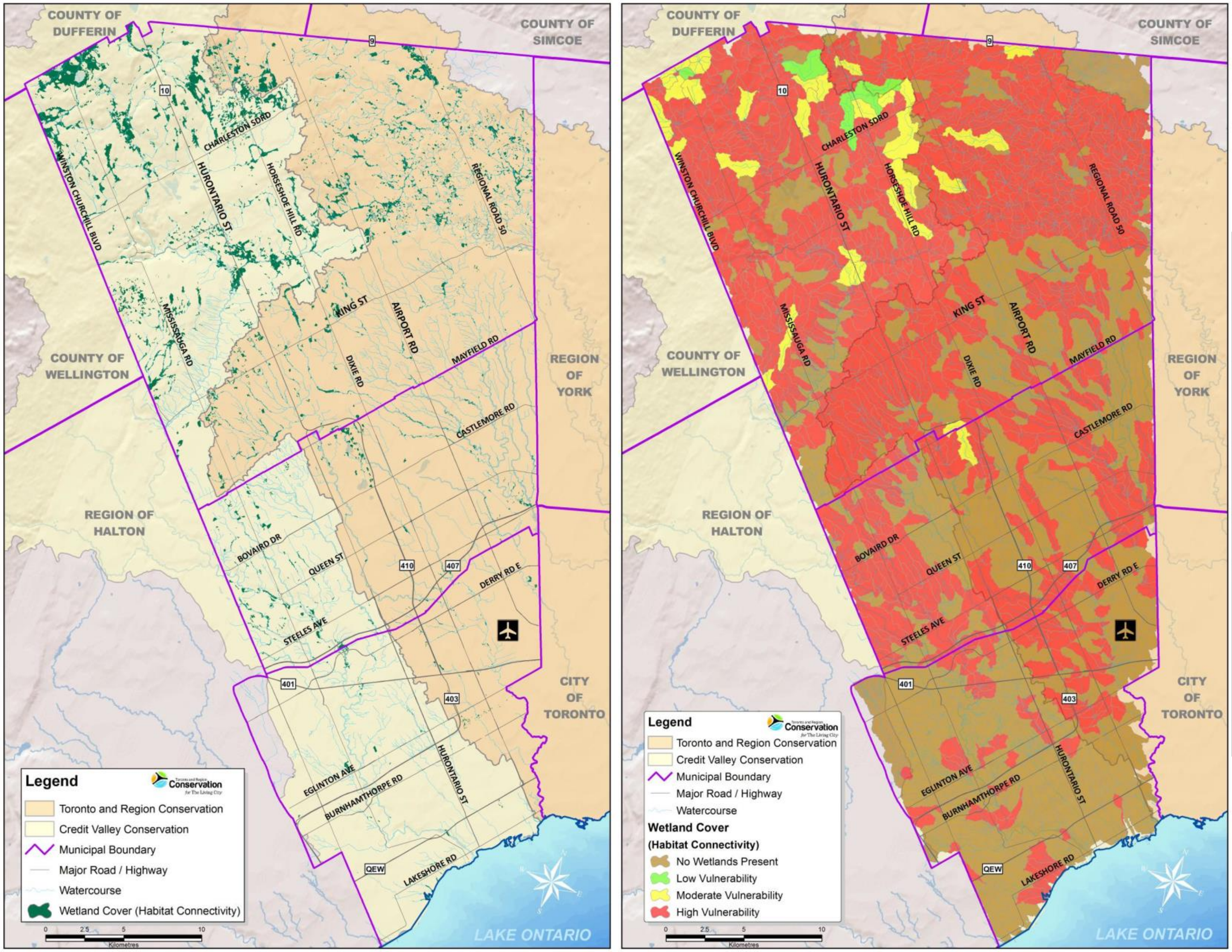


Figure 25: Wetland Cover (A) and Vulnerability Characterization of Wetland Cover (Habitat Connectivity) at the 30ha Catchment Level (B)

Range-based Thresholds Applied to Characterize the Gradient in Peel:

Low Vulnerability: Upper third percentile of wetland cover

Moderate Vulnerability: Middle third percentile of wetland cover

High Vulnerability: Lower third percentile of wetland cover

Hydrologic Connectivity, Wetland Type and its Reliance on Water Source

The level of hydrologic connectivity in wetlands depends on its water source, which is interpreted based on its functional type (i.e. swamps, bogs, marshes, fens). In north Peel, the Humber and Credit watersheds contain the highest number and coverage of wetlands than any other area in the region. Wetlands found in north Peel are comprised of many functional types, but the majority is made up of swamps and marshes (TRCA 2008c). For instance, in the Credit watershed, wetlands are classified as 81% swamps, 18% marshes and less than 1% bogs (Hotte *et al*., 2009; Lantz *et al*., 2010). Across the region as a whole, there is no clear gradient of wetland type as you move from north to south (swamps are most dominant); however, there are fewer wetlands in middle and south Peel (see Figure 26). Only a few bogs exist in in north Peel (i.e. in the Upper Main Humber just northeast of Regional Road 50 and Old Church Road, in the Upper Credit around Highway 10 and 24 south of Highway 9) and in middle Peel (i.e. Heart Lake Conservation Area contains a Tamarack-leatherleaf treed bog that is described as significant and extremely rare with a vegetation community requiring exact geophysical conditions in the Conservation Area), whereas no bogs are found in south Peel (TRCA 2006b; TRCA 2010a). In both middle and south Peel, wetlands are considered to be smaller, less connected and of poorer quality (e.g., containing fewer species with less diversity) (CVC 2012b). However, the degree of hydrologic connectivity in these areas depends on the number of water sources available. For instance, Rattray Marsh is considered hydrologically well-connected given its location at the Lake Ontario shoreline, its proximity to watercourses and its functional type.

Functional Wetland Types used to Characterize Vulnerability based on water source:

Low Vulnerability: Fens, Marshes within 30m of a watercourse

Moderate Vulnerability: Marshes further than 30m from a watercourse

High Vulnerability: Bogs, Swamps

Figure 26: Wetland Type (A) and Vulnerability Characterization of Wetland Type (Hydrologic Connectivity) at the 30ha Catchment Level (B)

Urban Forest Canopy and Natural Forest Cover: Thermal Refuge and Shading

Urban forest canopy in Peel Region provides an important source of shade and thermal refuge from the heat, reduces heat stress, and provides habitat for terrestrial species. Prior to settlement, Peel Region was covered mostly by natural forest as part of a well-connected system (MNR 2009) that had the capacity to recover from extreme weather events and disturbances (e.g., logging and deforestation) common to the area. Today, urbanization has reduced the extent, the size and the resilience of the forest canopy found in Peel Region. A study conducted in Peel's urban areas (TRCA *et al*. 2011) identified that the majority of trees are currently small in diameter (over 70% are less than 15.3cm in diameter and are not mature) due to recent plantings in new development areas which have not yet had the time needed to reach their full size potential (TRCA 2015c; TRCA *et al*. 2011). An analysis of Peel's urban forest canopy based on land cover derived from satellite imagery (TRCA *et al*. 2011) found that more than 7,681 hectares of urban portions of Peel Region are covered by forest canopy representing 13% of all areas examined (see TRCA 2011). The tree species which comprise this canopy varies widely by land use (TRCA *et al*. 2011). For instance, Norway maple (*Acer platanoides*) and white and green ash (*Fraxinus americana, F. pennsylvanica*) are dominant in residential areas and conifers such as Austrian pine (*Pinus nigra*) and white spruce (*Picea glauca*) are common in commercial and industrial areas (TRCA *et al*. 2011). While the tree species diversity in urban areas is lower than recommended for each municipality in the region, the most common tree species in general are Maple species (*Acer saccharum, A. platanoides, A. negundo)*, Ash species (*Fraxinus americana, F. pennsylvanica, F. nigra*) and Spruce species (*Picea abies, P. pungens*) (TRCA *et al*. 2011). Table 16 summarizes the most common tree species in Mississauga and Brampton as of 2011 (TRCA 2011a; TRCA 2011b).

Table 16: Most Common Tree Species by Land Use (expressed as percent of total leaf area)[8]

	Open Space & Natural Cover	Commercial & Industrial	Residential (low, medium, high density)	Agriculture	Other
Brampton	Manitoba maple, 12%	European buckthorn, 29%	White spruce, 17%	Eastern cottonwood, 23%	Hawthorn, 27%
Mississauga	Sugar maple, 43%	Blue spruce, 29%	Norway maple, 12%	N/A	Sugar maple, 22%

In addition several exotic invasive species are also abundant throughout the region such as European Buckthorn (*Rhamnus cathartica*), exotic bush honey suckle (*Lonicera spp.*) and

[8] Data unavailable for Caledon; please note percentages not meant to add to 100%

Norway maple (*Acer platanoides*). It should be noted that the EAB threatens some of the most common urban trees – Ash (*Fraxinus americana*, and *F. pennsylvanica*). In fact, since the completion of this study (2011), the dominant species have likely shifted (i.e. ash trees no longer dominant) due to the EAB. In combination with climate change, urban areas are susceptible to significant changes to the composition, structure and function of urban natural areas; as well as, the loss of street trees and ecological services provided by all of those trees and their associated natural areas.

Urban forest canopy and Natural Forest Cover are highest in north Peel, though urban f canopy has only been examined in urban areas (Caledon East at 29% and Bolton at 17%) and contains the highest leaf area density (2.74), implying the highest amount of ecosystem services being delivered per unit area of urban forest. Figure 27 illustrates urban forest canopy and Figure 28 illustrates natural forest cover in Peel Region.

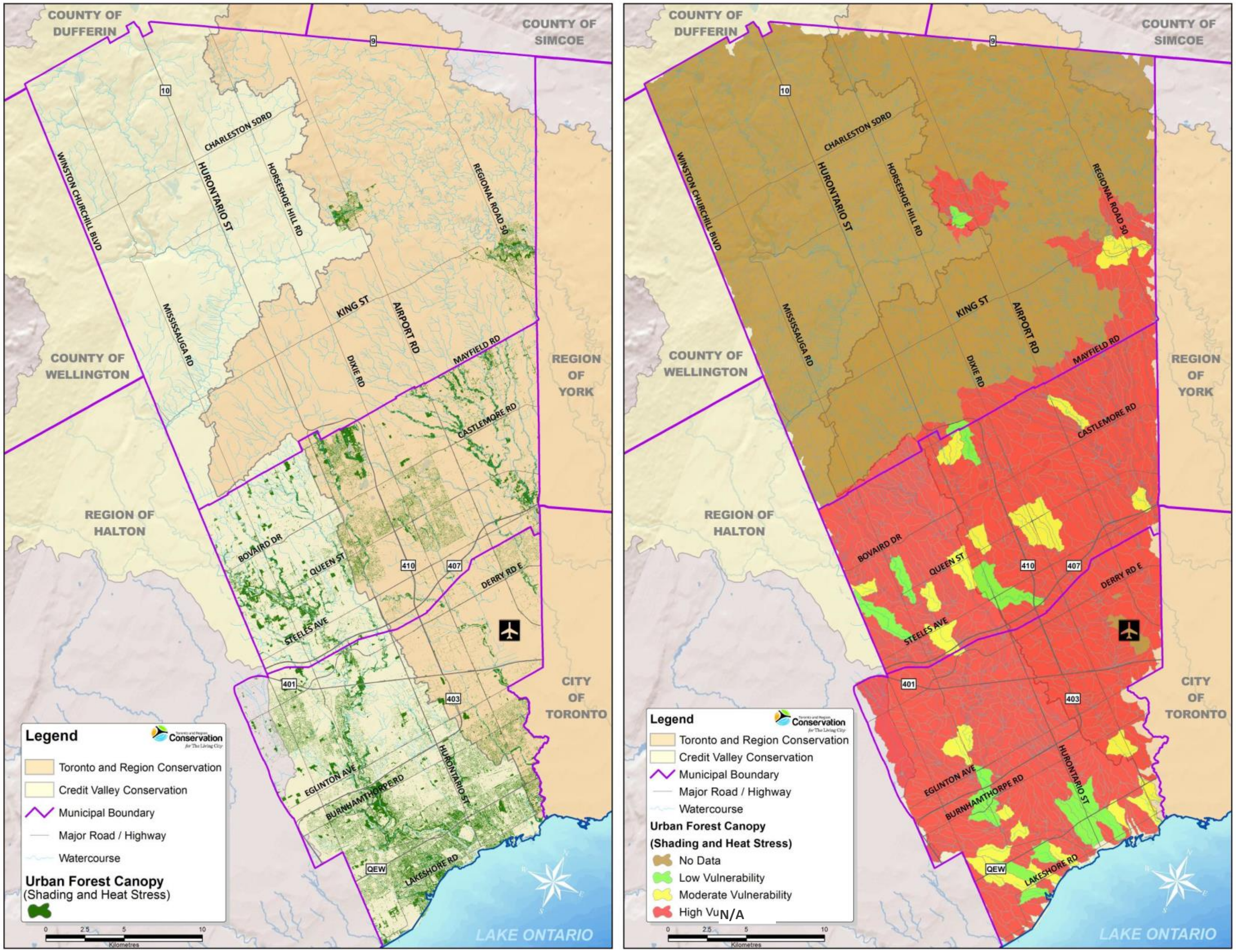


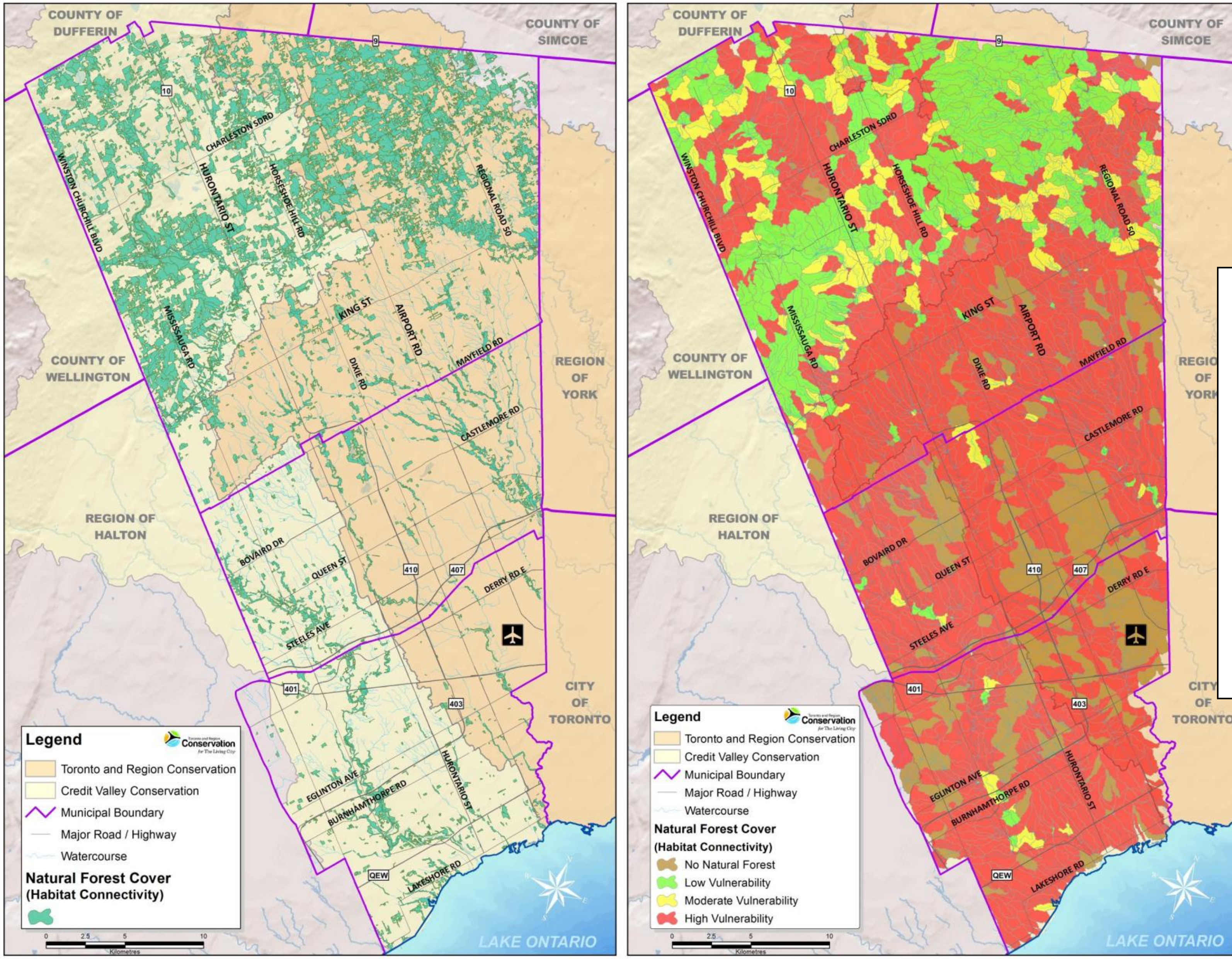
Figure 27: Urban Forest Canopy (A) and Vulnerability Characterization of Urban Forest Canopy (Heat Stress & Shading) at the 30ha Catchment Level (B)

Range-based Thresholds Applied to Characterize the Gradient in Peel (a count of raster pixels in each 30ha catchment):

Low Vulnerability: Upper third percentile of urban forest canopy

Moderate Vulnerability: Middle third percentile of urban forest canopy

High Vulnerability: Lower third percentile of urban forest canopy



Range-based Thresholds Applied to Characterize the Gradient in Peel):

Low Vulnerability: >40% Natural Forest Cover

Moderate Vulnerability: 30-40% Natural Forest Cover

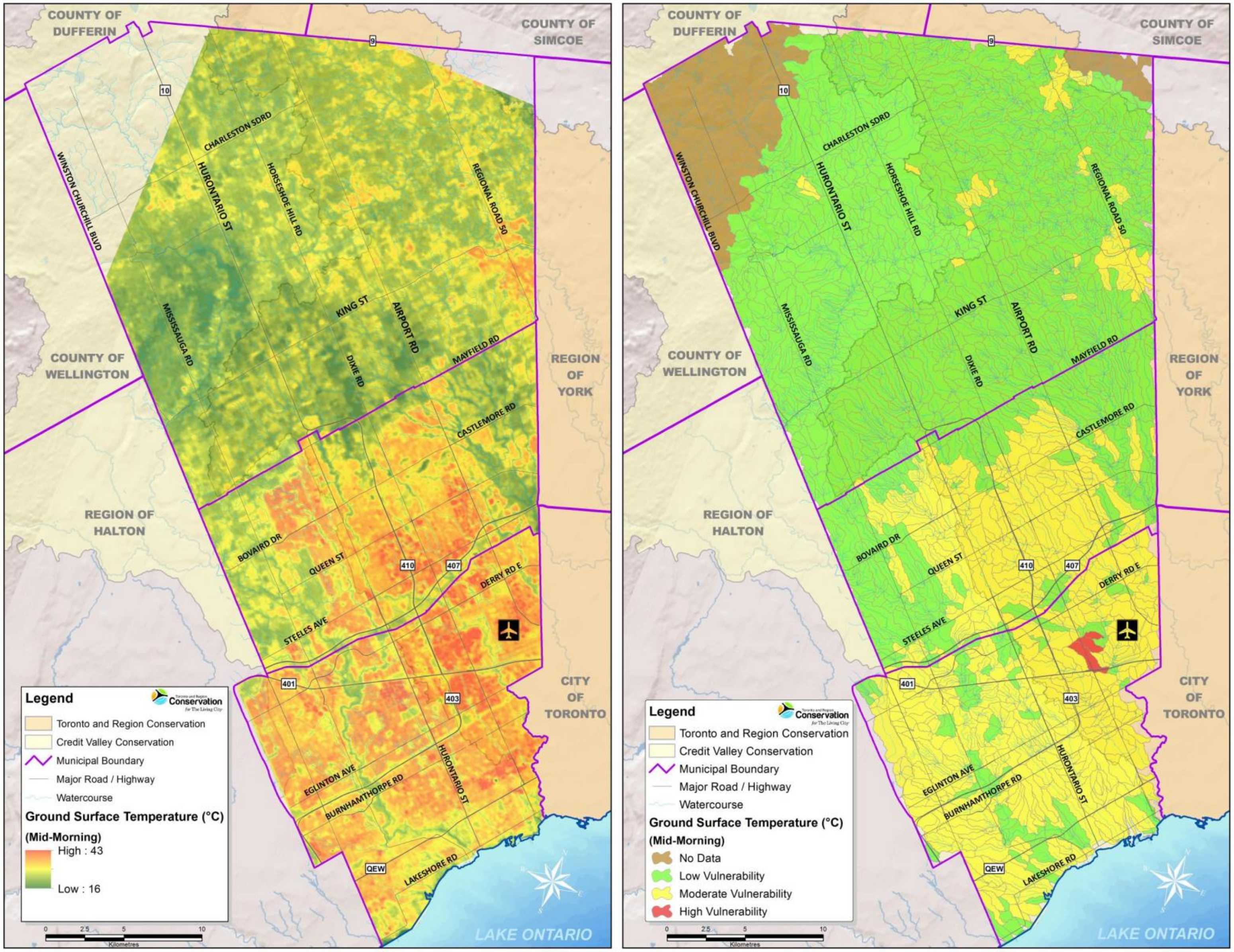
High Vulnerability: <30% Natural Forest Cover

Figure 28: Natural Forest Cover (A) and Vulnerability Characterization of Natural Forest Cover at the 30ha Catchment Level (B)

Middle Peel contains the least amount of urban forest canopy in all of the region (11%), as well as the lowest leaf area density (at 0.54), implying a degraded level of ecosystem services delivered per unit area of urban forest (TRCA *et al*. 2011). This is likely the result of the large proportion of commercial and industrial lands, recent development in this area that have newly planted trees that are small, as well as agricultural lands which limit the amount and distribution of urban forest canopy. This may also be due to the fact that many of the urban forest planting and management techniques used in new subdivisions prevent trees from growing (e.g. highly altered soils associated with development restricting growth). However, urban forest canopy is much higher in some particular areas in middle Peel associated with higher natural cover (e.g., in Heart Lake Conservation Area, in West Brampton between Steeles Avenue and Bovaird Drive and in the lower reaches along tributaries in the West Humber). In south Peel, urban forest canopy is higher overall (at 15%) than in middle Peel but lower than north Peel (TRCA *et al*. 2011). Specific areas found in south Peel contain significantly more urban forest canopy than other local areas. For instance, higher urban forest canopy is present along the Main Credit River valley corridor, as well as in some older residential neighbourhoods along the shoreline (Aquafor Beech Limited 2011b). At the shoreline, the highest amount of urban forest canopy is adjacent to the mouth of the Credit River and west along the waterfront in areas near Rattray Marsh Conservation Area where it occurs in pockets that range from 34% to more than 55% canopy.

Thermal Gradient: Warming of Land surface temperatures & Urban Heat

Land surface temperatures (thermal gradient) play an important role in Peel Region, with some areas exhibiting high amounts of thermal regulation from urban forest canopy and natural cover, but others heavily influenced by the urban heat island effect. It is important to distinguish between thermal regulation of natural cover and urban forest canopy, and the impacts of extreme heat and urban heating on terrestrial biota itself. Vegetation located in the urban matrix is likely currently experiencing heat stress and drying particularly in the summer season especially if soil quality and space for root growth is restricted (e.g. for street trees). Valley corridors may buffer this heat stress to some extent, although still provide large value for shading and refuge for biota. Vulnerability indicator data were obtained through two separate satellite imagery analyses: one conducted mid-morning on August 23, 2009 (see Figure 29) and another mid-afternoon on June 18, 2014 (see Figure 30). Both of these dates when temperatures were obtained occurred within a cooler year relative to Environment Canada's climate normal (Environment Canada 2015). This implies that land surface temperatures may in fact reach even higher extremes during hotter years. In north Peel, mid-morning temperatures were identified to be almost entirely less than 24˚C, with only two significant areas above 25˚C (namely Bolton and Caledon East where urban lands exist) (TRCA Land surface temperature ortho-photo thermal analysis). It appears that mid-afternoon temperatures are not significantly higher in north Peel, with the exception of the core area of Bolton, which reached above 30˚C. Other areas had temperatures between 15˚C and 29˚C. A clear distinction in land surface temperature in the afternoon exists between areas north of the Etobicoke Headwaters and West Humber subwatersheds (which are cooler on average) compared to areas to the south which seem to experience higher urban heat island influences.



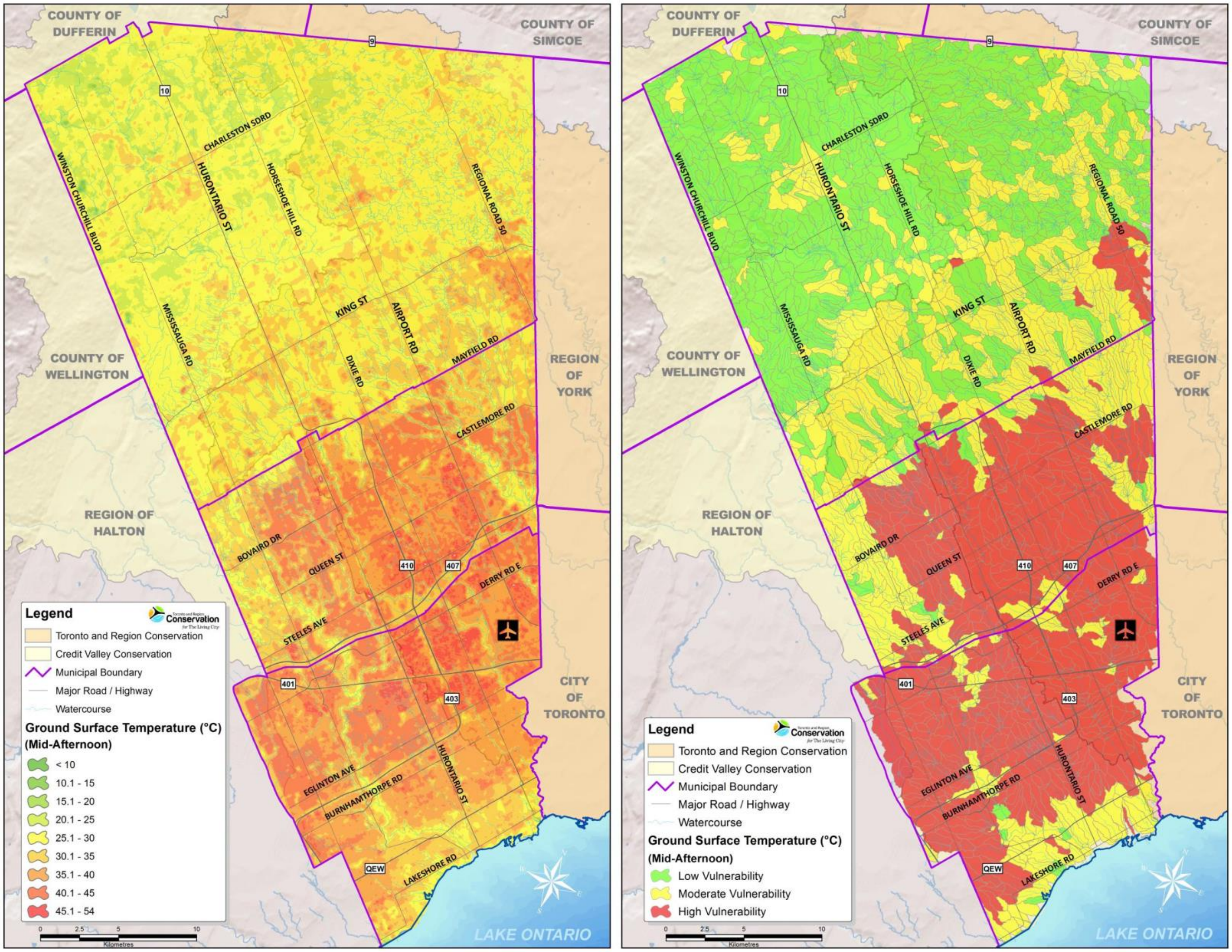
Range-based Thresholds Applied to Characterize the Gradient in Peel:

Low Vulnerability: Less than 24˚C

Moderate Vulnerability: Between 25˚C and 29˚C

High Vulnerability: Greater than 30˚C

Figure 29: Mid-Morning Ground Surface Temperature on August 23, 2009 (A) and Vulnerability Characterization of Mid-Morning Ground Surface Temperature at the 30ha Catchment Level (B)



Range-based Thresholds Applied to Characterize the Gradient in Peel:

Low Vulnerability: Less than 29˚C

Moderate Vulnerability: Between 29˚C and 36˚C

High Vulnerability: Greater than 36˚C

Figure 30: Mid-Afternoon Ground Surface Temperature on June 18, 2014 (A) and Vulnerability Characterization of Mid-Afternoon Ground Surface Temperature at the 30ha Catchment Level (B)

Mid-morning temperatures in middle Peel identified temperatures to range from less than 24˚C in a few areas (notably, in West Brampton between Steeles Avenue and Bovaird Drive where habitat connectivity is also described as high quality and higher amounts of urban forest canopy is present, as well as in the south portion of the West Humber subwatershed), ranging upwards to 30˚C in all other areas in middle Peel (e.g., downtown Brampton) (TRCA Land surface temperature ortho-photo thermal analysis). This spatial thermal gradient trend continues in the mid-afternoon temperatures exhibited on June 18, 2014. Specifically, lower tributaries in the West Humber and west Brampton have temperatures between 29˚C and 36˚C, whereas most remaining areas in middle Peel exhibit temperatures well above 36˚C ranging upwards to 54˚C where heavy urban lands exist (TRCA Land surface temperature ortho-photo thermal analysis).

In South Peel, mid-morning temperatures are well above what is found in north Peel (recall that on average most temperatures were found to be less than 24˚C), with temperatures mostly reaching above 30˚C, with some pockets reaching even further extremes at 43˚C (i.e., areas just southwest of Pearson International Airport where little natural cover and urban forest canopy exist). In south Peel, there are two notable features which provide significant thermal regulation (bringing temperatures down to less than 24˚C): the Lake Ontario shoreline influence in areas furthest south and along the Main Credit River valley corridor (TRCA Land surface temperature ortho-photo thermal analysis). Similar to areas in middle Peel, spatial trends between morning and afternoon temperatures remain the same, implying that the Main Credit River valley corridor and the Lake Ontario shoreline provide vital thermal regulation and cooling from heat stress to nearby areas, but that these areas may also have terrestrial vegetation more stressed due to heat. Specifically, these areas maintain temperatures between 25˚C and 35˚C in mid-afternoon, whereas the rest of south Peel exhibits temperatures upwards of 35˚C reaching 54˚C in areas with very little urban forest canopy and natural cover (TRCA Land surface temperature ortho-photo thermal analysis).

Soil Quality and Nutrient Supply for Terrestrial Vegetation

Soil quality in the Region of Peel may help buffer some climate-induced stresses on local vegetation communities (such as 'edge effects' from impervious cover and/or heat stress from warming of the ground surface). Nutrient supply information is interpreted through the amount of organic carbon present in the first 10 cm of soil (A-horizon soil layer). Information from the Peel County Soil Survey (Hoffman & Richards 1953) indicates that the majority of soils contain between 0 to 3% organic carbon in the A-horizon, with all soils containing more than 1% carbon content, where less than 1% is considered 'degraded' soil quality (Amacher, O'Neill, and Perry 2007). Further, some areas contain higher amounts of carbon (3 to 10%), such as the West Humber south of Mayfield Road, the upper Mimico and the middle Etobicoke watersheds in middle and south Peel. In addition some patches of soil, associated with marshes and swamps, contain even higher amounts of organics between 5 and 15%. Notably, this information may have shifted since collection and should be interpreted cautiously. However, it assumed that good quality soils in many of the non-urban areas of Peel can retain more nutrients and moisture and are therefore are less vulnerable under times of drying conditions or drought in the summer season.

Existing Sensitivity of Terrestrial Vegetation to Urban Heat and Climate

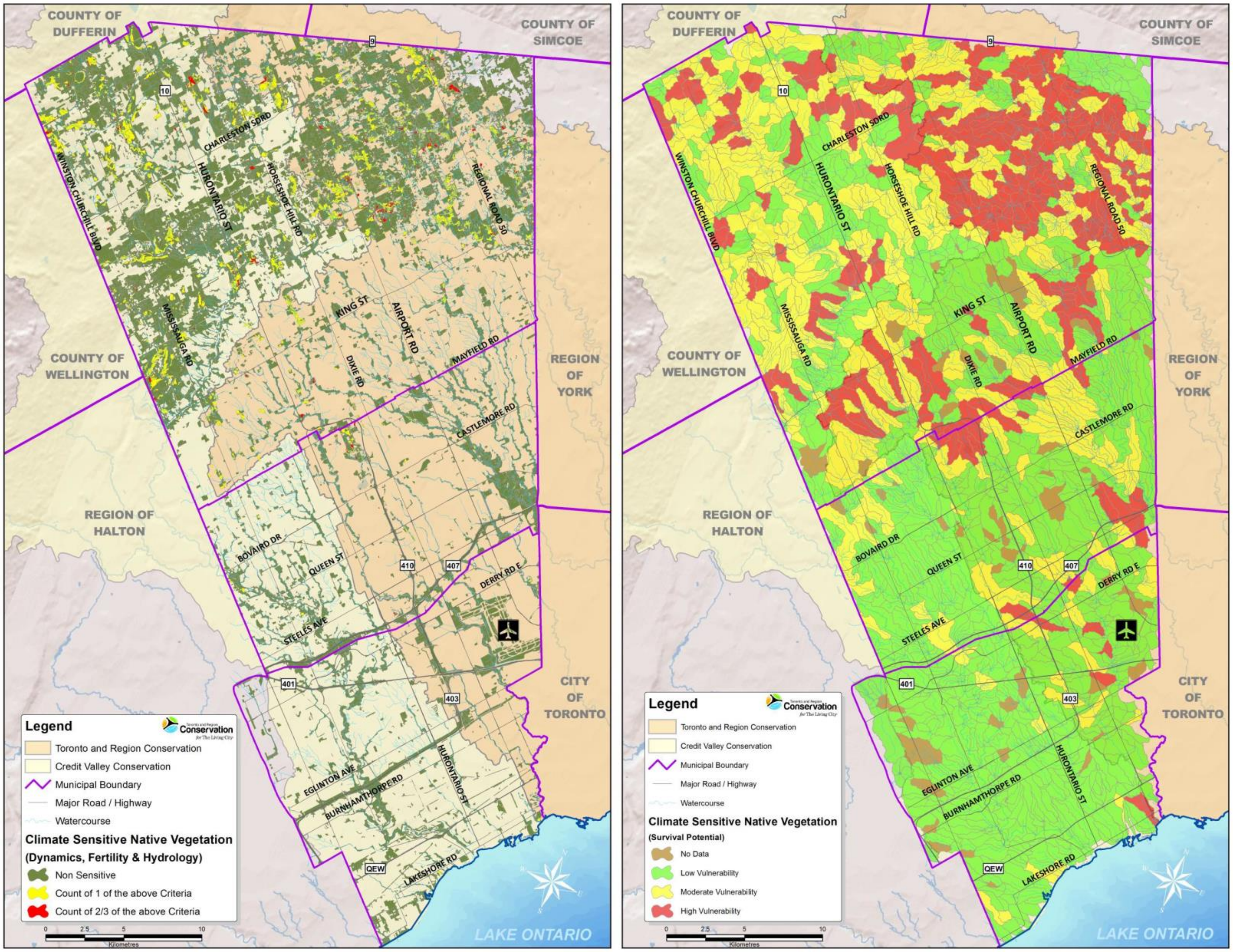
As described above, soil quality within an area can buffer climate induced stresses on vegetation communities present and influence their community range. Building on the methods of the ecological land classification developed by MNRF (Lee 2012) and local CA Natural Heritage System Strategies (TRCA 2007; CVC 2015b; CVC 2015a), ELC data were obtained from the TRCA, CVC, and the City of Mississauga's Natural Areas Survey (NAS) database. These describe vegetation types and ecosites associated with a particular area. Based on internal CA expertise, the comprehensive suite of criteria used to evaluate and assign priority ranking and scoring were refined to consider only those directly response and/or sensitive to climate conditions. In other words, ELC information was scored on a subset of the full criteria available. The following three criteria were identified as climate-sensitive and were used in calculating a score for native climate sensitive vegetation (from TRCA 2007).

Hydrology: Some communities require stringent hydrological conditions, for example, most wetland communities need to have a particular moisture regime. Certain forest types need a subtle combination of good drainage and the presence of groundwater.

Fertility: Some communities require a high level of fertility while others require a low level of available nutrients. In general, specialist native vegetation communities depend upon relatively low-fertility conditions.

Dynamics: Some communities such as bluffs, beaches, and dunes, are dynamic and depend upon natural erosion processes. Others depend upon periodic ground fire. Unnatural disturbances such as trampling in a heavily-used recreation area or storm runoff-caused gully erosion are not counted.

ELC codes with a higher sensitivity score are considered more vulnerable to climate change, given the multiple factors that may influence their survival (hydrology, fertility and/or dynamics). In other words, it was assumed that an ecosite or vegetation type that was dependent on more of these criteria is more vulnerable to climatic changes than an ecosite not dependent on any or as many. Appendix C summarizes all ecosites (with their ELC codes) found in Peel Region and their assigned climate sensitive scoring based on these criteria. Figure 31 illustrates climate sensitive native vegetation spatially mapped throughout Peel as well as its vulnerability characterization.



Thresholds defined based on the number of climate sensitive criteria (hydrology, fertility, and dynamics):

Low Vulnerability: Non Climate Sensitive Native Vegetation

Moderate Vulnerability: Climate Sensitive Vegetation based on 1 of the above criteria

High Vulnerability: Climate Sensitive Vegetation based on 2 or more of the above criteria

Figure 31: ELC Climate Sensitive Vegetation Native Vegetation (A) and Vulnerability Characterization of Climate Sensitive Native Vegetation (Survival Potential) at the 30ha Catchment Level (B)

As a whole, 10.6% of land cover in Peel Region contains climate sensitive native vegetation ecosites, 4.1% of which are located in urban areas (See figure 32). In north Peel there is significantly more natural vegetation present than in middle and south Peel. As a result, there is more climate sensitive vegetation present (e.g., those which are rated moderately and highly vulnerable). Specifically, Albion Hills Conservation Area, areas around Centreville Creek, the upper branches of the West Humber, the Etobicoke Headwaters and Cheltenham to Glen Williams in the Credit watershed all contain highly vulnerable climate sensitive vegetation (see Figure 31 for spatial mapping a vulnerability characterization). For instance, in the areas in and around Albion Hills Conservation Area, the following ecosites are rated highly vulnerable: white cedar mineral coniferous swamp, Tamarack white cedar treed fen, Bluejoint mineral meadow marsh, Black Ash organic deciduous swamp, and White Cedar organic mixed swamp. Middle and south Peel are comprised of mostly low vulnerability vegetation (e.g. non climate sensitive ecosites); however, some exceptions do exist. For example, Heart Lake Conservation Area and areas in the Upper Mimico are considered highly vulnerable based on the ecosites present there, mostly to hydrology (e.g., narrow-leaved cattail mineral marsh, Pondweed submerged shallow aquatic).

The presence of climate sensitive vegetation in urban areas where thermal gradients exist, may pose a particular threat to these ecosites' future survival. For instance, 4.1% of natural cover within the urban matrix in Peel Region contains climate sensitive native vegetation (as mentioned above). An analysis was conducted to examine all climate sensitive native vegetation ecosites present in areas of Peel with land surface temperatures greater than 30˚C in mid-afternoon (see Figure 31). Ecosites that exist in this condition include marsh ecosites (e.g., Broadleaved cattail organic marshes, duckweed marshes, pondweed marshes), swamp ecosites (e.g., Silver maple swamps, Willow Mineral Thicket and Deciduous swamps, and cattail organic swamps), and forest ecosites (e.g., White cedar hardwood mixed forests, white cedar conifer forests). Further, the presence of exotic invasive plant species throughout Peel Region may further stress native vegetation and its survival to climate change. Notable exotic invasive plant species have already been found throughout Peel, which are known to reproduce aggressively and displace native vegetation, such as European Buckthorn, Dog Strangling Vine, Exotic Bush Honeysuckle, and Norway Maple (TRCA, 2011a).

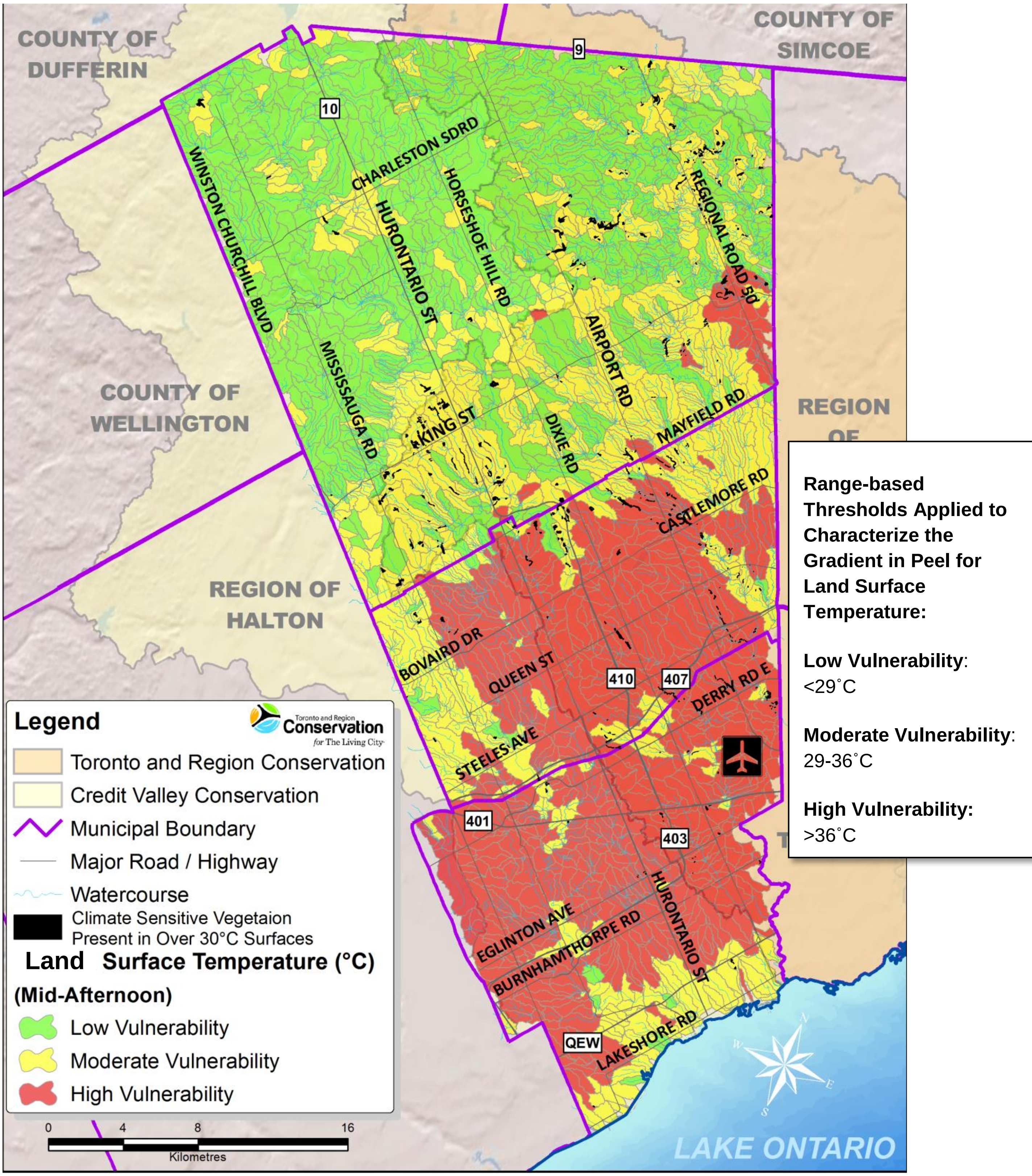


Figure 32: Areas where Land Surface Temperature (Urban Heat Island) is above 30˚C in Mid-Afternoon, where Climate Sensitive Native Vegetation Ecosites are also present

Future Vulnerability in Peel's Terrestrial System

Pervious Cover and Vulnerability to Increasing Disruptions to Hydrology

Given the context of limited pervious cover in both the lower (urbanized) and middle (urbanizing) areas in Peel, the upper areas in the region become incredibly valuable under climate change for maintaining infiltration and attenuation of water. Outside of the potential for further loss of natural cover due to future urban development (see section 6.1.4), it is not anticipated that large swaths of pervious or natural cover will dry up under a future climate. However, climate change may shift soil and moisture conditions thereby shifting the amount of water able to infiltrate into the subsurface, or it may dry out some natural components in the summer season (i.e. areas of wetlands) and thus change water attenuation properties. Furthermore, there may be increasingly variable delivery of precipitation to be infiltrated. Riparian wetlands in particular are likely to be inundated more frequently resulting in changes to their disturbance regime and subsequently affecting the biological composition and soil characteristics (Costanza *et al*. 2008). Wetter conditions overall (Auld *et al.*, 2015) will likely produce more water flowing over lands, and if a lack of pervious cover exists, flooding may be exacerbated (An Taisce 2012; TRCA 2008d). Urban land cover modifies the production and delivery of runoff to streams and the resulting rate, volume, and timing of streamflow (Konrad and Booth 2005; Nelson, Sadro, and Melack 2009). These changes may become exacerbated from increased amounts of water that could increase the frequency of high flows, redistribute water from baseflow to stormwater flow, increase daily variation in flows to streams from land and reduce low flows in the summer season (Konrad and Booth 2005). For example, one study (Paul and Meyer 2001) found that increasing imperviousness from a natural condition up to 20 and 75% resulted in a two-fold and five-fold increase respectively in the volume of stormwater runoff. In a GTA study conducted on the west Don and upper Rouge subwatersheds, the i-Tree Hydro model simulated the effects of tree and impervious cover on stream flow and demonstrated that the removal of current impervious cover (56.5% in the West Don and 31.5% in the Upper Rouge) could decrease total flow by an average of 7.4% and 28.6%, respectively (Vaughan Parks and Forestry Operations 2012). Conversely, empirical literature suggests that an increase in flood frequency could cause a shift in species composition along with other ecosystem impacts (N LeRoy Poff, Brinson, and Day 2002). In middle and south Peel especially, climate change is likely to deliver more water that could exacerbate flooding on an annual basis. Depending on how extreme events occur, the summer season may lead to drying and if severe enough, increases in attenuation properties where wetlands exist in north Peel.

Topography and Grade: Vulnerability to Increases in Surface Volume Runoff

Similarly, topography and grade are not expected to change significantly, if at all, as a result of climate change in Peel Region. Slopes, and topography, theoretically could change as a result of urbanization (digging, etc.) but this is not anticipated to be a significant vulnerability in Peel Region. The degree to which a soil drains water (*soil drainage*) however does influence the amount of surface volume runoff that may flow across the landscape. Specifically, the slope of the land is an important factor in determining whether a contaminant (in water) released will become run-off or infiltrate to supply an aquifer. With a low slope, such as in areas in the West Humber and Etobicoke Headwaters, a contaminant is less likely to become run-off and therefore more likely to infiltrate the aquifer (Schindler 2001; University of Texas 2014). With wetter conditions annually expected by the 2050s, areas in Peel that are currently vulnerable due to poorly drained soils (see Figure 23), such as the Upper Mimico, are more susceptible to climate drivers that could increase the amount of surface runoff. For instance, low-lying topographical areas are more susceptible to flooding under extreme precipitation events (Horton *et al*., 2012) but may not be vulnerable if soils are well drained., depending on the intensity and duration of the event In north Peel, topographically higher areas typically contain higher slopes associated with the ORM and thus may be less vulnerable given that soils are well drained; however, locally low-lying areas or areas that are urban may be vulnerable to increased overland flow volumes associated with increased precipitation throughout the year on average, or due to extreme precipitation events. On the other hand, areas containing higher slopes such as the ORM may be vulnerable to shifting moisture availability particularly for vegetation due to higher temperature and an increased rate of runoff due to more intense rainfall events. Largely urban areas (i.e. Mimico watershed in Peel Region) that contain heavy industrial land uses with poorly drained soils in the south and imperfectly drained soils in the north may be more vulnerable to increased surface volume runoff if exposed soils are unable to infiltrate water where they exist. For instance, a study conducted in Vancouver suggests that increased runoff volumes are likely due to increases in total and peak rainfall and that even by 2020 (note: the study was completed in 2006), the amount of runoff is predicted to be equivalent to the runoff associated with a watershed that is 87% impervious (Denault *et al*., 2006), which is very similar in conditions to south Peel.

Habitat Connectivity: Vulnerability due to Increased Edge Effects and Range Shifts

Habitat connectivity (natural forest cover) is relatively low in some parts of Peel region (see Figure 24 for a map of habitat patch quality), and especially in the lower and middle areas; there is higher likelihood of increased edge effects such as higher rates of spread of invasive species, increased heat stress to vegetation, and drying effects on habitats. In north Peel, the habitat connectivity is generally high, which indicates that the edge effects may be relatively moderated as long as there is no additional habitat fragmentation and loss due to urbanization (Fay, *et al.*, 2003; Harper *et al.*, 2005; Knapp *et al.*, 2002; Mielnick & Dugas, 2000; Nippert *et al.*, 2009). However, north Peel also has higher amount of climate sensitive vegetation (community range) that may be impacted by changing climate, which may make north Peel susceptible to changing habitat connectivity conditions due to shifts in habitat type or through habitat loss (Esser, 1992; Knapp *et al.*, 2001; Sala *et al.*, 1988).

Northern vegetation communities (e.g. conifers) in Peel's natural forests, in general, are likely to shift their range due to impacts of changing temperature and precipitation patterns affecting the tree survival, growth, and phenology. In north Peel, where there are extensive natural forests with climate sensitive vegetation, this may decrease the suitability for some species and wildlife could be impacted (habitat connectivity). However, this depends on the magnitude of impacts, habitat connectivity outside of Peel Region and fauna tolerances (e.g. sensitive amphibians, migratory birds) taking refuge in these areas (Allen *et al.*, 2010; Dale *et al.*, 2010; Dietz &

Moorcroft, 2011; Dukes *et al.*, 2009; Joyce *et al.*, 2014; McDowell *et al.*, 2008). This decrease in habitat connectivity could significantly impact species by constraining gene flow, reducing species' ability to move and seek refuge, and could lead to fewer species in the region or in fact could cause a shift in species composition due to emerging species making up the diversity (Beck *et al*., 2011; Choat *et al*., 2012; Joyce *et al*., 2014; Staudinger *et al*., 2012; Staudt *et al*., 2013). In north Peel where habitat patches are mostly made of natural forests, shifts in successional trajectories due to longer growing season may impact the habitat quality for wildlife.

In middle and south Peel where habitat is mostly comprised of natural and urban forest patches that are less extensive and less connected combined with low species diversity and urbanization pressure, there is increased vulnerability to pest and invasive infestation and further reduction in quality and extent of habitat patches (Campbell *et al.*, 2009; McMahon *et al.*, 2010; Vose *et al.*, 2012). Under climate change; however, the lack of connectivity in the south is concerning as a barrier for the migration and shifts of more adaptable terrestrial species moving north (e.g., Carolinian tree species) that may unable to colonize due to Lake Ontario and urbanization along the shoreline to Niagara and the narrow pinchpoint along the Niagara Escarpment through Hamilton.

An analysis conducted by the TRCA as part of their Valley and Stream Crossings Guidelines (TRCA 2015e) identified priority habitat patches in the Humber, Etobicoke and Mimico watersheds (see Figure 33). It should be noted that CVC is also currently undertaking a Road and Valley Crossings analysis, the results of which are not included in this assessment. These priority ratings do not represent vulnerability, but rather priority for maintenance and enhancement to contribute to regional terrestrial connectivity for species in the future. Regional connectivity refers broadly to the connectivity among all high quality habitat patches across the landscape in a particular watershed. Regional connectivity is important for ecological processes required for long term population persistence in the landscape (e.g. dispersal, gene flow). The target terrestrial natural system's higher quality habitat patches (L1-L3) (TRCA 2007) were defined as the target for maintaining and, if possible, enhancing regional connectivity based on future land use conditions. The future land use data were compiled from municipal Official Plans, natural heritage plans, and secondary plans. This was used to define the general resistance value for wildlife movement ranging from one to five, with five posing most resistance to wildlife movement (i.e. urban impervious land uses) and one posing the least resistance (i.e. natural cover). The relative contribution of each location in the watershed to the overall regional connectivity of all high quality habitat patches in the watershed was calculated using a connectivity metric called "current density" quantified with analytical software, Circuitscape (McRae and Shah 2009). Circuitscape uses a circuit theoretic approach (McRae and Shah 2009), which has been widely used in U.S. and elsewhere for landscape connectivity analyses. Habitat patches shown in red indicate lowest priority for maintenance and enhancement, whereas those in dark green indicate the highest priority. Notably, the gradient of colours illustrated in Figure 33 is relative to the watershed they are found in. Thus, high priority areas of the Upper Humber are not directly comparable to those in the Upper Etobicoke, but both are important in maintaining and enhancing regional connectivity.

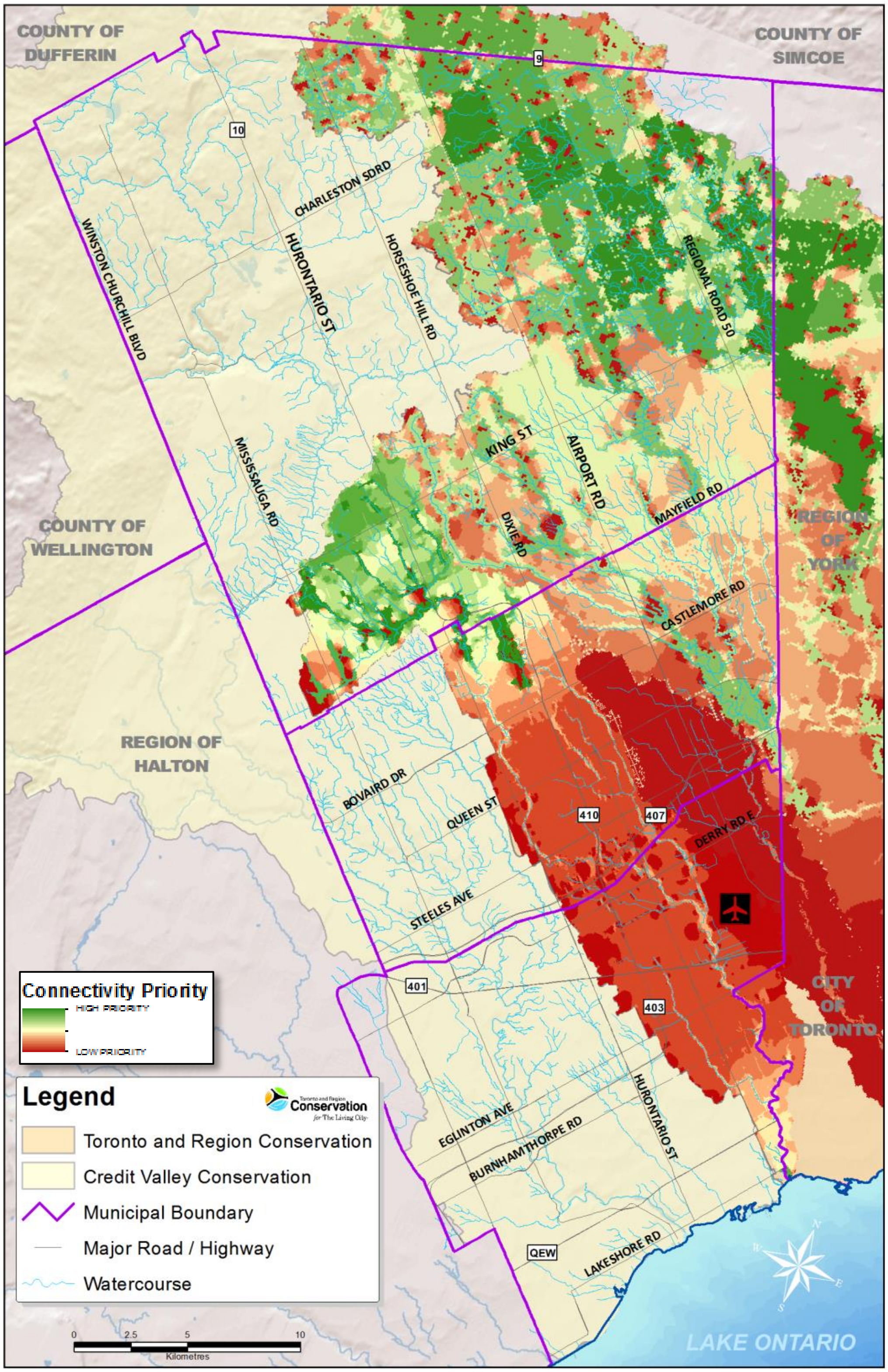


Figure 33: Habitat Connectivity Priority for Enhancement and Maintenance: Modeling for the TRCA Jurisdiction in Peel Region.

Hydrologic Connectivity: Vulnerability of Water Source Disruption to Wetlands

Hydrologic connectivity, or water source disruption to wetlands, is particularly important under climate change and may be significantly impacted. Due to their large wet area and shallow depths, wetlands are particularly vulnerable to water losses by evapotranspiration. Any variation in climate that increases the relative importance of evaporation compared to precipitation is likely to result in drying out of wetlands. For instance, shorter warmer winters and longer summers imply that wetlands relying on precipitation as their dominant water source (e.g., bogs) in Canada will be under increasing stress due to water shortage (Environment Canada 2013). Wetlands are in general vulnerable to changes in their water supply depending upon their functional type (Schleupner 2011). Some types of wetlands are less likely to be affected by climate change. These include wetlands fed by large deep groundwater systems which tend to maintain a steady flow even under large climatic variations. Many fens may be in this category if the groundwater flowing in to them constitutes an important part of the total water input (Environment Canada 2013). Marshes along the margins of lakes and rivers with stable water levels are likely to be insensitive to climate change (Environment Canada 2013), such as Rattray Marsh. However, coastal marshes such as these also provide important ecosystem services in maintaining shoreline integrity and stability (Tomalty and Komorowski 2011) and as a result are important to conserve. In the hydrologic connectivity analysis (see Figure 26) this point was captured by indicating those wetlands within 30 m of a watercourse as low vulnerability and those further than 30 m as moderate vulnerability. Swamps on the other hand may actually disconnect from their groundwater supply if drying becomes significant and are therefore similar to a bog (CVC *et al*. 2009). Both swamps and bogs, therefore, are assumed to be highly vulnerable to losing their hydrologic connectivity.

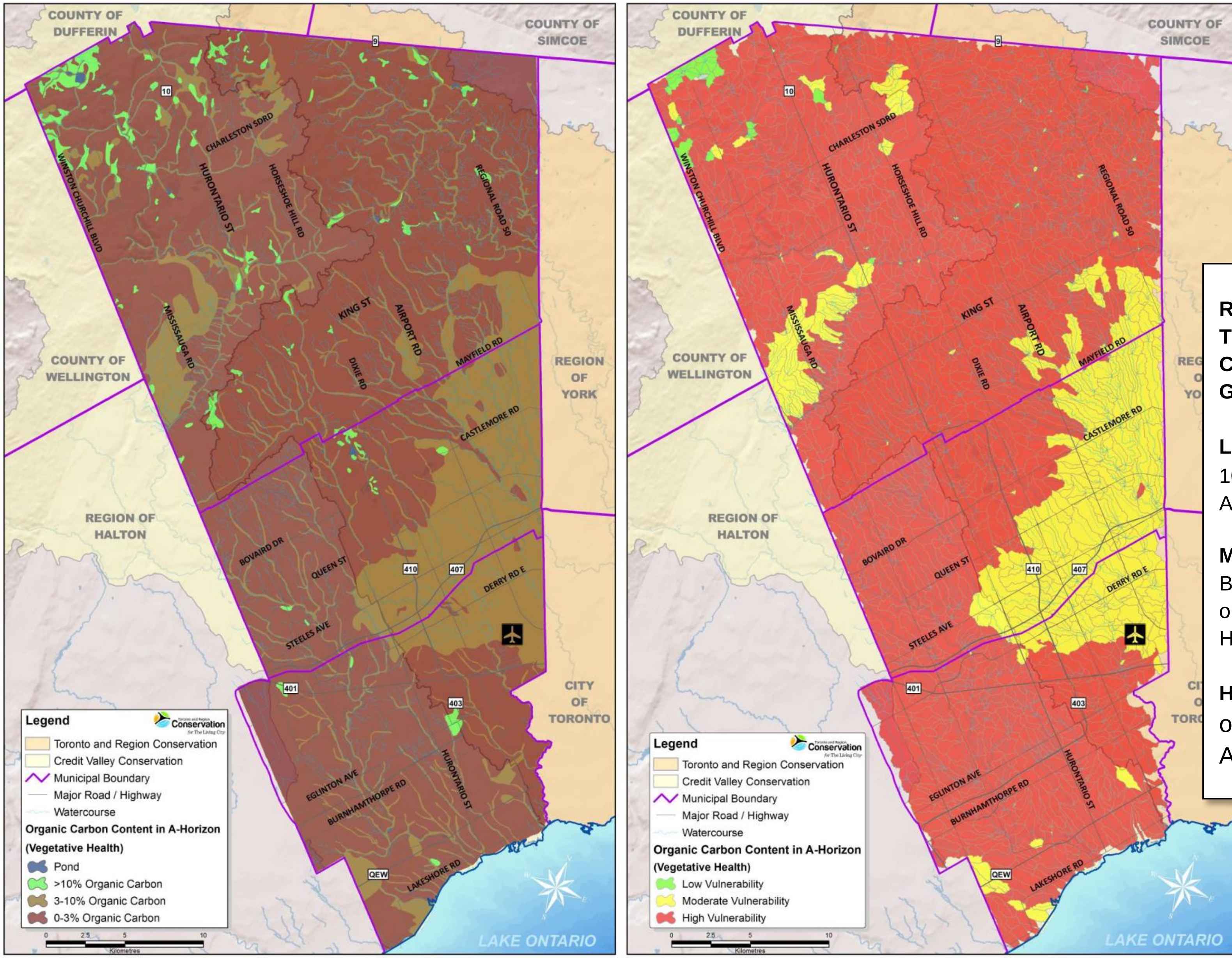
An analysis conducted on the Credit watershed in north Peel demonstrated that most wetlands are rated between medium sensitivity and low sensitivity to climate change, with the majority being ‘medium’ based on a series of criteria rated for wetlands in the jurisdiction (CVC, 2009). However, an analysis conducted by TRCA across all of Peel which took into account the level of hydrologic connectivity based on wetland type and their distance from a watercourse (see Figure 26) identified that the majority of wetlands in north Peel are highly vulnerable to drying (likely due to the high number of swamps in this area), which may act similar to bogs and become precipitation-fed only when drying occurs (Hotte *et al*., 2009; Lantz *et al*., 2010). Other wetlands in north Peel range between moderate vulnerability (e.g., marshes further than 30 m of a watercourse) and low vulnerability (e.g., marshes within 30 m of a watercourse), but these do not comprise the majority. For instance Rattray Marsh is rated as low vulnerability given its location at the Lake Ontario shoreline, its proximity to watercourses and its functional type. These findings are consistent with those found in the CVC Wetland Restoration Strategy which identified that Rattray Marsh has ‘medium’ sensitivity to climate change in general, but not drying or disconnection of its water source in particular (CVC, 2009).

More generally, responses of wetlands to a wetter, warmer year include changes in elevation, boundary or edge distribution, areal extent (wetland to water area), and composition of soil or sediment (Day *et al*. 2008). On the other hand, increasing precipitation on an annual basis could lead to greater inundation. Greater inundation, which could be expressed as changes in the area, depth, duration, frequency, seasonality, and volume of surface water, generally reduces riparian vegetation abundance (IPCC 2013), although potentially not in summer when precipitation may not change significantly and drying may become a more important impact (Auld *et al.*, 2015). Studies conducted on future wetland vulnerability (to drying) in Peel Region indicate that under ensemble climate model projections of changes in air temperature and precipitation, by the 2080s, ~33%, 30-50% and 14-36% of the wetlands will have a low, mid and high vulnerability to climate change, respectively (Chu 2015). This vulnerability to drying does not take into account functional types and the proximity of some wetlands to surface water flows and thus differs from the results illustrated in Figure 26; however, does imply a gradient in vulnerability to hydrologic connectivity based on baseflow support to wetland features. In general, wetlands in north Peel were the most vulnerable to climate change, which corroborates analyses conducted on wetland vulnerability in this assessment (Chu 2015).

Soil Quality: Buffering Soil Moisture Depletion in a Hotter Climate

The characteristics of soil (soil quality) found in a surficial component can influence its permeability, and particularly the amount of organics and moisture found in the soil. A soil with very low permeability is more vulnerable to shifts in precipitation since less water is available for subsurface flow paths (Bruce *et al*., 2008; Day *et al*., 2008; Eimers, Buttle, & Watmough, 2008; Eimers, Watmough, Buttle, & Dillon, 2007; Hotte *et al*., 2009; Jyrkama & Sykes, 2007b; Reid & Holland, 1996). On the other hand, a soil that is very thin is more vulnerable to increases in temperature at the surface since it has a lower capacity for maintaining moisture thereby drying out surficial vegetation. For instance, soils found along the Niagara Escarpment brow in the Credit Watershed are thinner but may be buffered by well forested systems. Another example could be thin soils over Queenston shale in Peel below the Niagara Escarpment where less forest cover exists and the formation of badlands is possible due to higher erodibility from desiccation of vegetation compared to other soil types (Hoffman and Richards 1953).

Similarly, a component characterized by soils with very high permeability (e.g. sandy loam) in proximity to urban land cover, are more vulnerable to increasing temperatures compounded by anthropogenic factors such as the urban heat island affect from higher evaporation and ET rates thereby potentially reducing soil quality and moisture availability (Capital Region District, n.d.; Klein, 2013; Quant, 2014, B. MacVicar personal communication, October 22, 2014; D. Ford personal communication, November 3, 2014). Reduced precipitation poses a threat for the natural systems if there is not enough water to facilitate healthy growing conditions. Drought conditions can also lead to decreased soil nutrients, and plant withering and mortality. Soil nutrients and moisture provide an important buffer in drought events, wherein certain soils have the ability to retain moisture that can then facilitate plant and ecosystem health during times of insufficient water supply. In Peel Region, soils in general are rated between moderate and low vulnerability, indicating there are few areas where soil quality will compound vulnerability in the terrestrial system (see Figure 34 for a map of organic carbon stored in the soils of Peel Region). Some areas contain higher amounts of carbon implying a less vulnerable state, such as the West Humber south of Mayfield Road, the upper Mimico and the middle Etobicoke watersheds in middle and south Peel.



Range-based Thresholds Applied to Characterize the Gradient in Peel:

Low Vulnerability: > 10% organic carbon in the A-Horizon

Moderate Vulnerability: Between 3 and 10% organic carbon in the A-Horizon

High Vulnerability: < 3% organic carbon in the A-Horizon

Figure 34: Organic Carbon Content in the Soil A-Horizon (A) and Vulnerability Characterization of Organic Carbon Content (Vegetative Health) at the 30ha Catchment Level (B)

Urban Forest and Natural Forest Canopy: Reducing Urban Heat (at the Trees' Expense) to Shelter Humans and Biota

Forests (urban forest canopy) will aid communities in adapting to a changing climate by reducing the urban 'heat island' effect (thermal gradient). Specifically, trees lower the ambient temperature through shading and transpiration (i.e. releasing water vapor), where evapotranspiration refers to evaporation by soil and transpiration by plants (TRCA 2015c). However, with warming temperatures and the existing urban and urbanizing context through much of middle to south Peel, urban heat island and air quality are likely to be adversely affected with implications on human health. Increasing temperatures will generally favor increased tree growth due to longer growing season and increased photosynthesis rate (CCSP 2008). However, north Peel has a substantial amount of climate sensitive vegetation (community range), which may mean that the positive impact of general warmer temperatures and a longer growing season may be offset by the relatively higher sensitivity of these vegetation communities (see Figure 31). This may mean that some vegetation, especially vegetation communities, which are more sensitive to water/moisture availability, may be more vulnerable (Johnston 2009). Some of the northern tree species may not be able to adapt to the increasing temperature and may be replaced by more southern species that are expanding their range (Joyce *et al*. 2014; Beck *et al*. 2011). However, it is important to consider barriers to these southern, more adaptable species, which include lower habitat connectivity in south and middle Peel Region, urbanization along the shoreline extending from the Greater Toronto Area to Niagara, and the Niagara Escarpment acting as a pinchpoint. In other words, the replacement of these northern tree species may be challenging under a future climate without adequate management of habitat and species.

As a result of these shifts in range, the vegetation structure is likely to change due to changing communities (Joyce *et al*., 2014; Staudinger *et al*., 2012). If more southern species are able to migrate north, in such cases it is likely that some of these communities may shift to more moisture resistant / hardy vegetation communities (Joyce *et al*. 2014; Beck *et al*. 2011). This may decrease the heat street regulating capability to a certain extent. In Peel Region as a whole, urban forest canopy has moderate vulnerability both in upper and middle to south Peel for different reasons (see Figure 27).

In north Peel, some specific climate sensitive vegetation communities (e.g. deciduous swamps) that are sensitive to moisture conditions may be replaced by hardier communities (e.g. shrubs) to mitigate the impacts of dry summer (Beck *et al*., 2011; Joyce *et al*., 2014; Staudinger *et al*., 2012), thereby decreasing the ability to regulate heat and air quality. In middle to south Peel, there is less urban forest canopy (except along valley corridors and the shoreline) and urbanization has stressed the nature of urban forest, which may make the urban forest canopy more vulnerable. Given the increased stress of the urban environment (compacted soil, inadequate space for roots and growth, more heat island effect) combined with the low species diversity (dominantly a few species) and age structure (younger and smaller trees) of vegetation, there may be higher vulnerability to drying and heat stress (Johnston 2009). Additional stressors, such as the EAB, can also exacerbate this vulnerability and threatens some of the most common natural forest and urban forest trees, such as Ash (*Fraxinus americana, F. pennsylvania, F. nigra*). In combination with climate change, natural and urban forest are susceptible to significant changes to the composition, structure and function, and as a result, significant ecological services provided by all of these vulnerable tree species may be lost. This implies that there is greater vulnerability from direct radiant heating, drying due to water evaporation from soils, and other edge effects (e.g. invasive vegetation spread) except in some areas with high natural cover (e.g. along shorelines and valley corridors). In newer settlement and commercial areas (especially in middle and south Peel), which mostly contains younger and low diversity of trees, the urban forestry practices need to be more extensive to maintain and enhance natural cover to mitigate increased vulnerability to the already stressed urban terrestrial systems.

If regular maintenance of urban forest canopy occurs (i.e. pruning and watering so that trees have a stronger form able to withstand climate impacts), trees in the urban matrix may be less vulnerable to climate impacts, especially under dry conditions. Currently, there are numerous areas throughout Peel where existing tree canopy in the urban matrix can be expanded. Figure 35 illustrates existing urban forest canopy and possible urban forest canopy by land use for Mississauga, Brampton, Bolton and Caledon East (TRCA *et al*. 2011).

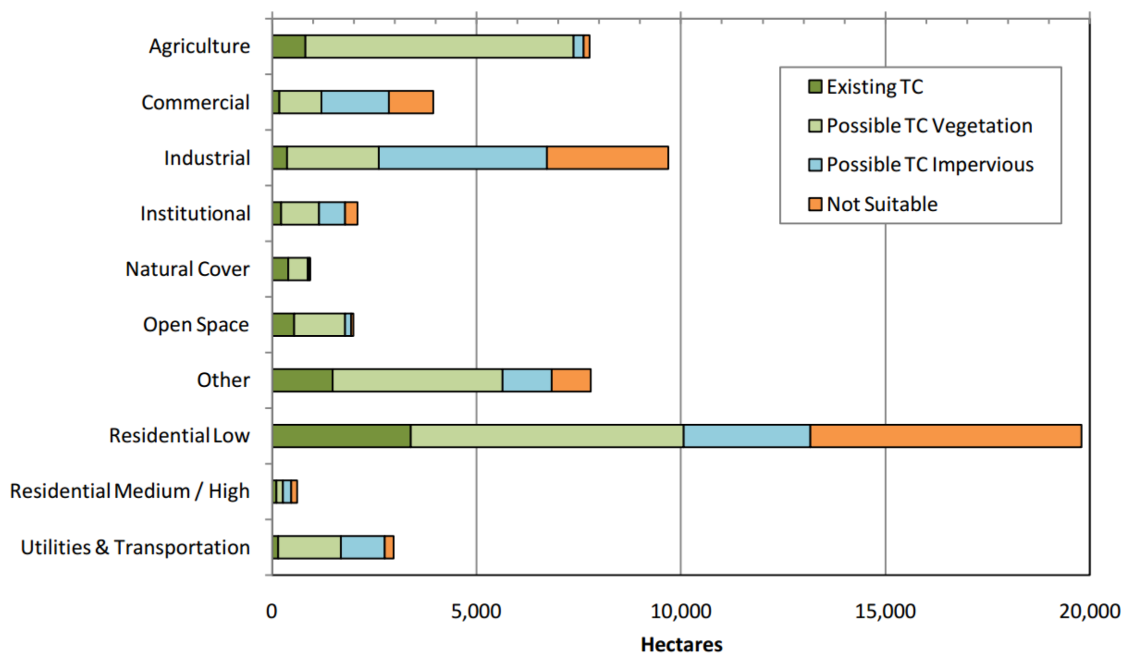


Figure 35: Existing Tree Canopy and Possible Tree Canopy for Mississauga, Brampton, Caledon East and Bolton, Summarized by Land Use

By strengthening municipal and provincial policies and practices for reducing impervious surfaces, urban forest canopy can aid in buffering the vulnerabilities stated above. As temperatures and moisture conditions change, the distribution of tree species may shift in the urban environment as well, such as some southerly tree species moving farther north, resulting in novel composition of tree species in forests. This may alter the composition of urban species diversity, which may have many intended and unintended consequences on the overall forest habitat quality.

Thermal Gradient: Exacerbation of Urban Heat Island and Implications to Climate Sensitive Terrestrial Ecosites

Increasing temperatures associated with climate change are likely to exacerbate the urban heat island effect in urban areas of Peel, and the warming of land surface temperatures (thermal gradient). Currently, land surface temperatures have been found to range upwards of 40˚C by mid-morning and 50˚C by mid-afternoon in urban areas of middle and south Peel where natural cover and urban forest canopy are insufficient (e.g. downtown Brampton, southwest of Pearson International Airport) (see Figures 28 and 29). These land surface temperatures may in fact reach even higher during hotter years, since data were collected during cooler than average years compared to Environment Canada' climate normals (Environment Canada 2015). Under a future climate, habitats (diversity and extent), and the quality of recreational services are likely to be adversely affected due increased 'edge effects' (e.g. urban heating, increased vulnerability to invasive species, increased exposure to chlorides, etc.), although areas with higher amounts of natural cover and urban forest canopy provide opportunity to regulate thermal gradients at the ground surface (e.g., Rattray Marsh and other coastal wetlands, some areas along the Main Credit River valley corridor and Lake Ontario shoreline, West Brampton between Steeles Avenue and Bovaird Drive, and the south reaches in the West Humber subwatershed).

However, increased edge effects (e.g., increased blowdown, drying) as well as pest infestations in general may be the result of higher land surface temperatures exacerbated from climate change (Richards 1993; Alvey 2006; Laćan and McBride 2008). More specifically, heat can be a key driver of insect pest outbreaks, such as on urban trees, along with a myriad of other factors like humans introducing invasive species in natural components. However, since urban warming is similar in magnitude to global warming predicted in the next 50 years, pest abundance on city trees currently may foreshadow widespread outbreaks as natural forests and components also grow warmer (Meineke *et al*. 2013). Mild winters allow insect pests that are normally killed during cold spells to overwinter, which may allow pests with a more southerly range being able to move north and have a greater likelihood of surviving (Greifenhagen and Noland 2003). Areas with lacking species diversity or that are already degraded (e.g. Rattray Marsh), have limited ability to control pest outbreaks and exposes populations to the threat of species-specific diseases or pest outbreak increasing the likelihood of mass mortality (Richards 1993; Alvey 2006; Laćan and McBride 2008). Also, concentrations of ground-level ozone are expected to increase with the onset of hotter summers, which can cause visible leaf injury, climate sensitive vegetation growth reductions and altered sensitivity to biotic and abiotic stresses (United States Department of Agriculture 2012). This in combination with drought conditions can leave terrestrial species and other plants more vulnerable to pathogenic fungi and pests such as the Asian long-horned beetle (Clean Air Partnership 2007).

The higher extent and diversity of climate sensitive native vegetation in north Peel (e.g., those in Albion Hills Conservation Area, around Centreville Creek, the West Humber, the Etobicoke Headwaters and in Cheltenham to Glen Williams) (see Figure 31) may be reduced and stressed under a future climate as a result of sensitive thresholds of these vegetation species being crossed and/or growth requirements not being met (community range). These vegetation communities become less resilient and the overall diversity may become reduced. The changes in climate may favor only a few species, resulting in simplified vegetation composition with limited diversity and complexity, which ultimately could result in constant turnovers with no specialized community establishment, thereby compromising the resiliency of the ecosystems (Vose, Peterson, and Patel-Weynand 2012; McMahon, Parker, and Miller 2010; Campbell et al. 2009). For instance, if vegetative cover is stressed enough, Caledon's badlands (despite being the result of historical grazing) may become more common as a result of moisture stress and disturbances in climate sensitive ecosites in Peel Region. This is especially true if there are additional stressors from changing land use. Nevertheless, if the terrestrial system is permitted to go through a natural or assisted succession process such that a diverse resilient native and non-aggressive future native communities are maintained and expanded, the ecosystem services are likely to be sustained (Joyce *et al*. 2014; IPCC 2012; Adams *et al*. 2009).

Middle and lower areas in Peel that are comprised of mostly low vulnerability climate sensitive native vegetation (community range) (with some exceptions, like Heart Lake C.A) will likely exhibit the same impacts as described above; but be further exacerbated by 'edge' effects associated with the urban matrix they are found in. For instance, climate sensitive native vegetation (what remains following historical development) in these areas already experience higher land surface temperatures (thermal gradient), reducing moisture and availability, and are more susceptible to the spread of invasive species due to lower diversity of species present and lack of competition in the urban environment (Cregg and Dix 2001).

Implications to Ecosystem Services in the Terrestrial System

The terrestrial system in Peel Region delivers numerous ecosystem services to the region's residents, with key ones identified as: water quality regulation, air quality regulation, regulation of the urban heat island effect, moderation of extreme wind damage and ice damage, flood attenuation, and moderation of the rate of spread in invasive species, and habitat support (refer back to Table 3 for full list of ecosystem services). The degree to which these ecosystem services are currently being delivered varies and depends on the relative condition of the terrestrial component and its location. For instance, literature suggests that air pollutants can travel 115 to 570 m from the edge of roadways before reaching ambient background concentrations (Karner *et al*. 2010), and natural components located in proximity to air pollutants may provide significant air quality regulation services for humans living nearby. Given the gradient in vulnerabilities that exist in Peel Region, implications from climate change to ecosystem services will not be spatially uniform.

Ecosystem services delivered in north Peel, where ecological function is high, are contributing significantly to the quality of life for local residents while providing benefits to downstream communities (e.g. water quality, air quality and flood regulation). It is known that numerous Peel residents in south and middle Peel travel north to visit areas of greenspace for recreation, including those living outside of Peel. In some ways, one can say that ecosystem service beneficiaries in north Peel stand to lose the most with climate change. There are highly vulnerable components of the terrestrial system present (e.g. wetlands, climate sensitive vegetation) in this area and the experience of losing something “for the first time” is generally more acute than the incremental loss of something already degraded or ‘under-performing’.

To get specific, we need to refer back to the GIS analysis; there are a lot of wetlands (swamps and some bogs) highly vulnerable to drying in northern Peel (see Figure 26); water quality regulation (filtration and cycling of nutrients) in particular would be lost/reduced in the summer if wetlands dry out (Flanagan *et al*. 2014) as these services are tied to aquatic vegetation and the microflora that are connected to them, both of which are lost when the wetland dries (Zedler and Kercher 2005). However, because some areas of northern Peel contain more significant recharge to the groundwater system, this vulnerability may be mitigated to some extent. With minimal aquatic plant uptake, it is possible that nutrient-laden runoff could become the source of more frequent and unsightly algal blooms in local streams and lakes. However, it must be considered that when a wetland becomes drier, the capacity for water storage in the soils logically increases and flood attenuation may similarly increase (Desta *et al.*, 2012; An Taisce, 2012), although some literature (Flanagan *et al*., 2014) suggests that this “extended” storage capacity is low. As it is not known if wetland soil desiccation thresholds would be crossed under the future climate scenario, current levels of flood regulation may not be affected so long as the wetlands, even dry ones, remain on the landscape. In contrast, water quality regulation, provision of habitat and passive recreational opportunities would be the most negatively implicated ecosystem services in the north with respect to wetlands and vulnerability to climate change.

Shifts in successional trajectories of sensitive vegetation communities in north Peel would lead to different community assemblages as well as different component types (i.e., conversion from treed forest to shrublands) (Morgan *et al*., 2004; Staudinger *et al*., 2012); this would likely affect the service delivery of habitat support and diversity (Natural England and RSPB 2014). The impact on the habitat diversity and/or quality will impact recreational benefits, leading to fewer opportunities for bird-watching and lower quality of nature trails. As native species shift or die-back, there would likely be a lag time for new species to establish, possibly moving up from the south. This window of change or disruption could reduce the moderation of invasive species spread and allow for the aggressive, fast growing varieties to fill the vegetation void.

In middle and south Peel, air quality regulation is already compromised where urban forest canopy is low and this may be exacerbated from increased stress and drying of tree species (e.g., from drought, insect infection) (Clean Air Partnership 2007; Meineke *et al*. 2013). However, there are numerous opportunities to improve local air quality through natural vegetation, such as the urban forest, and literature suggests that vegetation can improve air quality between 15 to 50% and these improvements can travel downwind benefiting other communities (Janhäll 2015; Baldauf *et al*. 2008; Brantley *et al*. 2014). The amount of air quality regulation being delivered by a certain natural component; however, depends on species and their physical characteristics. Low urban forest canopy may also implicate the moderation of wind and ice damage, particularly when extreme storm conditions happen. Further, the human health benefits provided by the urban forest are incredibly important, and have been shown to extend beyond improvements to local air and water quality to include greater social cohesion, improved concentration and enhanced cardiovascular function (Hotte *et al.*, 2015).

6.1.4. *Implications of other Anthropogenic Stressors*

In addition to climate change, other significant stresses on natural systems exist. This section will focus on two: (1) aggregate extraction and (2) future urban development.

Aggregate Extraction

The extraction of aggregates (e.g., gravel, sand, clay, earth, shale, and stone) in Ontario is regulated under its *Aggregate Resources Act* (1990). While aggregates are primarily used for construction and maintenance of numerous types of infrastructure, such as highways, bridges, and sewer mains, their extraction often becomes controversial as a result of the damage and impacts cased to natural systems and landscapes in local communities (Binstock and Carter-Whitney 2011). Aggregates processing typically involves the drawdown of the groundwater table to allow for extraction activities when the site is active. Following decommissioning, the groundwater table may rebound resulting in the formation of human-made inland lakes and ponds (SENES Consultants Limited 2013); however, often neglected impacts of these processes include the flattening of the water table (lowering the upslope and increasing downslope) and potential thermal warming of groundwater.

Historically, numerous aggregate extraction pits were active in Brampton as urban growth met the needs of population demand. To date, these have resulted in a number of industrial ponds. Currently, a number of active extraction sites exist in Caledon (i.e., the Caledon Pits) as aggregates are required in construction, maintenance and repair activities locally and throughout Southern Ontario.

Potential impacts from aggregate extraction can implicate the groundwater, aquatic and terrestrial systems in Peel Region. Groundwater levels may decrease locally due to required pumping for extraction activities, and as a result decrease baseflow and support to aquatic features at the surface such as headwater streams of watersheds in Peel (Sandberg and Wallace 2013). For example, baseflows in the Credit River upstream of the confluence with Caledon Creek, and upstream of the Forks of the Credit are known to be of concern as a result of the extraction activities ongoing in Caledon (Blackport Hydrogeologic, CVC, Environmental Water Resources Group, Water Systems Analysts 2001). This may implicate fish habitat as well as water quality. For the latter, aggregate extraction may eventually alter riparian vegetation through drawdown of the groundwater table in local areas and as a result reduce riparian cover and worsen turbidity and water chemistry. Similarly, wetlands are sensitive to changes in groundwater levels and specifically shifts in their hydroperiod and extraction can exacerbate these vulnerabilities that are already flagged with future climate change (Les Landes *et al*. 2014). Finally, aggregate extraction can physically impact terrestrial ecosystems by breaking up corridors, encroaching on habitats, and decreasing the amount of deeper interior habitat that has already been reduced due to urban development in Peel Region (Blackport Hydrogeologic, CVC, Environmental Water Resources Group, Water Systems Analysts 2001).

While standard regulations are in place for individual aggregate extraction licenses, there is presently no comprehensive mechanism to assess cumulative impacts of combined land use changes and impacts to regional water supply systems. Notably, select case studies have been completed to conduct cumulative impact modelling for multiple quarries in the CVC jurisdiction (in subwatersheds 16 and 18), which could be built on to develop this understanding further (Blackport Hydrogeologic, CVC, Environmental Water Resources Group, Water Systems Analysts 2001).

Future Urban Development

Future urbanization in Peel Region is expected to be a larger stress compared to climate change overall in the short term (H. Durr and P. Van Kappelan personal communications, October 16, 2014) due to the need to accommodate planned growth in population and employment allocated to the Region by the Province. Natural systems within new development areas in the Region should be protected, maintained or restored, and enhanced to be more resilient than they are currently, or else they will become more vulnerable. It is for this reason that resilience measures and climate adaptation must be identified and integrated into land use planning recommendations happening today.

For the current context, planned growth areas in the Region of Peel are illustrated in Figure 36 along with aquatic, terrestrial and wetland cover from ecological land classification (ELC) information.

As part of this assessment, future growth was considered to inform how vulnerabilities of the natural systems may change – and particularly to understand where opportunities for harmonizing land use planning and development with a more resilient natural system exist. This considers areas where new growth is approved or may be considered in the future (or ‘area of new or considered growth’) and is illustrated in Figure 37. Under a business-as-usual development future, pervious cover is expected to be reduced in Peel Region as growth is accommodated in existing built up areas and new greenfield areas. Should conventional development practices occur, it estimated that future vulnerabilities of the natural systems will increase. However, there are many opportunities for a different future: to improve the compatibility of land use planning and development with reducing vulnerabilities to climate change. Planners and policy-makers are pivotal in these discussions and work is underway in the Peel Region to plan and achieve a future condition that is resilient, including watershed planning consistent with implementing the amended provincial Growth Plan. Figure 37 illustrates all lands classified as greenfield and agricultural and rural lands in a hatched pattern, implying that there are important opportunities to improve the compatibility of land use with reducing vulnerabilities through discussions with planners and policy-makers. It should be noted that decisions at upper and lower tier municipalities in the region have not been made to urbanize these hatched areas. For example, the Town of Caledon has initiated a future visioning exercise for the “whitebelt” areas in Caledon, which is not yet complete, and any decisions to expand urban boundaries will be subject to completing future growth conformity exercises, including growth allocations for future growth forecasts in Peel, comprehensive review studies, and decisions by Regional and area municipal councils.

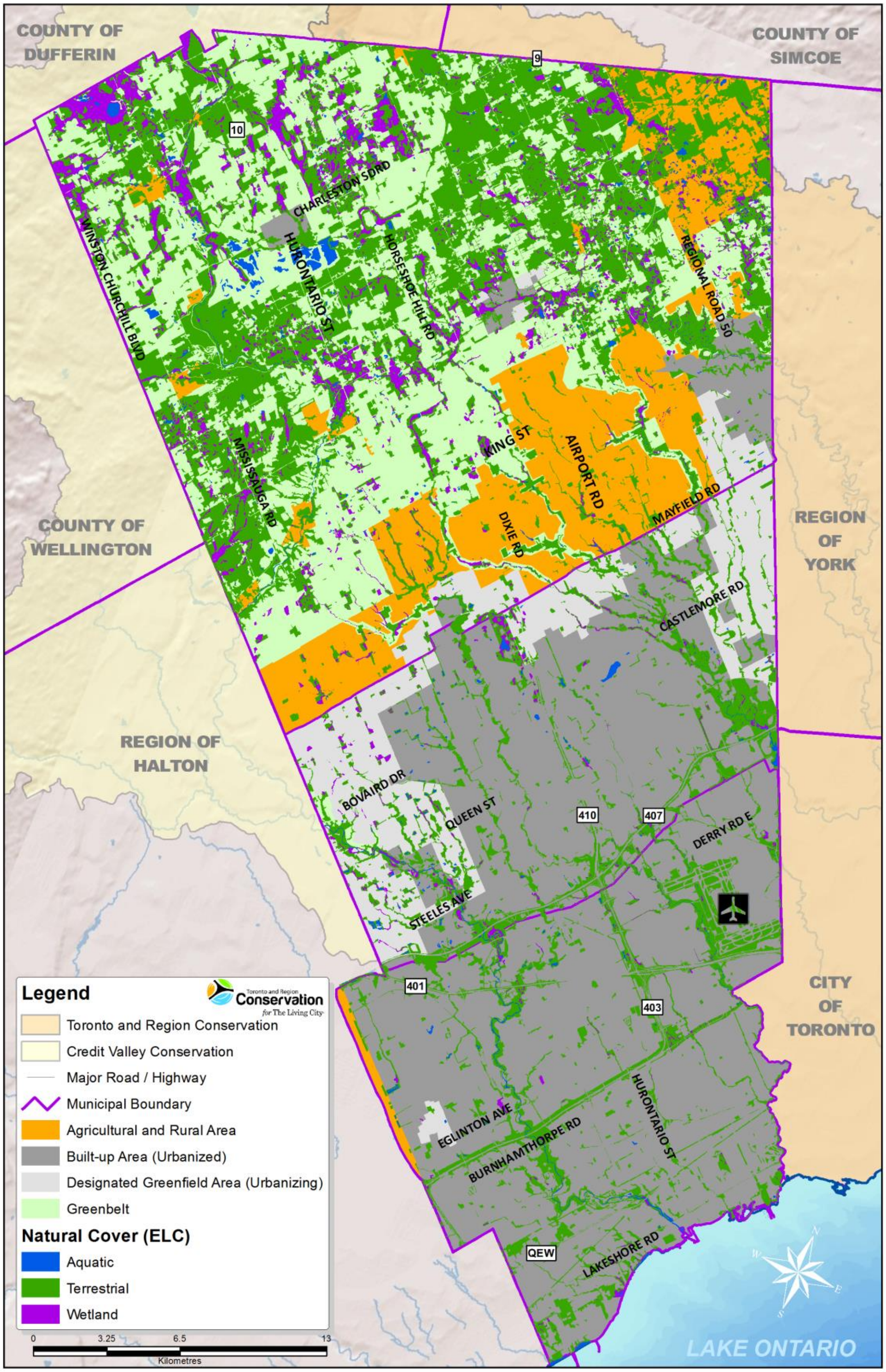


Figure 36: Planned Growth Areas in the Region of Peel, including Natural Cover (ELC) Information

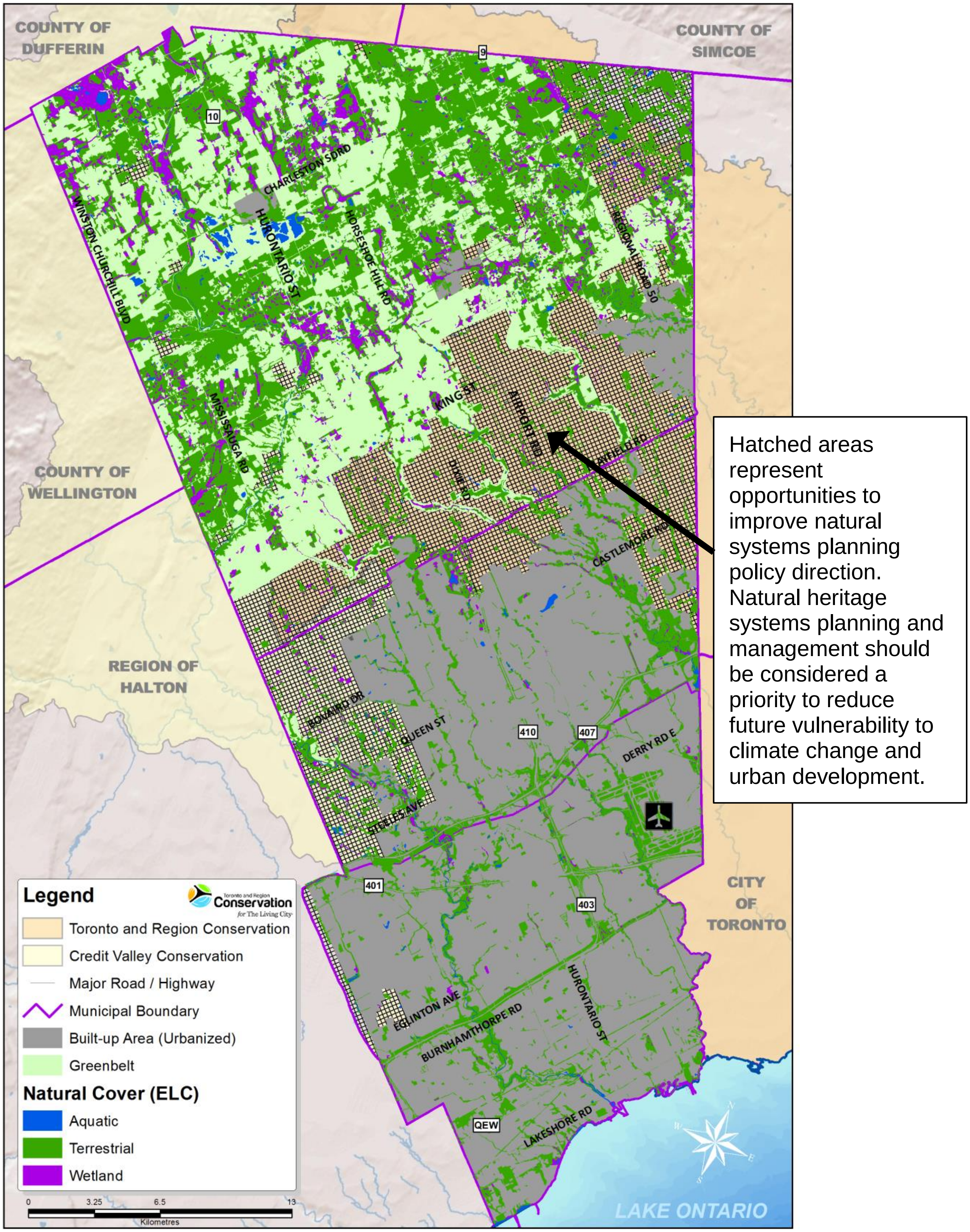


Figure 37: Areas in Peel where Current Existing and Potential Future Urbanization or Agricultural/Rural Development may be considered

Under a business-as-usual growth, the vulnerability of the natural systems in 5 of the 12 focal areas is likely to be increased due to urbanization in the near future. Table 17 summarizes all focal areas assessed and identifies the following 3 areas to be most vulnerable to future urbanization impacts: the West Humber (which is already undergoing urbanization in its southern reaches), the Etobicoke Headwaters and Fletcher's Creek. The area of Cheltenham in the Credit River watershed and Centreville Creek in the Upper Humber River are also under threat due to select growth areas. Many of these areas are located in the lower portion of Caledon or the northern portion of Brampton where growth pressures are highest.

Table 17: Focal Area Storylines in Peel Region affected by Areas of New or Considered Growth

Lower Tier Municipality	Storyline Name	Urbanization Influences under Area of new or considered growth?
Caledon	Upper Main Credit River to Cheltenham	**No*** (within Greenbelt)
Caledon	Centreville Creek in Upper Humber	**Yes** (select growth areas)
Caledon	Albion Hills Conservation Area	**No** (within Greenbelt)
Caledon	Etobicoke Headwaters	**Yes** (new urban)
Brampton	West Humber	**Yes** (currently urbanizing)
Brampton	Heart Lake	**No** (within Conservation Area)
Brampton	Spring Creek	**No** (already urban)
Brampton	Upper Mimico	**No** (already urban)
Brampton	Fletcher's Creek	**Yes** (currently urbanizing)
Mississauga	Cooksville Creek	**No** (already urban)
Mississauga	Rattray Marsh	**No** (within Conservation Area)

* Future development in areas outside the Peel Region boundaries, to the north and west, may impact groundwater and aquatic systems in and around the Upper Main Credit and Tributaries

The interaction of climate change and footprint of urban growth could result in significant reconfiguring of headwater streams (i.e. in Etobicoke Headwaters), including further loss of habitat, function and services. For instance, significant loss in flood attenuation and infiltration could occur if tableland wetlands, pervious cover, and areas with natural forests in the West Humber, Etobicoke Headwaters and Fletcher's Creek are lost or impaired due to future urbanization (assuming business-as-usual). These attenuation areas are particularly important given their relative "upstream" location in Peel Region. If current development practice is not altered from business-as-usual to an approach that prioritizes ecological function maintaining water on the landscape, and infiltration (see Figures 12A and 12B; Recharge for modeled recharge, or a proxy for infiltration, to the groundwater system in Peel) is reduced to near zero, downstream areas in Peel may become more vulnerable (see Figure 17 for existing flood vulnerable areas), especially because wetter conditions throughout the year are predicted for Peel (Auld *et al.*, 2015). It should be acknowledged that historical work by CAs has improved the knowledge and management of headwater features to better address the issues of stormwater and flooding. However, active and future planning can be improved through the implementation of existing guidance and ongoing research that protects headwater features and considers wetland water balance through the land use review process, including the evaluation, classification and management of headwater drainage features guidelines (CVC and TRCA 2014) and the wetland water balance monitoring protocol (TRCA 2016), which enhance existing stormwater management guidelines (TRCA and CVC 2012).

In addition, waters in and downstream of urban areas will be warmed even further as a result of higher air temperatures, higher volumes of warm stormwater runoff entering the aquatic system, and potential reductions in groundwater discharge due to increased urbanization and/or water taking. Figure 18 (Modeled Future Maximum Weekly Average Stream Temperatures across Peel Region; Chu, 2015) highlights projected acute thermal warming of rivers and streams throughout the region by the 2050s, and these may be worsened in areas of lower Caledon and upper Brampton. Modeled groundwater discharge conducted under a future urban growth scenario in the Humber watershed illustrated that the West Humber subwatershed may experience the greatest loss in groundwater discharge due to urbanization, which may be exacerbated by the shallow aquifer depth and short flow paths in this area (TRCA 2008d). Specifically, reduction on groundwater discharge and associated losses in stream baseflow are in the order of 1 L/s per kilometre of stream and are greatest in the West Humber (10% - 50% reduction from baseline conditions), linked to the extent of planned development in this area (TRCA 2008d). The East branch of the West Humber is the most reliant on the shallow groundwater system and may have a major baseflow reduction of 68% under future urban growth scenario compared to baseline conditions which would likely cause the streams to flow only for a few months of the year or only during storm events, thereby greatly reducing their aquatic habitat functions (TRCA 2008d).

Peel Region estimates that nearly all population growth out to 2041 (per their Growth Plan Amendment #2) is anticipated within the lower and middle areas, and, as a result, this growth will likely be satisfied by Lake Ontario surface water supply (CVC 2015c). Future, external development pressures outside of Peel, however, are predicted to further impact the groundwater and aquatic systems due to increased municipal supply water taking (CVC, 2015).

The pressures of new development and intensification also pose challenges to the urban forest canopy in two main ways: poor soil quality and restricted growing space. Urban development practices that remove or degrade soil and reduce the quantity and quality of surface and groundwater can produce unviable growing conditions for trees. Space for all forms of critical infrastructure in the urban environment is limited – particularly along city streets. So the trees that line our streets often have very little room in which to expand their roots and branches. In many cases, poor soil quality, combined with restricted space, creates an environment that is inhospitable to trees (TRCA 2015c).

Ultimately, the current vulnerability of natural systems to climate change will be exacerbated by future, business as usual development. The extent to which ecological function is impaired and ecosystem services are lost in Peel is dependent on the decisions made in future growth planning and in creating the future of Peel Region.

6.2. **Focal Area Storylines**

This section will present eleven focal area storylines throughout Caledon, Brampton and Mississauga (see Figure 11) to provide additional detail for watershed managers, conservation authority staff and ecosystem scientists to understand and better develop adaptation actions. These have been identified based on data availability and information (including GIS analysis completed for this assessment), but no implied prioritization should be made between storylines or between areas of Peel Region. In other words, if data were distributed uniformly across the entire region, these particular storylines may not have been selected. Furthermore, these storylines have been selected where sufficient data are able to identify compounding and buffering vulnerabilities at a local scale – specifically important to understand as part of implementation.

Focal area storylines are presented as groups within this report (Sections 6.2.1 to 6.2.3) to assist the reader in understanding similar ecological processes and vulnerability interactions where possible, and to ensure 'like' comparisons are being made. In other words, a storyline describing a distinct Conservation Area differs in how it is presented than a watercourse storyline in this assessment. Three groups of storylines are presented:

1. Conservation Area Storylines (e.g., Albion Hill C.A., Rattray Marsh C.A.);
2. Subwatershed Storylines (e.g., West Humber, Etobicoke Headwaters); and
3. Watercourse Storylines (e.g., Fletcher's Creek, Spring Creek).

The scope of these focal areas generally speak to either groundwater/aquatic vulnerabilities or groundwater/terrestrial vulnerabilities, however this reflected more the type of available datasets with spatial continuity; it is not intended to lessen the importance of integrating all three systems and make transparent how disruptions in one system can have consequences that transmit through space and time to affect the other two systems.

6.2.1. *Conservation Area Storylines*

Albion Hills Conservation Area

Albion Hills was established in 1954 as Ontario's first conservation area in response to a high demand for public recreation areas generated by the rapidly growing urban centres in and around the City of Toronto (TRCA 2008a). It is located in central east Caledon, in the upper reaches of the main branch of the Humber watershed at the confluence of the Centreville Creek and Main Humber River (TRCA 2013a). It is bordered by Patterson Sideroad to the North, Old Church Road to the south, and Highway 50 and Humber Station Road east and west respectively. The property is situated on approximately 495 hectares of land in the Main Humber sub-watershed. Natural features within this conservation area consist of natural forest (64% of the Conservation Area), meadow (9%), successional forest (2%), and a concentration of wetlands (4%). Albion Hills Conservation Area is largely recognized as an area of high quality natural cover, habitat and aquatic health within the Humber watershed, in part attributed to the large tracts of quality natural forest which connect to the larger greenspace system throughout the Humber watershed (TRCA 2013a).

This high quality characterization described in existing reporting identified this storyline area as valuable for describing what a resilient and healthy ecosystem looks like, and to describe the factors in the natural systems which will interact with climate drivers (see Table 18). 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 Peel Region is more complex. That being said, certain trends can be elucidated with higher confidence such as warmer temperatures. On average, the summer is likely to be drier, but potentially punctuated by heavy rainfall events. A climate scenario of a ‘warmer drier summer’ was considered most relevant for this municipal focus area.

Table 18: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Albion Hills Conservation Area

Components	Vulnerability Factors	Vulnerability Indicators
• Natural Forest • Wetland • Meadow • Rivers & Streams	• Aquifer Maintenance • Hydrologic Connectivity • Community Range • Soil Quality • Habitat Connectivity • Urban forest canopy • Thermal Gradient	• Recharge • Wetland Type • Climate Sensitive Native Vegetation • Soil Organic Carbon in A-Horizon Layer • Patch Quality • Forest Cover • Water Temperature

Current Conditions in Albion Hills Conservation Area

Located entirely within the ORM, Albion Hills Conservation Area has been identified as a significant contributor to groundwater recharge which is vital to maintaining a functioning and healthy watershed (TRCA 2013a). This recharge contributes to aquifer maintenance in the groundwater system. Recharge modeling conducted in this area using the York Tier 3 model indicates that not only Albion Hills Conservation Area but much of the surrounding lands to the east and southwest are significant recharge zones, associated with the ORM topography and soils in this region. Specifically, modeled recharge in this area ranges from 270 to 360 mm/year, which is in contrast to much of central and southern Peel where recharge is much lower. Notably, many other areas in northern Peel (Caledon) are also significant recharge zones as well.

Given the high recharge rates found in Albion Hills, it is likely that hydrologic connectivity is not currently disrupted, although this was not explicitly discussed in any existing condition reporting. It appears that hydrologic disruption is not likely in this area given high quality cover, high recharge and its location in a higher area of precipitation in Peel Region (Environment Canada 2015; Auld *et al*. 2015). Analyses conducted in the region identify that Albion Hills Conservation

Area contains both swamps and marshes and vegetation present on the surface in Albion Hills is characterized as diverse and of high quality (community range). There are 119 vegetation communities found in Albion Hills Conservation Area, 39 of which are typically found in wetland and aquatic communities and are considered of regional concern (TRCA 2013e). In fact, 4 plant species which are of concern regionally have no record elsewhere in the Toronto Region jurisdiction, and 3 of which are entirely unique to the ORM Area.

Soil quality underlying vegetation in Albion Hills largely contains organic carbon content between 1 and 2% in the A-horizon soil layer. In addition some patches of soil, likely associated with marshes and swamps, contain higher amounts of organics between 5 and 15%. This is consistent with numerous other soils found throughout Peel Region and is associated with relatively good to high quality soil. Notably, this information has likely changed since the initial soil survey was released in 1953 (Hoffman and Richards 1953) and since updates were completed in the 1970s through the Canadian Soil Information Service (CanSIS)[9]. Thus, results based on these data should be interpreted cautiously. However, it assumed that good quality soils in Albion Hills Conservation Area can retain nutrients and moisture well particularly in the summer season.

Albion Hills Conservation Area has also been identified as providing high quality habitat connectivity in the upper Humber. It is described as a 'vital link' connecting available green space with large potential for further improvements of other conservation areas and larger patches within the upper Humber and the larger Humber watershed greenspace system connecting the ORM to Lake Ontario (TRCA 2013a). The area is primarily forested with good sized, well-connected patches of natural forest, interspersed with meadow, successional and wetland areas (TRCA 2013e). Natural forest coverage in Albion Hills was examined and it was found that the majority of the area contains greater than 40% cover. This is in contrast with numerous areas to the south in Peel Region where natural forest cover is either between 30-40% or well below 30% cover. Habitat patch analyses indicate that Albion Hills contains 'high quality' patches, which reflects that it facilitates healthy habitat for terrestrial biota, and is in line with descriptions from existing reports. This demonstrates that connectivity within and surrounding Albion Hills should be maintained.

Albion Hills currently contains a high level of natural forest, which provides important shading and refuge for residents from the heat. While urban forest canopy has not been characterized in and around Albion Hills Conservation Area, it is assumed that with low areas of urban land cover and high amounts of natural forest cover (through ortho-photo interpretation), heat stress and drying are not a significant concern in this area. Further, the fact that Peel residents come to Albion Hills Conservation Area for trail use and enjoyment of the forested areas implies a higher quality of shading and refuge from the urban areas elsewhere.

[9] http://sis.agr.gc.ca/cansis/

Briefly considering aquatic conditions in Albion Hills Conservation Area, thermal gradient has been flagged as a known concern through observed water temperatures. Two thermal monitoring stations exist in and around Albion Hills, one located upstream of Albion Pond and at Patterson Sideroad and Humber Station Road and the other located in Albion Pond at the outlet. The station upstream exhibits a coldwater thermal regime whereas the station downstream exhibits a warmwater regime (TRCA 2011c). Both stations are considered to have moderate thermal stability (see Appendix G). Modeled maximum weekly streamwater temperature in these tributaries (Chu, 2015) reflects these upstream-downstream differences as well. According to the Centreville subwatershed characterization (TRCA 2008a), many reaches of Centreville Creek likely support cold water aquatic habitat conditions year round; however, in-stream water temperature monitoring suggests that some reaches are likely being impacted by sun exposure and the presence of natural or man-made ponds upstream. In 2002 and 2003 an inventory identified 17 ponds created by on-line hydraulic structures (i.e., dams) throughout the Centreville Creek subwatershed as a whole, one of which is in Albion Hills Conservation Area Opportunities exist to convert ponds created by on-line hydraulic structures (i.e., dams) to off-line ponds, which would contribute to reducing downstream thermal impacts and improve the health of fish communities by providing a greater range of accessible habitat (TRCA 2008a).

Future Vulnerability in Albion Hills Conservation Area

In terms of aquifer maintenance, it is anticipated that Albion Hills will remain fairly resilient under a changing climate. The presence of significant recharge and high quality natural cover (especially treed vegetation) will buffer much of the additional heat stress introduced by warmer temperatures. However, given the presence of climate sensitive vegetation (especially sensitive to hydrology) if there is prolonged dry periods there may be some risk to these vegetation from the drying effect thereby affecting their moderating function on recharge. It appears that significant hydrologic disruption is not likely in this area (hydrologic connectivity) given the high amounts of recharge and its location in a higher area of precipitation in Peel Region (Environment Canada 2015; Auld *et al*. 2015). GIS analyses conducted in the region identify that Albion Hills Conservation Area contains both swamps and marshes (see Figure 26), which are considered moderate and low vulnerability, respectively based on their wetland type. It should be noted that if hydrologic disruption were to occur to particularly vulnerable wetlands in this area (i.e. swamps or marshes further than 30m from a watercourse), consequences could be significant. For instance, the hydrologic connectivity in this area may become stressed under extreme drought conditions, and this may pose significant problems to the vegetation. The location of Albion Hills within the protected greenbelt secures it from further urbanization. This indicates that there is only a low threat from further land use change on hydrology, which would otherwise have exacerbated future climate change impacts.

Similarly, the soil quality in Albion Hills is likely to be maintained into the future given that soils are of relatively high quality compared to the rest of the region. The presence of good amount of natural cover will facilitate the maintenance of the soil quality as they buffer from heat and drying stress induced by warmer drier summer conditions (Amacher *et al*. 2007). In addition, given that it is a good recharge area, it will likely provide consistent soil moisture even when the climate may shift to warmer drier conditions (Girvetz *et al*. 2009).

The high diversity of vegetation communities present in Albion Hills Conservation Area is associated with numerous species that are also considered sensitive (community range) to hydrology, fertility and/or dynamics (climate-driven criteria). Approximately a quarter of all species are considered sensitive to climate-driven factors including hydrology, such as Alder Mineral Thicket Swamp, Fresh-Moist White Cedar Hardwood Mixed Forest, White Pine Cultural Woodland, and Reed Canary Grass Organic Meadow Marsh. The majority of climate sensitive vegetation species in this area are rated as at least moderately vulnerable, if not highly vulnerable. In other words, numerous vegetation species are sensitive to shifts in more than one climate-driven criterion, such as shifts in the hydrology and changes in dynamics (e.g., a Winterberry Organic Thicket Swamp is sensitive to both hydrology and fertility). This implies that while a high diversity exists in Albion Hills Conservation Area, climate change may cause some dieback or stress to those considered climate sensitive. If there are prolonged dry periods some of these vegetation may not be able to survive over longer time periods (Rustad *et al*. 2001), thereby contracting their range. In such cases it is likely that the vegetation composition may change to more tolerant shrubby communities (Staudinger *et al*., 2012).

It is also expected that habitat connectivity in Albion Hills will be relatively maintained under future climate change scenario, assuming no anthropogenic impacts. The high percent of natural forest and wetland cover in the conservation area along with the relatively undisturbed surrounding land use will ensure that structurally the habitat are well connected within and beyond the Conservation Area boundary.

Given that the Albion Hills Conservation Area is located in greenbelt and is protected from further land use change, it is likely that the trees will remain relatively stable and not become significantly more vulnerable. However, if climate sensitive vegetation in the area shifts to more tolerant shrubby vegetation may replace some of the treed species (Staudinger *et al*., 2012), in which case the tree canopy may decrease with climate change (Allen *et al.*, 2010). This may be buffered to some extent by the fact that the area has significant recharge and the drying effect of climate change may be somewhat moderated compared to other areas in Peel Region.

Considering future vulnerability of aquatic conditions in Albion Hills Conservation (thermal gradient), climate change is likely to warm existing water temperatures even further (C Chu 2015). Future modeling of maximum weekly streamwater temperature (see Figure 18) indicate that by the 2050s, temperatures near the upstream monitoring station could be spiking to 26˚C and at the downstream monitoring station could be spiking to 29˚C. This implies that water temperatures may exceed thermal regime thresholds, which are 26˚C for coldwater and 30˚ for warmwater regimes. This ultimately means that fish requiring coldwater will suffer from a reduction in habitat (Poff *et al*. 2002; Browne and Hunt 2007). Oxygen concentrations may also decline in these warmed waters, further degrading deep-water habitat during the stressful summer months (Poff *et al*. 2002). Warmer waters could also cause an influx of coolwater fish species and the possibility of exotic species expanding their ranges northward and altering angling opportunities. While new fish species may become available, the expansion of warm water and exotic species may negatively affect native fish populations (Dove and Lewis, n.d.). Should thermal impacts be mitigated through existing opportunities of the removal or upgrading of on-line ponds upstream, there is potential for retaining more coolwater habitat in the near future, though climate change independently may cause warming of waters by the 2050s in Albion Hills Conservation Area

Implications of Future Urban Growth in Albion Hills Conservation Area

It is not anticipated that Albion Hills Conservation Area will be impacted by urban land use under the future urban growth scenario in the future. This does not mean land use will not be shifting surrounding the Conservation Area; however, large increases in ‘edge effects’ as a result of urbanization are not anticipated. Additionally, under the Oak Ridges Moraine Conservation Plan (ORMCP), Albion Hills Conservation Area falls under the natural core area designation which aims to protect the greatest concentrations of key natural heritage features by restricting any new intensive development across the moraine (TRCA 2013a). In other words, there is some aspect of protection already in place for this area thus potentially decreasing its vulnerability, although these protections are not permanent.

Implications to Ecosystem Services

Ecosystem services provided by Albion Hills Conservation Area, such as supporting habitat diversity, recreational and aesthetic services for Peel residents are currently considered to be of high quality. The conservation area, on average, hosts 120,000 people throughout the year (TRCA 2013a), and the number of visitors will likely increase as a result of population growth and residents seeking refuge from a warmer climate. Users are offered a unique experience given the wide range of recreational opportunities provided, such as swimming, picnicking, fishing, canoeing, camping, educational programs, hiking, and bird watching. Climate change is expected to pose stress on the natural systems, but does not threaten a full scale loss of vegetation species. There is the potential for degradation in the ecosystem depending on how climate change manifests. For example, increased drying or competition from invasive species may cause vegetation dieback and reduce the quality of aesthetics and enjoyment for residents accessing this conservation area and greenspace. Along with climate impacts, there may be additional stresses as a result of human activity increasing in the CA (e.g., trampling, invasive species introductions, recreational infrastructure wear). Ultimately, natural areas such as Albion Hills must be protected and conserved in order for it to be a valuable refuge for Peel residents, and continue to deliver high ecosystem services (which may become even more valuable if areas further to the east and southeast of the conservation area urbanize).

Box 3: Nature Makes You Healthy!

We use the old adage, “A change will do you good”, almost as a prescription for health. Sometimes it is a “change of scenery” that we need, and for some that could mean a walk in nature, a canoe trip, or a view of a garden through a window. What if in Peel the scenery we resort to is affected by the next 35 years of climate change? Will that change “do us good”? Whether or not we admit it, human beings are tied to nature, in how we relate to it, how we use it, and how we escape to it.

Escape from Urban Heat Island

Where vegetation and its cooling effect are lacking in urban areas, heat is reflected by built surfaces (e.g., asphalt) and is released from buildings unmitigated. As a result, built form in the city is on average 10 degrees hotter than those outside of it (Auld *et al.*, 2015). It’s very likely that Peel Region will experience hotter temperatures by the 2050s, including extreme heat waves. Access to shade is, and will become even more, crucial to find refuge from the heat. The urban forest (natural areas, parks, backyard trees, street trees) especially plays a large role in providing this valuable shade. It’s a spiraling effect: hotter temperatures that stress humans can stress nature as well, and a reduction in vegetation then limits the urban cooling effect. Conversely, adding and actively managing the urban forest and natural systems can help to reduce these heat stresses.

Comfort and Enjoyment in the Outdoors

Some of our fondest memories are made in nature, such as camping, hiking, and swimming outdoors in a lake. Granted, beauty is in the eye of the beholder and, with respect to mental health benefits, in the mind of the beholder. But by 2050 the landscape condition and aesthetic value we find may cause concern rather than comfort. Heavier rainfall events could increase the cloudiness of our water and decrease its beauty and quality. Swimmers may be hesitant to jump in to waters with more silt and sediment washed in them from a heavy rainfall a few days earlier. Warmer temperatures may stress vegetation and ecosystem function. Campers might find themselves swimming in the same lakes we do now but unable to hear birds calling out to one another or hear frogs croaking somewhere deep in the forest. Birdwatchers may have to travel further to seek out their favourite birds, which have moved further north. Even more concerning, heatwaves or extreme events might keep people indoors, hesitant to face the extreme elements and miss out on their jaunts outdoors to clear their head or exercise. Mentally, people may become more worried over their safety and find less peace of mind with a less aesthetically pleasing or degraded natural environment.

Winter enthusiasts will also likely be affected, with less snow being accumulated for activities such as tobogganing, skiing and other winter recreation. In addition, shorter winter seasons may reduce the period of ice cover on outdoor lakes and ponds which could limit skating and ice fishing. Warmer temperatures on average may increase the length of the growing season, or days with temperatures above freezing. In this case, some opportunity exists for people to get outside more often in warmer weather, assuming extreme events do not prevent them from doing so. It will ultimately depend on how climate change is manifested in Peel Region, but increasingly frequent and intense summer rains may disrupt outdoor routines of residents, such as regular exercise, and experiences such as picnicking hiking and camping. What is certain is that we will benefit from being stewards of our environment, protect it, and prepare for changes in climate so that current and future residents of Peel can enjoy nature the way we do now.

Heart Lake Conservation Area

Heart Lake Conservation area is located south of Mayfield Road in the Etobicoke Watershed, and is surrounded by predominantly urban land use, although supports high quality forests and wetland vegetation communities (see Figure 38) (TRCA, 2006). There are a few inland lakes and ponds within this conservation area. The largest is Heart Lake, which is 17.5 hectares in size and has an average depth between five and six metres, but a maximum depth of approximately ten metres (TRCA, 2006). The lake receives water from both groundwater and surface flows; the direct inputs of groundwater through finer grained/organic deposits that form the lake bottom (TRCA 2010a). The Heart Lake wetland complex has been described as provincially significant wetlands (PSW) by the Ministry of Natural Resources and Forestry (MNRF). The majority of wetlands types within the complex are thicket swamps, cattail, graminoid and herbaceous marshes that overlay thick organic soils (or muck) (TRCA 2006b).

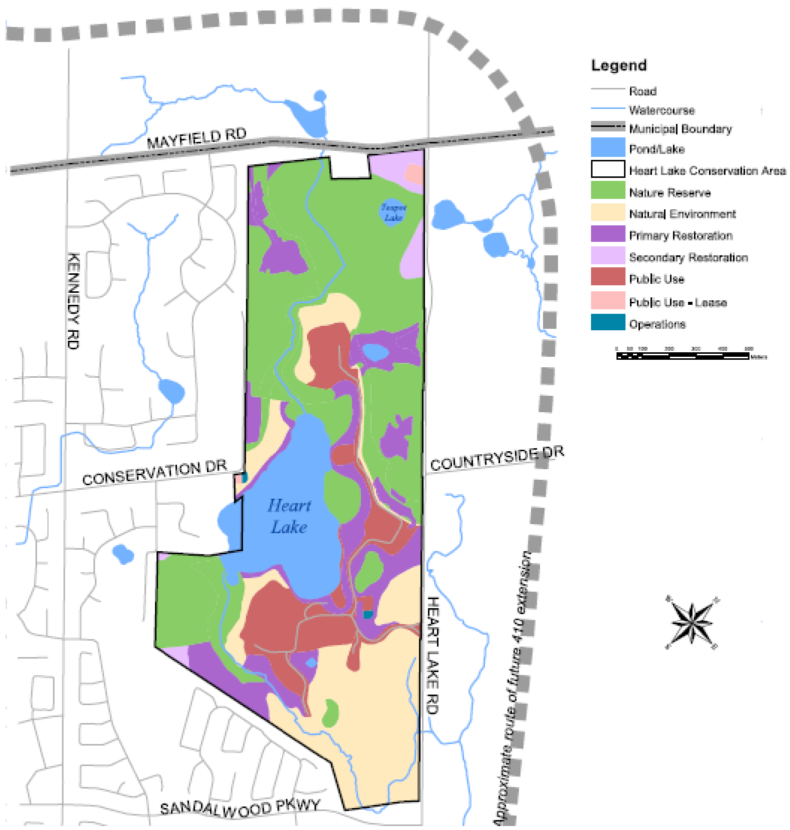


Figure 38: Heart Lake Conservation Area (from TRCA, 2006b)

This storyline was selected to characterize in further detail how climate change may manifest in inland lakes and ponds. In addition, some known issues exist in Heart Lake particularly with nutrient and phosphorous loadings, which are described in more detail below. While this storyline will focus on Heart Lake, a number of important inland lakes and ponds exist in the Conservation Area, such as Teapot Lake, which is sustained predominantly by groundwater originating from a deep aquifer system and has no surface water inflows or outflows (TRCA 2006b). It is termed 'meromictic' since it lacks any vertical turnover in water stratification on a seasonal basis. Teapot Lake has been described as "extremely rare" with a vegetation community requiring exact geophysical conditions; its bottom sediments are never mixed and contain a complete sediment record of the region over the last 12,000 years (TRCA, 2006). In terms of Heart Lake and the focus of this storyline; however, the following vulnerability factors and indicators are described (see Table 19).

Table 19: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Heart Lake Conservation Area

Components	Vulnerability Factors	Vulnerability Indicators
• Inland Lakes & Ponds	• Area-to-Depth Ratio • Topography & Grade • Thermal Gradient • Water Chemistry • Community Range	• Water Levels • Soil Drainage • Water Temperature • Total Phosphorus

Current Conditions in Heart Lake Conservation Area

As kettle lakes are relatively closed systems, due to the fact they receive little if any water via surface run-off, their hydrology is relatively simple. These ecosystems are also sensitive to environmental changes, as they tend to only receive water via the groundwater system (sometimes only seasonally), and from rain and snow falling directly on their catchment area (Warner 2015). Heart Lake is a relatively small lake by area (area-to-depth-ratio), as it is only 17.5 hectares in size, but it is the largest Lake found in Conservation Area. Its overall depth is between five and six metres, but it reaches a maximum depth of approximately ten metres, which is deep enough to sustain a coldwater condition at its bottom through the summer months. The Heart Lake ecosystem is largely supplied by the groundwater system, as there is currently no true inlet or outlet watercourse, as is the case in some other kettle lake ecosystems and by precipitation from rain water and snow melt. A small earthen dam was constructed in 1959 at the original outlet on the south end of the lake to raise the water level (Gartner Lee Ltd, 2006). The Lake may only be connected to the surface water system of the Etobicoke Creek in very high water level events, when the lake level rises above the berm and water spills over top, a condition that has not apparently changed since 1957 (Johnson, 1957). Baseflow sampling in the headwaters tributaries of Spring Creek has shown that Heart Lake itself was not contributing to surface water flows to this system (TRCA, 2010a).

Under the Provincial Groundwater Monitoring Network (PGMN) program, TRCA operates two groundwater monitoring wells within Heart Lake C.A., one of these is on the shore of Heart Lake, and is called Well W-366. The other is located SW of Heart Lake Road at Countryside Drive and referred to as Well W-021. Examples of groundwater levels are illustrated for these wells below (Figure 39).

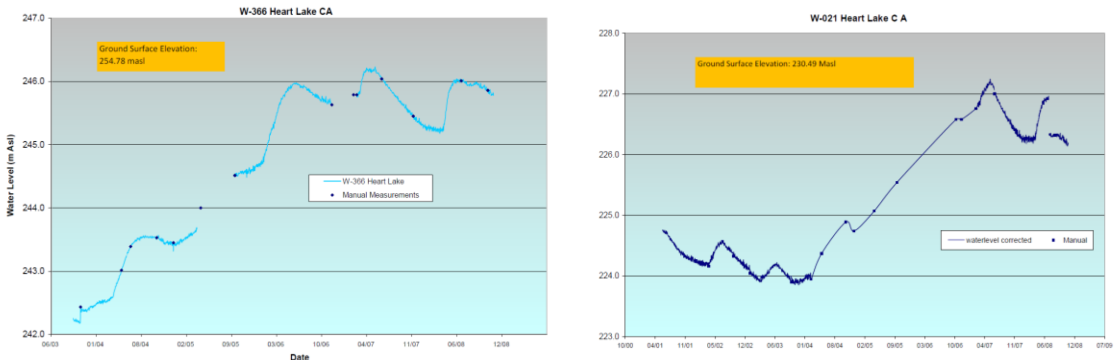


Figure 39: Groundwater Levels at Well W-366 and Well W-021 in Heart Lake Conservation Area

Current groundwater hydrograph results for Well W-366 indicate rising groundwater levels of about 4.0 meters between 2003 and 2009. The original water table in this area was between 5 and 15 m below grade (TRCA, 2010a). This increasing trend if it continues, it would likely lead to an increase in the amount of baseflow discharge to the West Branch of the Main Etobicoke Creek (TRCA, 2010a) and potentially more discharge to Heart Lake.

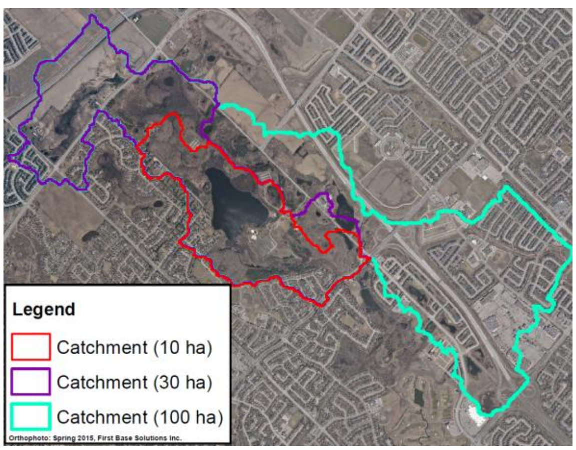


Figure 40: Heart Lake Conservation Area Catchments (10, 30 and 100 ha)

According to GIS analyses conducted as part of this assessment (see Figure 23 for Soil Drainage mapping) Brampton is predominantly covered by imperfectly drained soils in the South Slope and Peel Plain (indicating moderate vulnerability). These soils are characterized as such based on soil type, topography and grade. Heart Lake and its surrounding C.A.; however, contains well drained soils (indicating low vulnerability). This implies that not only is the area important for habitat, refuge, etc. but that it also is providing substantial infiltration for water, potentially avoiding flooding further downstream in the Etobicoke watershed. Further evidence to this effect is that recharge is documented as the highest in the Etobicoke watershed at roughly 380mm/year in the wetland complexes surrounding the lake. However the Heart Lake catchment has also been urbanized over time, and resulted in more rainwater being diverted away from the historic catchment area through the surrounding sewershed. There is likely to be a limited amount of additional impervious cover added to the catchment area, along with related stormwater sewer infrastructure, further altering the areas overall hydrology. The total annual recharge to the watershed has been reduced by approximately 14% as a result of urbanization near or around Heart Lake (Gartner Lee Limited, 2006).

There is not an extensive data set available regarding the thermal gradient of Heart Lake; however the Interim Report for Citywide Lake Management and Monitoring did provide data from the surface waters to the deepest portion of the Lake from August 2004 to July 2005. Based on existing data, the lake can begin the stratification process in early May. A thermocline in the Lake develops at depths between ~ 3 to 7 m, which continues through the summer into early fall (September) when the lake then experiences turnover in November. The maximum surface temperature of the Lake in this 2005 examination was 26.5°C, when it peaked in June. The hypolimnetic temperatures ranged between 7 to 10°C over the summer period, providing opportunities for coldwater habitat. Cooler temperatures in October cause the loss of lake stratification, resulting in a uniform lake temperature from water surface to the lake bottom. In the winter, the Lake bottom becomes the warmest habitat at approximately 3.5°C. More recent water temperature data taken from the Solar Bee at Heart Lake in 2008 illustrates that surface water temperatures in June were 21°C and were 9°C by November, so there is a range of seasonal variation in the Lake’s thermal conditions defined by the climate year.

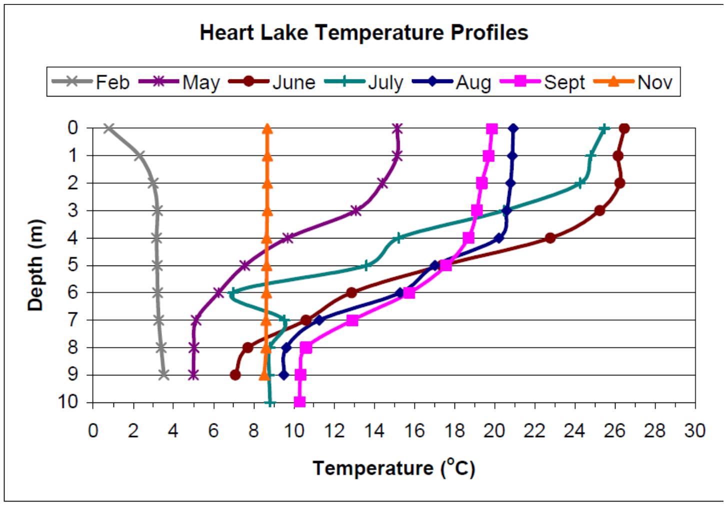


Figure 41: Heart Lake Temperature Profiles

It was reported that Heart Lake was a good largemouth bass fishery in the 1920's (Stocek, 1964). Recognizing the successful fishery in the past and the angling potential of the lake, TRCA undertook a program of coarse fish removal in 1957. Seven species were removed: Creek Chub, Pumpkinseed, Brown Bullhead, Golden Shiner, White Sucker, Central Mudminnow, and Brook Stickleback. No bass were found. Since being chemically reclaimed in 1957, Heart Lake has been stocked with fish. The initial stocking consisted of largemouth bass (a warmwater species) and rainbow trout (a coldwater species). Since that time, annual stocking of rainbow trout have been made. At present, the lake has a cold water put-and-take fishery with between 4500 to 6000 rainbow trout stocked each year, which began in 1960; however none survive to reproduce the following year. This despite the fact there is suitable thermal habitat. In May 1958, 424 largemouth bass and 5 smallmouth bass were stocked as brood stock. According to the 1960 Progress Report, subsequent stocking was deemed unnecessary as the bass had apparently established quite well, with adequate numbers in each age class representing a relatively stable population.

After the 1957 reclamation, it was found that Brown Bullheads had survived, and other species have since been re-established. In 2014 and 2015 the community composition here remains largely the same, the community consists of six species but has a slightly different assemblage than in the past. The current species assemblage includes Brown Bullhead, Largemouth Bass, Pumpkinseed, Rock Bass, Central Mudminnow and Common Carp. Dillon Consulting (1991) reported that the trophic structure of the aquatic community was skewed in favour of top carnivores (piscivores) and lacked forage species: herbivores, and omnivores. The current system is one that favours a warm water and wetland dominated community that is generally tolerant of lower oxygen levels.

Heart Lake is currently being aerated with a “Lake Lung” to influence lake water chemistry and to reduce internal phosphorus loading. Water quality of Heart Lake is currently considered to be good, with consistent minor exceedances of the PWQO for Phosphorus in the surface waters. Deeper water in the Lake likely still experiences higher levels of phosphorus. In 2004 before the installation of the new Solar Bee system, the lake illustrated that its surface waters were generally in the eutrophic zone with readings of 0.035- 0.1 mg/L of phosphorus with deeper water reflecting hyper-eutrophic conditions at 0.1 mg/L (Gartner Lee Ltd, 2006).

The oxygen levels in the lake in the past have also been noted as a concern, as they can be low. This has been the case despite the fact the Heart Lake had an operational lake lung (now a solar bee aerator) installed to improve the lake environment. The Lake is still considered to have generally poor water quality for lake swimming due to nutrient loading, and from waterfowl, as well as its characteristics as a kettle lake (Heart Lake Conservation Area Master Plan (2006). Teapot and Heart Lakes are the only two lakes that receive phosphorus from agricultural fields in Brampton, which is appears to be a significant source of loading, estimated to be about 9.6 kg/yr (24%). The entire lake has been predicted to receive roughly 40.6 kg/yr of phosphorus a year, of which 20% is predicted to come from atmospheric deposition. (Gartner Lee Ltd, 2006). The atmospheric loading level appears to be very similar to those levels predicted for Lake Simcoe, which could be as much as 27% of the total load (Ontario Ministry of the Environment 2010). However, there appears to be limited data on phosphorus levels in the Lake as it stands today, as it is not regularly monitored for this parameter. The Lake has a very high potential for primary productivity and is reliant on an artificial control system to manage it.

Future Vulnerability in Heart Lake Conservation Area

If precipitation increases throughout the year overall but remains consistent to historical conditions throughout the summer season, the precipitation-to-evaporation ratio will likely reduce and change the water budget and hydraulic residence times of inland lakes and ponds in Peel region. This could lead to a shift in area to depth ratios (Vincent, 2009). Heart Lake could be particularly sensitive to climate extremes and affected by very dry winters, and by hot summers punctuated by periods of extended draught. Less precipitation or a change in how it falls, or changes in evaporation rates related to less ice cover could affect local recharge functions affecting the overall volume and water levels of the lake. Increases in temperature in the Region of Peel under a shifting climate is likely to increase the rate of evaporation of water from surface features (Kinkead 2008; Vincent 2009; Chu 2011), which could reduce water levels in inland lakes and ponds depending on their sources of water and relative contribution (e.g., groundwater, surface water) (Browne & Hunt 2007, University of Technology Hamburg, 2006). Depending on the severity of draught and ambient air temperature, the ground water system might be reduced or eliminated altogether for certain portions of the year. These changes may result in reduced/lowered lake levels. However the strength of response is very difficult to gauge, as there is a gap in the described understanding of this lake’s groundwater system or overland flow drainage system.

The existing analysis of Heart Lakes' landscape conditions illustrates its importance to the Watershed and downstream aquatic ecosystem from a topography and grade perspective. The implications of future forecasted extreme precipitations events, and longer durations of no precipitation between events, makes the value of this resource even more important; acting both as a sink and a source of water depending on the climate extremes experienced. While there is likely still some limited development that will occur within the periphery of the drainage area of the lake that may affect its ability to store and release water, its functions are very likely to remain intact for the future.

Increased air temperatures affecting the thermal gradient may also impact inland lakes and ponds through direct radiant heating (Browne & Hunt 2007), which may pose a threat to species and habitat conditions. There is an increased vulnerability to the potential for new invasive species introduced to the lake to become established as a result of the ecosystem changes. Warming waters may lead to higher rates of primary production and decomposition (Friberg *et al.* 2009*)* as noted below, increasing detritus accumulation in the Lake bottom, which in turn could lead to, or increase the risk of, hypolimnetic anoxia (Dove-Thompson *et al.,* 2011). A longer summer season could enhance eutrophication of waters, and lead to oxygen depletion in deep zones thereby eliminating refugia for coldwater or cool water fish species during the summer months, and potentially many species during the winter months. However, depending on how climate change manifests itself there is a potential for the vulnerability to anoxic over winter conditions in the Lake to become lessened over time. As winter warming occurs we may observe a lessening in the period of ice cover reducing the lakes vulnerability to over winter anoxic events (Vincent. 2009; Lemieux *et al.,* 2007). However the opposite may also true, as small enriched lakes in southern Canada, can have prolonged winter stratification which leads to oxygen depletion of the hypolimnion, resulting in the winter kill of fish stocks.

Inland lakes and ponds such as Heart Lake and the related aquatic ecosystems that are not connected to another watercourse at the surface are more vulnerable to stochastic events. For example, predicted increases in air temperatures in addition to prolonged summer draughts may impact the volume of the groundwater available to recharge the lake which help to keep it cool. Fish and aquatic ecosystems that become stressed or die under warming water conditions have little to no ability to recruit new individuals, and sustain their populations. This is particularly true for fish and aquatic ecosystems that are cold or cool water dependent (e.g. Central Mudminnow) (Dove *et al.,* 2009).

Increasing precipitation, particularly short duration extreme rainfall events throughout the year may affect lake water chemistry, increasing loadings from surface waters to the lake or ponds which could reduce water quality or lead to eutrophication of waters (Browne & Hunt 2007, Poff *et al.* 2002). Under past conditions (2005) Heart Lake has illustrated that it has total phosphorus levels that are of some concern as they can be elevated above the PWQO guidelines, and oxygen levels can also be low. This has been the case despite the fact the Heart Lake had an operational lake lung (now a solar bee aerator) installed to improve the lake environment. The Lake is still considered to have generally poor water quality for lake swimming as mentioned above (TRCA, 2006). There is also an increasing vulnerability that aesthetic qualities for the lake will be further reduced in the future.

Changes in water chemistry can also affect ecosystem structure and function of the lakes and ponds found within the CA. This is particularly true where there is a system shift, for example, if Teapot Lake which has not historically received surface water inputs suddenly begins to receive surface water supply as a result of larger and more intense rainfall events. This heavy or new input of water and nutrients into the inland lake may entirely change the nutrient concentrations in the water and could lead to eutrophication, shift the chemical concentration and alter the water budget (S. Sharma personal communication, November 3, 2014). Also seasonal variation in water volume strongly influences what kinds of species can flourish in an aquatic system (Poff *et al.,* 2002). Therefore, a change in regional climate that alters the existing hydrologic regime has the potential to greatly modify habitat suitability for many species and cause significant ecological change (even if the thermal regimes remain unchanged) (Poff *et al.,* 2002).

Periodic reductions in total lake volume, elevated temperatures and potentially elevated levels of total phosphorus load from more intense rainfalls, as well as atmospheric deposition, illustrates that the issue of phosphorus in the lake is likely to become more apparent in future. One specific change will very likely be the increased growth of algae in the lake. The lake will become more vulnerable to increased primary productivity (e.g. algal blooms) and a reduced water quality and clarity level. Higher productivity in inland lakes and ponds could increase the number and growth of undesirable species (e.g. invasive species) as many are better suited to the potentially new ecological condition (Dove and Lewis, n.d.). The compounded effects of the changing climate on the Heart Lake ecosystem with likely affect many of the aquatic ecosystem components found here, affecting community composition in terms of both flora and fauna richness, and trending towards a less diverse and more disturbance tolerant community.

Implications to Ecosystem Services

As the lake is a kettle ecosystem that is largely governed by an interior draining system that is also situated within a protected Conservation Area management context, there are a number of services that are anticipated to remain largely unchanged into the future. Services like the regulation of erosion and flood attenuation will not change due to the lack of an inlet or out let feature; the regulation of urban heat island (UHI) effect won't change substantially because the overall quantity of natural cover won't change appreciably. The regulation of UHI might actually decrease slightly as the lake temperatures are likely to increase overall. The lake system will also remain unchanged for the provisioning service it provides, as there is currently no potable water use of the property from the natural water features found here.

Did You Know?

Heart Lake receives between 3000 and 5000 Rainbow Trout each year from the TRCA Glen Haffy fish hatchery for the purpose of recreational angling. However, these fish do not successfully overwinter to reproduce in the lake.

There are several inter-related ecosystem services that are likely to change in response to the currently predicted future climate scenarios. The potential for reduced water levels in the lake and a corresponding increase in water temperatures as air temperatures rise, may cause the local flora and fauna and ecosystem processes in and around the edge of the lake to change.

One ecosystem service that may benefit from this change is the lakes ability for water quality regulation (of runoff contaminants and assimilation of wastewater). As the lake becomes shallower, its edges may become more suitable for macrophyte growth, and it may increase the amount of available wetland habitat, which would change its ability to process and store contaminants (potentially carbon), perhaps substantially increasing it. However there are also likely to be negative ecosystem changes in response to an increase in wetland cover, such as an internally driven increase in phosphorous loading. This may create/increase issues in the lake, particularly since the lake environment has little to no flushing capacity to reduce phosphorus levels. The current state of the lake related to phosphorus is largely mechanically controlled by the solar bee lake circulation system. However, despite the use of this technology there are still water quality concerns, like low oxygen levels, these are likely to persist or potentially be exacerbated in the future. There may need to be an increased reliance on mechanical aeration solutions to adapt to changing conditions. The potential future algae and macrophyte growth in the lake might also become problematic for other ecosystems services provided by the lake, like its recreational services such as its natural aesthetics and/or fishing opportunities.

The potential changes in lake levels, temperature and nutrient load are very likely to affect the lake's habitat diversity and how its ecosystems function. The local flora, fauna and ecosystem processes in and around the edge lake are very likely to change. Maximum lake temperatures on an average climate year reach 26.5°C, which is already above the threshold for cold or cool water aquatic ecosystems. While the Hypolimnetic temperature currently holds at 7 to 10°C over the summer, this is likely to change as well. While the lake will likely always offer thermal refugia, the amount that is suitable will likely change over time. These changes will potentially eliminate cool water aquatic ecosystems that exist in the lake now, potentially affecting some of the recreational angling activities that take place at Heart Lake, or at very least change them.

Additionally as the lake responds to climate change influences, it will also likely begin to lose its ability to Moderate of the Rate of Spread of Invasive Species. Heart Lake already has one invasive species present in what appears to be low numbers. As the Lake responds to climate change, the ecosystem is anticipate to trend towards more suitable habitat for this and potentially other invasive species. An increase in invasive species here may further degrade its ability to provide the ecosystem services desired by Peel Region. The lake species richness is also likely to decline, trending towards a less diverse and more disturbance tolerant community. The lake itself also provides other important ecosystem services to the surrounding community such as substantial recreational opportunities for tourists like hiking, swimming, bird-watching, paddling, wildlife viewing, among other activities. Climate change in this area is likely to stress and/or change some of the natural system components that help to maintain the quality of these other services.

Box 4: Rising Chloride In Our Streams

The newest climate science illustrates that it is our winters that are warming the fastest, especially from a seasonal perspective (Kingsbury 2015). While many people may intuitively think this to be a good thing, there are many unperceived negative consequences to the natural world around us. One of those involves salt, and the chloride levels in our water. Road salt, is most often used when temperatures hover around the freezing point in the winter. As climate change proceeds it is anticipated that there will be an increasing number of days which will hover around 0°C (Auld *et al.*, 2015). This will lead to the increased need for the use of road salt on roads, as a safety and liability measure. An increase in road salt use means an increase in salt being washed into our rivers and streams, raising their chloride levels. These elevated chloride levels in our rivers put stress on freshwater adapted aquatic species, as this is not just a bit of salt being added, but a lot.

In 2011 a woman took photos of 15-20 blue crabs in Mimico Creek, which are a salt water species. How could salt water crabs be living in freshwater? The answer is that salinity testing in Mimico Creek during this time registered the highest chloride levels in Peel's jurisdiction at 20 ppt. Lake Ontario registered 1 ppt. The Blue Crab needs at a minimum 20 ppt of chloride to survive (A. Wallace and Biastoch 2015). Some of our most urban rivers appear to be reaching that threshold. In the Toronto Region many water quality stations already exceed water quality guidelines for chloride, some doubling it. Maximum chloride levels are already being seen at *one third the concentration of sea water* and with more salt applied to roads as a result of climate change, these levels will only increase. This occurs despite the declaration of road salt as a toxic substance by the Federal government in 2001 (A. Wallace and Biastoch 2015). Elevated levels of chloride are known to affect health, growth and hatching rates of freshwater aquatic species and, when high enough, allow for the creation of new habitat for exotic and potentially invasive species (Cañedo-Argüelles *et al*. 2013).

Rattray Marsh Conservation Area

Rattray Marsh is located in south Mississauga in the Sheridan Creek watershed (see Figure 42), is well-studied, and is considered an important natural component in the Lower Credit zone of the watershed based on its size and function (Harrington and Hoyle Ltd. 2009). Its surrounding conservation area consists of 94 acres of lakeshore, marsh wetland, field and woodland habitats (CVC Foundation 2015). Rattray Marsh is one of the last remaining baymouth bar coastal wetlands in the western end of Lake Ontario, where the marsh is separated from the lake by a bar formed as a continuation of the shoreline (Harrington and Hoyle Ltd. 2009). It was recognized internationally in 1969 and since designated as an Environmentally Significant Area, a Provincially Significant wetland, and an area of Natural and Scientific Interest (CVC Foundation 2015). Furthermore, it is one of the few remaining coastal wetlands in the Greater Toronto Area and is part of the Rattray Marsh – Turtle Creek Centre for Biodiversity in the Credit River Watershed Natural Heritage System (CVC 2015a).

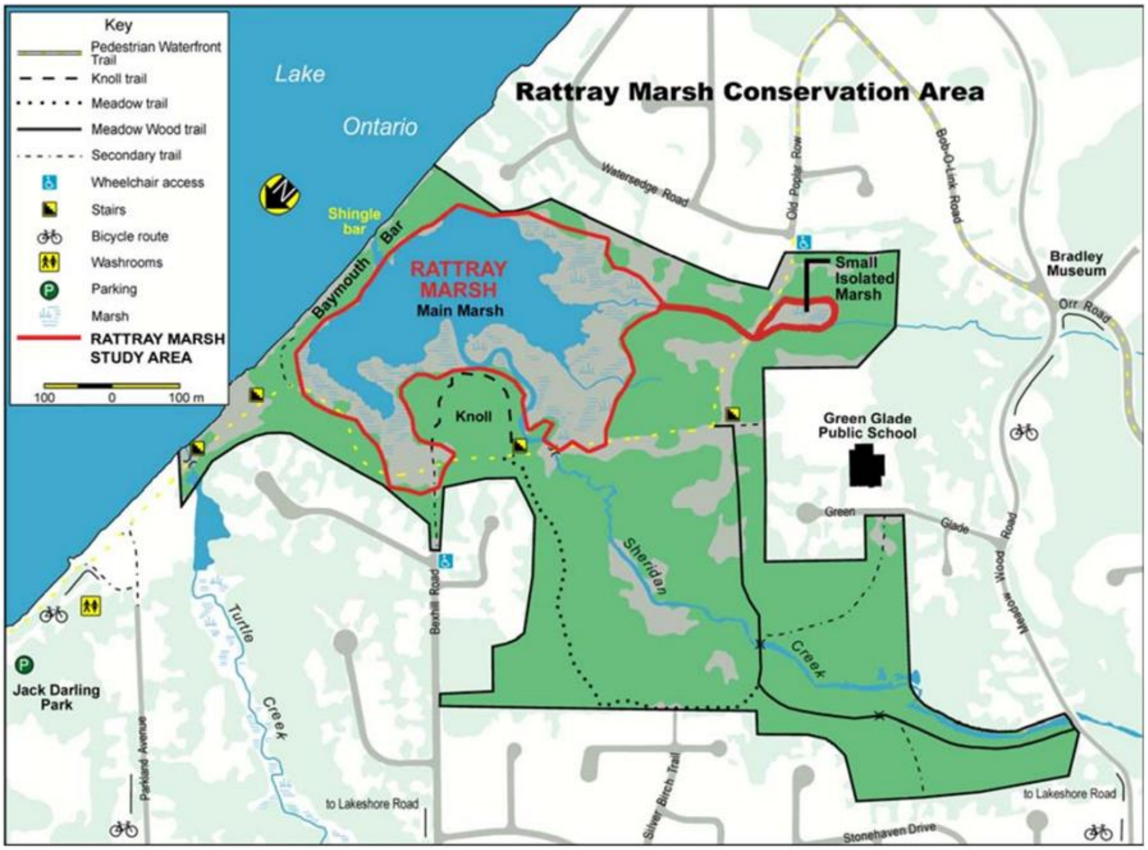


Figure 42: Rattray Marsh and Its Surrounding Conservation Area

The southern, coastal location of Rattray Marsh within Peel Region creates a unique storyline in terms of how climate change will be particularly relevant in driving vulnerability (see Table 28). Specifically, it was determined that summertime shifts in climate are most telling in driving vulnerability: warmer temperatures and potentially drier conditions driven by similar precipitation amounts to today but coupled with higher evaporation rates may produce a series of impacts which could increase the vulnerability of Rattray Marsh. Terrestrial system vulnerability (see Figure 21) rated Rattray Marsh as moderately vulnerable to climate change as a whole, although some specific vulnerability factors differ in their rating (e.g., are rated low vulnerability) (see Table 20).

Table 20: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Rattray Marsh Conservation Area

Components	Vulnerability Factors	Vulnerability Indicators
Wetlands	• Habitat Connectivity • Thermal Gradient • Hydrologic Connectivity • Low Species Diversity	• Habitat Patch Quality • Land surface temperature • Wetland Type (Hydrology)

Current Conditions in Rattray Marsh

Although there are several wetlands in proximity to the Lake Ontario shoreline Peel Region (e.g., Meadowvale Swamp, Creditview Marsh, Winston Churchill Marsh, Rattray Marsh), they are spatially separate and isolated from one another in terms of riparian cover and upland linkages. In other words, there is little habitat connectivity (Hotte *et al*., 2009). Rattray Marsh has historically experienced ecological degradation caused by sediment build-up in Sheridan Creek, the impacts of which are exacerbated today due to exotic species in the marsh (e.g., carp) and poor water quality (Harrington and Hoyle Ltd. 2009). It remains an important source of habitat given its location within the built environment. Landscape analyses conducted by CVC indicate that this habitat patch is considered moderately vulnerable based on its size, quality and connectivity to the broader landscape (CVC 2011c). This evaluation may, in part, be due to 'edge effect' impacts being exhibited from the urban land use surrounding Rattray Marsh and its conservation area. For instance, impervious cover increases the flashiness of surface water flow and decreases the surface water quality entering the wetland. Specifically, a CVC water quality monitoring station located in Sheridan Creek (which flows into Rattray Marsh) demonstrated very high concentration of chloride (7 times the PWQO), and exceedances of total phosphorus concentrations giving this station marginal water quality (CVC 2013a). Rattray Marsh acts to polish water quality through constant uptake, but to its detriment (CVC *et al*. 2009). Of note as well is that Rattray Marsh is adjacent to Turtle Creek marsh, which is out of scope of a detailed analysis but based on CVC expertise is identified to be more stable and provide a refuge for some Rattray flora and fauna, thus increasing its resilience.

Land surface temperatures also play an important role in and surrounding Rattray Marsh due to its urban environment, creating a thermal gradient. Data were obtained through two separate satellite imagery analyses: one conducted mid-morning on August 23, 2009 and another mid-afternoon on June 18, 2014 (see Figures 28 and 29, respectively). Mid-morning temperatures identified Rattray Marsh to be within the 20-29˚C range, which is cooler than other urban areas in mid and southern Peel which reached well over 30˚C (Landsat8 Land surface temperature thermal imagery). This thermal regulating trend is consistent and even more pronounced in the mid-afternoon. Mid-afternoon temperatures identified Rattray Marsh to be 20˚C (at the shoreline) and 35˚C inland in the conservation area, which are both significantly cooler than surrounding areas in Brampton and Mississauga which range upwards to 54˚C at the ground surface (Landsat8 Land surface temperature thermal imagery). Furthermore, satellite data collection occurred in mid-morning and mid-afternoon throughout a cooler year relative to Environment Canada's climate normals (Environment Canada 2015). This implies that land surface temperatures may reach even higher extremes during hotter years. Overall though, data appear to show Rattray Marsh influencing the surrounding landscape and reducing heat stress; additional analyses would be required to understand to what extent the marsh is providing regulation (i.e. repeated land surface temperature monitoring throughout the summer where average temperatures and the distance from Rattray Marsh where these temperatures are reduced are recorded).

Rattray Marsh receives its water supply from groundwater and surface water, the latter via Sheridan Creek (CVC 2010). It is also coastal marsh along the Lake Ontario shoreline, and within 30 metres proximity to a watercourse which maintains important hydrologic connectivity between Sheridan Creek and Lake Ontario (LOISS 2011). Thus, water levels in the marsh are controlled by both flow in the creek and lake levels (Harrington and Hoyle Ltd. 2009). Modeled recharge in and around Rattray Marsh indicates that it is located within a 'cluster' of higher recharge (ranging between 135 and 180mm/yr) found in the southwest portion of Peel Region. This stands out against much of Mississauga (which contains lower recharge values) and could imply that Rattray Marsh has strong, continuous hydrologic connection (see Figure 26).

Rattray Marsh is described as large and varied, with the ability to support varied plant communities and a large population of insects, fish and wildlife. However, historical degradation in the ecosystem, as well as current pressures due to the presence of invasive species has impacted the species diversity in the marsh. Invasive species, in particular, that have been introduced into the marsh stress the natural vegetation (e.g., large disruptions to ash trees by EAB), reduce the ability of young vegetation to become established (e.g., Canada Geese), stir up sediment while feeding (e.g., carp) and prevent the re-establishment of plants. This instability reduces the number and variety of plants (and the insects and wildlife that depend on them) in the marsh and overall diversity (Harrington and Hoyle Ltd. 2009). Therefore, the species diversity of Rattray Marsh has been described as "degraded" relative to wetland complexes located in northern portions of Peel (CVC 2012b). Further, it is described as having a lack of diverse species and higher proportion of weedy (invasive) species relative to native species (CVC 2012b). These low diversity assemblages are consistent with edge effect impacts often associated with urbanization and fragmentation (Cudmore *et al.*, 2008). Further evidence of this condition is that as of 2008 CVC identified Rattray Marsh as a priority area for restoration to return the diversity of vegetation to be more representative of the original native communities that are characteristic of this region (Krick 2008). In fact, carp and phragmites control are currently ongoing at Rattray and sediment removal was conducted in 2014/2015. However, it is noted as part of these restoration efforts that many areas of Rattray Marsh conservation area are already dominated by a number of invasive species and from a feasibility standpoint may be impossible to restore to a completely native species state (CVC *et al*. 2009). Analyses conducted in this report using ELC information from CVC and the City of Mississauga identified Rattray Marsh as moderately vulnerable to climate change due to the amount of climate sensitive native vegetation present, particularly to changes in hydrology (see Figure 31) (data from CVC and the City of Mississauga).

Future Vulnerability in Rattray Marsh

Higher temperatures and drier conditions by the 2050s could increase the stress on the vegetation present in Rattray Marsh (Cregg and Dix 2001), and particularly depending on how precipitation falls may compromise structural and functional connectivity between habitats. For instance, there may be an elimination of 'stepping stone' patches (habitat connectivity) for wetland species like the Spring Peeper and Wood Frog, both of which are present in Rattray Marsh (CVC 2012b). This could increase the vulnerability of more specialized species of wildlife to obtain the habitat resources required for their survival. Furthermore, future climatic conditions may favour ‘edge’ species that are more tolerant of warmer and drier conditions in the summer season, which are therefore more adaptable (Cregg and Dix 2001; Dukes *et al*. 2009). These edge species include invasive species with a competitive advantage over native species that may be more specialized in terms of their requirements.

Future warming by the 2050s will likely increase the urban heat island effect in Peel Region (thermal gradient) (Auld *et al.*, 2015). Rattray Marsh’s ability to regulate surface temperature (thermal gradient) may be compromised given that the treed vegetation may not be able to function as efficiently, especially because climate sensitive native vegetation comprises Rattray Marsh which is rated moderately vulnerable to climate change (see Figure 31). This is particularly important if there prolonged drought conditions are exhibited in the summer season. However, this effect may be offset to some extent since there are multiple water sources feeding the marsh (e.g. groundwater, hydrologic connection to Lake Ontario). This effect may also be offset by the shift of vegetation from forested to more shrubland and meadow that can withstand warmer and drier summer conditions. However, a no-regrets strategy suggests that it would be prudent to assume higher land surface temperatures will increase vulnerability in Rattray Marsh, given that uncertainties exist with how specific vegetation species perform under climate change.

If future climate conditions produce more prolonged drought conditions, which is anticipated in the growing season (Auld *et al.*, 2015), groundwater discharge at the surface may be compromised thereby reducing the hydrologic connectivity of the marsh. The fact that Rattray Marsh located in an already urbanized area future urbanization is not expected to change the current dynamics of the hydrology. However, there is concern around intensification in existing urban areas and what challenges this may pose to the natural systems under a future climate, but this requires a greater understanding and additional study. In general though, Rattray Marsh is considered to be a hydrologically well-connected feature and the disruption in its water source is not anticipated under a typical warmer, drier summer by the 2050s; however, prolonged drought conditions may stress the system.

Given the existing stresses and quality of the habitat, low diversity of species assemblage and threats of invasive species today (e.g., European Buckthorn, Tartarian Honeysuckle, garlic mustard) are all present in southern Rattray Marsh (Krick 2008), the diversity condition of Rattray Marsh is likely to degrade over time as a result of climate change, without human intervention (Krick 2008). Higher temperature and drier conditions in summer combined with low native species diversity is likely to provide some already established invasive species a competitive advantage over native species as they have increased tolerance level for both temperature and moisture conditions (Allen *et al.*, 2010; Dale *et al.*, 2010; Dietz & Moorcroft, 2011; Dukes *et al.*, 2009; Joyce *et al.*, 2014; McDowell *et al.*, 2008). Further, native vegetation that is considered climate sensitive is present in the marsh (e.g., fresh moist hemlock hardwood, dry fresh white pine/oak mixed forest), and these are mostly sensitive to hydrology. Drier conditions may particularly be of concern for these sensitive vegetation species, especially if much hotter conditions dominate in the summer season. It should be noted; however, that human interventions are ongoing: Rattray has recently been dredged for sediment removal and carp access has been controlled. This was, in part, to increase climate resilience in the marsh by restoring deep water refuge and habitat diversity. In fact, from preliminary observations by CVC, new species or improved populations are already being documented including 90% submergent cover compared to less than 10% prior to this restoration.

Implications to Ecosystem Services

Rattray Marsh currently provides key ecosystem services for the local area, including important habitat provision for migrating bird species (Aquafor Beech Limited 2011b; CVC 2012b), regulation of urban heat in southern Mississauga, as well as recreation and aesthetic services for residents. With a changing climate and particularly a warmer and drier summer season by the 2050s, vulnerability is expected to increase overall in Rattray Marsh from its current moderately vulnerable state (see Figure 21). Specifically, degradation of native vegetation or loss of species diversity in the marsh could reduce the aesthetic appreciation for the marsh for local residents thereby reducing its recreational benefits (e.g., to birders). Further, this degradation could impact habitat provisioning that currently exists for migratory species, as a result of species assemblage shifts and increasing dominance by invasive species (Joyce *et al*. 2014; Dietz and Moorcroft 2011; Allen *et al*. 2010). Algal blooms may become an issue as well as primary productivity is increased in the marsh as a result of future climate conditions. It is anticipated that the regulation of urban heat from Rattray Marsh may be reduced by the 2050s if shifts in species assemblage occur; however, this will depend on the how shifts in vegetation occur to smaller shrubs.

Box 5: Invasive Species Like Climate Change

What are invasive species and why do we care?

Invasive alien species are non-indigenous species that adversely affect biodiversity and habitats where they have been introduced, either accidentally or deliberately, outside their normal past or present distribution. The effects of these invasives can be economical, environmental and ecological, and today more and more people from all disciplines, not just biologists and conservationists, are taking notice. In 2008, an analysis concluded that globally invasive species are fundamentally an economic problem (International Union for Conservation of Nature (IUCN) 2008). In fact, billions of dollars in environmental damages are caused by these invasive species. In Canada, it is estimated that 16 invasive species found in the country cost between $13.3–$34.5 billion per year (Environment Canada 2004). Of course, there are numerous other direct and indirect social costs from invasive species as well, such as on human health, agriculture and our natural resources.

Why do invasive species like climate change?

Climate change, specifically changes in temperature and precipitation patterns along with the extreme weather events and a longer growing season, has profound implications on invasive species spread and establishment. Invasive species are aggressive and are highly adaptable. They are tolerant to a broad range of biophysical factors, and are often better suited to exploit the opportunities from a changing climate.

Warming temperatures will shift northward the geographic ranges of both native and invasive non-native species. As native species with specific temperature requirements shift northward (e.g. White Spruce or Brook Trout), this opens up a new niche for other invasive species that are shifting their range northward as well (e.g. European Buckthorn or Asian Carp). Warmer temperatures in the winter season may enhance winter survival of invasives as well, which could cause even more spreading of these competitive species (Dukes and Mooney 1999; Simberloff 2000). Changing precipitation means changes in moisture conditions especially in the summer. If drier conditions prevail and moisture is reduced, it will cause stress and the native ecosystem may be exploited by invasives that are more tolerant to wet or dry conditions. Native species, in contrast to invasive species, often have definite growth requirements that can be disrupted by changes such as the arrival of early spring and a longer growing season. Invasives have even been found to change their growth schedule more quickly in response to shifting climate than natives (Wolkovich *et al*. 2012). For instance, purple loosestrife (an invasive species) and has been found to crowd-out cattails and native wetland vegetation while it takes advantage of changing climate conditions faster. This relationship has strong ecosystem implications, where invasives can lead to a monoculture that supports few other species that rely on native species for food and habitat. These single-species dominated habitat would also compromise human benefit from the natural environment since there could be low diversity and less birding opportunity.

What can we do to minimize invasion with climate change?

It is inevitable that there will be higher spread of current invasive species, and that new invasives will be coming to Peel Region. Much can be done to minimize their spread and their impact, but there is no one-size-fits-all solution to managing invasive species (Sutherst 2000). Our diverse natural landscape requires different approaches including some where invasives should be accepted as part of a ‘novel ecosystem’ that is the result from climate (and land cover) changes. In other contexts, management should focus on a variety of approaches, such as increasing public awareness to avoid sources of invasives, creating an early monitoring system to detect new invasives spreading and restrict them before we lose control of their spread, and even incorporate broader landscape design into proactive measures to maintain diversity in our environment that hinders the spread of invasive species.

6.2.2. Subwatershed Storylines

Etobicoke Creek Headwaters

The Etobicoke headwaters are in the northernmost portion of the Etobicoke watershed located in lower Caledon (see Figure 11). The Etobicoke Creek watershed as a whole is designated as 71% urban, 22% rural and 7% urbanizing with less than 5% considered covered with natural forest (TRCA 2013b). Relative to the majority of the watershed, the headwaters are considered the highest quality from a terrestrial perspective as a result of limited urban development to date. Wetlands found in the Etobicoke watershed are dominantly classified as swamps and marshes, with the majority located in the Upper Etobicoke. However, in the entire watershed, only 0.6% of cover is classified as wetlands (TRCA 2010a). Most of the wetlands are found in and around the boundary of the Etobicoke headwaters and Heart Lake Conservation Area where relatively higher amounts of natural cover exist.

This focus area was selected given its important location in Peel Region (see Table 21). Specifically, it is under threat from future urban growth and a resulting potential loss of natural components. As such, given its current relative high function in the Etobicoke watershed it will become more important for conservation in the future, particularly if natural components and the services they provide are lost. Areas to the south of the Etobicoke Headwaters in Brampton and Mississauga, for instance, could become more vulnerable to climate impacts should the Etobicoke Headwaters function be degraded or lost. A climate scenario of a 'warmer drier summer, but punctuated by heavy rainfall events' was considered most relevant for this municipal focus area.

Table 21: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Etobicoke Creek Headwaters

Components	Vulnerability Factors	Vulnerability Indicators
• Groundwater • Rivers, Streams and Valley Corridors • Natural Forest • Urban Forest	• Aquifer Maintenance • Area-to-Depth Ratio (Aquifer Depth) • Topography & Grade • Flow Variation • Water Chemistry • Pervious Cover • Community Range • Urban forest canopy	• Recharge • Baseflow • Soil Drainage • Total Phosphorus • Natural Cover • Forest Cover • Climate Sensitive Native Vegetation • Urban Forest Canopy

Current Conditions in the Etobicoke Headwaters

Groundwater within the Upper Etobicoke is typically considered to be stored within a shallow aquifer system (aquifer depth) (TRCA 2010a). This system is believed to flow northward and opposite the direction of flow being supplied from the deeper underlying groundwater flow system (TRCA 2010a). Modeling conducted by the TRCA (see TRCA, 2008a) identified that the entire Etobicoke Headwaters is an area of low recharge (modeled using the West model) with values less than 45mm/year (aquifer maintenance) (see Figures 12A and 12B). These values are among the lowest recharge found throughout Peel Region, indicating a small but regionally important degree of aquifer maintenance to the groundwater system. Furthermore, some Etobicoke Headwater tributaries have been known to go dry in the summer season and thus may be vulnerable from a lack of groundwater support (TRCA 2010a). This may be because of the entire Etobicoke watershed, the majority of known water users are located in the Etobicoke Headwaters where water is withdrawn for agricultural uses (TRCA 2010a).

Soil types found in the Etobicoke Headwaters are mostly characterized as loams, with some significant areas of mucky soils that are very poorly drained (Hoffman & Richards 1953). The remaining area within the Headwaters contains mostly imperfectly drained soils (topography and grade), such as Chinguacousy Clay loam. An analysis conducted by the TRCA illustrates that generally drainage ratings vary significantly from poor (likely associated with low grade and/or mucky soils) to imperfectly drained, to well-drained (likely associated with higher soil grade and topography) (see Figure 23). Spatially, the upper half of the Etobicoke Headwaters is mostly imperfectly drained and the lower half, particularly some catchments immediately west of Heart Lake Conservation Area, contain more well drained soils.

A pervious cover assessment, completed in 2008, indicated low amounts of pervious cover for the Etobicoke Creek watershed as a whole (71% of the watershed is urban and 7% is urbanizing), with the exception of the headwaters which shows less than 10% of the subwatershed being impervious (TRCA 2013b; TRCA 2010b). A distinct spatial divide exists between the upper half of the Etobicoke Headwaters where land cover is mostly agricultural and natural (with some areas currently urbanizing) and the lower half of the headwaters, where lands are almost urban or urbanizing (see Figure 16). To date, the Etobicoke headwaters have not been subjected to highly altered flows (flow variation) or channelization that result from high levels of urban development over the majority of the catchment area; however, channelized (altered) tributaries are common and frequent in the main and lower Etobicoke watershed (see section 6.2.2) (TRCA 2010b). This translates to a natural flow regime characterized by seasonally high flows (spring and fall) and lower flows throughout the summer months. The Etobicoke Headwaters are characterized as '*sensitive'* to these flow regime variations, but not significantly impacted (TRCA 2010b). Within this area, approximately 50.6 km of watercourse contains 101 instream structures with only 37 identified as barriers to fish passage; the lowest number compared to other watercourses of similar length (TRCA 2010b). Specifically, road crossings are the most common barrier (20 in total), followed by natural barriers (15) and weirs (2). Many of the smaller headwater tributaries are known to become dry particularly in the summer months, thereby limiting fish habitat and aquatic connectivity. The stream bed is characterized as predominantly natural (as opposed to hardened concrete or modified) in all tributaries assessed (TRCA 2010a). Thus, current flow variation conditions in the Etobicoke Headwaters are considered fairly intact and of good quality; however, high potential consequences exist if this changes (see Section 6.1.4 and Section 7).

Water chemistry conditions in the Etobicoke Headwaters are not widely characterized, as only one water quality monitoring station is present near Mayfield Road in the lower portion of the subwatershed (TRCA 2015b). However, trends in total phosphorus can be characterized on a watershed basis. In general, the Etobicoke Headwaters contain slightly higher water quality overall compared to areas downstream in the Etobicoke watershed (the Mayfield station received a Water Quality Index, or WQI, of 51.5). For instance, two monitoring stations downstream (80006 just south of the 407 along Hurontario Street, and 80007 at the Etobicoke on boundary with Peel and Toronto) range from marginal water quality (a WQI of 49) in the middle Etobicoke to poor water quality (WQI of 33.7) in the lower reaches of the Etobicoke. For the Mayfield station, total phosphorus (TP) concentrations exceeded the Provincial Water Quality Objective (PWQO) of less than 0.03mg/L in monitoring conducted from 2006 to 2010 (TRCA 2011c; MOE 1994). Concentrations of TP at the Mayfield monitoring station reached just under 0.075mg/L. Downstream in the Etobicoke, all other stations similarly exceeded the PWQO over the same time period. In areas northwest of the Etobicoke Headwaters in the Credit Watershed (Cheltenham to Glen Williams, and Glen Williams to Norval) have been described as having a stable TP trend , and fluctuating between 0mg/L and 0.15mg/L thus sometimes exceeding the PWQO, although averaging below 0.03mg/L from 1999 to 2008 (CVC 2012b). Other water chemistry parameters examined in the Etobicoke Headwaters include total suspended solids (TSS). Mayfield monitoring station had an average TSS concentration of less than 10mg/L, which may be due to erosion, resuspension of bed sediments in watercourses and/or construction site runoff (TRCA 2011c).

The terrestrial system in the Etobicoke headwaters has previously been described as 'fragmented' (TRCA 2013b); however, compared to other areas downstream in the Etobicoke watershed, this area is considered one of the few remaining locations of good ecosystem function and terrestrial habitat. Furthermore, this storyline area is described as particularly important given that it has much of the remaining terrestrial species of concern for the watershed (TRCA 2010a). Vulnerability characterization analyses using ELC information identified that numerous climate sensitive native vegetation species are present in the Etobicoke Headwaters, although no spatial pattern in sensitivity is particularly present here (see Figure 31). Climate sensitive vegetation ecosites present in the Etobicoke Headwaters include those found in swamps, marshes (e.g., Cattail and burread Marsh, meadow marsh), tree species (basswood, sugar maple mixed and beech, hemlock mixed, hickory, ironwood, white ash, white pine, poplar), and successional lands. Most climate sensitive vegetation is sensitive to hydrology conditions in the headwaters at a minimum, with some being sensitive to fertility or dynamics as well.

From an urban forest canopy perspective; the Etobicoke watershed contains both natural forest cover in rural and natural areas and urban forest canopy in the southern portions and surrounding Heart Lake C.A (see Figure 27 for urban forest mapping and Figure 28 for natural forest mapping). Natural forest cover is characterized as low, likely due to the agricultural land uses in Caledon. Analyses conducted by TRCA identified that almost all of the Etobicoke Headwaters at a 30ha catchment unit contains very little natural forest cover. However, relatively speaking within the watershed, the Etobicoke headwaters contain the highest amount of natural forest cover, but this is still considered very little and is described as "fragmented" (TRCA 2013b). Urban forest canopy, on the other hand, has only been assessed for the lower portion of the Etobicoke Headwaters (in and around where urban lands exist starting in south Caledon and moving into Brampton), and ranges from 0 to greater than 56% canopy (TRCA 2007). Specifically, valley corridors along the tributaries contain the highest amounts of this cover type in the Etobicoke Headwaters, followed by what is found downstream in the valley corridors (which contains between 21 to 55%). Outside of these natural areas, urban forest canopy in Brampton is much lower (i.e. less than 15%), and in some areas no trees exist.

Future Vulnerability in the Etobicoke Headwaters

The shallow aquifer system (aquifer depth) underlying the Etobicoke Headwaters may place the tributaries in a vulnerable state as climate change processes unfold (Bovolo *et al*. 2009; Dove-Thompson *et al*. 2011; Green *et al*. 2011). Specifically, shallow aquifer systems typically have shorter flow paths from where groundwater is infiltrated into soils and where it is ultimately discharged at the surface and thus may be subject to increased amounts of warming associated with increasing temperatures (Bovolo, Parkin, and Sophocleous 2009). Warmer atmospheric temperatures and more sporadic rain events may leave the aquatic ecosystem with very limited water availability, particularly during baseflow periods (i.e., in summer), and providing warmer water inputs (N LeRoy Poff, Brinson, and Day 2002). When tied to other anthropogenic impacts on the landscape like increased impervious cover and increased water withdrawals there is likely to be even less infiltration capacity for the aquatic ecosystem. This might fundamentally change the form and functions of the watercourses found here. These effects will also cascade into the terrestrial ecosystems affecting both riparian vegetation and wetland ecosystems (N LeRoy Poff, Brinson, and Day 2002). Ultimately it is anticipated that less infiltration will occur here, reducing the already limited recharge capacity of the shallow aquifer system.

Low aquifer recharge rates, which are found in the Etobicoke Headwaters (see Figure 13) (aquifer maintenance), could imply that most precipitation infiltrating into the ground travels short flowpaths prior to being discharged at one of several key discharge points in the headwaters. Very little becomes a supply of water recharging the groundwater system. This limited recharge may shift due to changes in the timing, distribution and frequency of future precipitation (Allen *et al*. 2004). Numerous studies cite that changing precipitation, particularly how much falls in the spring time during the freshet and how much is available at the surface during the recharge period in spring, could change the amount of water reaching the aquifer system; although there is little agreement as to whether it will increase or decrease recharge since it likely requires scenario modeling exercises to determine the influence of local conditions (i.e. Allen *et al.*, 2004; AquaResource Inc. & EBNFLO Environmental, 2010; Doll, 2009; Eckhardt & Ulbrich, 2003; Green *et al.*, 2011; Mishra & Singh, 2010). Thus, vulnerability could be characterized as locally-specific within the Etobicoke Headwaters, depending upon where groundwater discharges at the surface and where it does not. Changes in recharge in general; however, may be the result of flashy recharge periods associated with extreme rainfall events (Jyrkama and Sykes 2007a) or extended dry periods with warmer temperatures and inadequate precipitation. Thus, vulnerability could be characterized as locally-specific within the Etobicoke

Headwaters, depending upon where groundwater discharges at the surface and where it does not.

Soils found in the Etobicoke Headwaters where still exposed (undeveloped) are not anticipated to change significantly as a result of climate change. Soil drainage ratings (topography and grade) are expected to remain consistent into the 2050s and thus surface volume runoff would not be significantly increased due to climate change alone. However, if urbanization occurs under conventional development, this is not the case; in fact almost all rainfall will become overland flow from the landscape, and contribute to the creation of downstream flooding problems. A very significant portion of the headwaters area is likely to be developed in the future (pervious cover) with some upper portions of the area remaining as greenbelt land into the future. Independently, climate change would result in only minor changes to attenuation or infiltration capacity within the catchment, but there is a negative synergistic effect when landscape change is considered, that exacerbates the environmental conditions (see section 6.1.4 for more details on these compounding vulnerabilities). The result of land development will be the substantial adjustment to the watercourses form and function as they adjust to new flow volumes. Compounding the anthropogenic effects of flow variation will be the changes tied to the seasonal distribution of rainfall and its overall intensities (F. J. Warren and Lemmen 2014) which will exacerbate these effects. The watercourses are anticipated to respond in a characteristic manner becoming both wider and shallower overall, and losing fine scale habitats (Center for Watershed Protection 2003). Under a changing climate, increasingly variable intense rainfalls and intermittent groundwater support may exacerbate flow variation leading to more watercourses becoming dry (or more frequent low flow conditions) creating a new “natural” condition. This new condition may create a positive feedback loop where water users may require more water, have less available, so even the same level of extraction pre-climate change, will now have a larger ecological impact.

In general, sources of phosphorus to the watershed include both point sources (wastewater and stormwater discharge, combined sewer overflows) and non-point sources (atmospheric deposition, fertilizer application, livestock waste, urban runoff, failing septic systems, and natural sources) (TRCA 2015b; CVC 2012b). It is uncertain if total phosphorus concentrations in the Etobicoke headwaters will increase overall (decreasing water chemistry), or if one source of total phosphorus currently present (agricultural lands) will simply be replaced for another (urban lands) in the future. However, the Etobicoke headwaters are considered to have low assimilation capacity under a future climate given that higher amounts of water may be evaporated from the watercourses and rising temperatures may stress the system. If the demand of water taking is increased from the Credit Watershed (i.e. in Cheltenham) into the future, this could further stress surface waters in the Etobicoke Headwaters. Under a future full build-out scenario as well, TP sources that are urban will likely play a much larger role in the Etobicoke Headwaters, exacerbated by warming water temperatures. With increased atmospheric warming, and particularly given the low urban forest canopy present in the Etobicoke Headwaters even along some valley corridors, thermal warming in watercourses is of concern. Increases in water temperature within watercourses of this subwatershed could affect the overall aquatic community composition and recreational fishing opportunities (Allerton

2010). Long term increases in temperature may alter the pH and dissolved oxygen available for aquatic species and communities (Allerton 2010; Great Lakes Information Management & Delivery System 2014). Warmer surface runoff inputs from ongoing and future urbanization will likely compound these impacts, further stressing cold and cool water aquatic ecosystem found here, and warming waters.

A warmer future climate with heavy rainfall events could also increase the turbidity of water being delivered to watercourses in the Etobicoke Headwaters (Bedford 1992; Kimmerer 2002; Cahoon 2006; Craghan 2012). This could be the result of increasingly intense and heavy rainfall events that accelerate mixing or loadings to surface waters bringing high amounts of sediment (Kimmerer 2002). This could be particularly problematic in this subwatershed given its already notably high (compared to TRCA jurisdiction water monitoring stations) concentrations of TSS. TSS in general is higher near the mouths of rivers or in urbanizing areas (e.g. those with development construction) and lower in upper reaches of a watershed (TRCA 2013e). Seasonally, it is highest in spring which is most likely due to snowmelt providing sediment to the stream that was applied to roads for traction during winter months.

Terrestrially, the Etobicoke watershed has limited amount of natural forests (less than 5% areal coverage) and wetland coverage, with most of these in the headwater area. Among these there are a significant number of climate sensitive vegetation communities (e.g. hemlock, white ash) that are sensitive mostly to hydrology (community range). Generally, vulnerability ratings based on climate-driven criteria range from low (a minority of species), to moderate and high (which together make up much of the entire subwatershed where climate sensitive vegetation is present). This diversity in vulnerability ratings and sensitivity of vegetation is specific to climate change, but in fact much of this vegetation is likely more vulnerable to urbanization and particularly those not found in the greenbelt protected areas in Caledon. Since the Etobicoke Headwaters also has underlying shallow aquifers (aquifer depth), this makes groundwater more vulnerable to climate change (Bovolo, Parkin, and Sophocleous 2009; Green *et al*. 2011) which has contributed to summer dry-up of upper Etobicoke tributaries (TRCA 2010a), the climate sensitive vegetation growth and survival will be challenging. The warmer summer and sporadic precipitation will exacerbate this condition and hamper tree growth and induce greater tree mortality (Richards 1993; Clean Air Partnership 2007; Laćan and McBride 2008). In such cases, some of these species may not be able to persist, and be replaced by more tolerant southern species or the community composition may shift towards shrubby species that are more resilient (Rustad *et al*. 2001). In addition, the increase in urbanization, mainly outside of greenbelt boundary, may induce additional pressure on some of the sensitive vegetation remaining in the Etobicoke Headwaters.

The Etobicoke Headwaters contains most of the limited amount of natural forested areas (tree canopy) in the watershed. These natural areas contain significant number of climate sensitive vegetation species that are sensitive to mostly hydrology (see Figures 27 and 30). Given that the Etobicoke Headwaters are highly vulnerable to shifting hydrology, these vegetation are at risk in future where warmer temperature and sporadic precipitation is expected, especially in summer (Auld *et al.*, 2015). Species such as white ash and hemlock are highly susceptible to changing moisture conditions and are at risk of increased mortality from drying and heat stress

(Joyce *et al*. 2014; Dietz and Moorcroft 2011; Allen *et al*. 2010). In addition, the fragmented nature of the natural cover in upper Etobicoke also hinders the ability of the existing tree canopy to buffer against the heat and drying stress. In the future, any urban expansion into these headwater areas will exacerbate this issue more. From an urban forest canopy perspective, these tree species will be more vulnerable in general to climate change, given their low species diversity, heat effects reflecting off impervious surfaces, soil compaction, restricted areas for root growth and mistreatment (Clean Air Partnership 2007; Greifenhagen and Noland 2003).

Implications of Future Urban Growth in the Etobicoke Headwaters

As the combination of future landscape and climate change unfold, the Etobicoke Headwaters will see a number of physical and ecological changes. The types of changes in the aquatic ecosystem are not unlike any other area of the jurisdiction; where the combination of climate and urban land cover changes could result in an altered flow regime, and therefore changes in aquatic habitat and species declines. The Etobicoke Headwaters are definitively under risk of urban development. More specifically, areas within the Etobicoke Headwaters within the Greenbelt, or those in the northern most and northwestern-most portion of the Etobicoke Headwaters, are currently protected from urban development. The remaining areas (i.e. those that are currently agricultural and natural) are not protected and could be developed into the future.

If the level of infiltration (see Figure 13 for modeled recharge) currently being maintained is reduced to almost zero as a result of urbanization, downstream areas in Peel will become even more vulnerable, especially because wetter conditions throughout the year are predicted for Peel under a changing climate (Auld *et al.*, 2015) which may increase the need for infiltration, particularly if it precipitation arrives in short extreme bursts as predicted. In addition, significant loss in flood attenuation and infiltration capacity could occur if tableland wetlands, pervious cover, and areas with natural forests in the Etobicoke Headwaters are lost due to urbanization. This could be particularly exacerbated if rivers and streams become channelized and/or lose their natural flow regime if development continues in a conventional manner. Ultimately, this could increase flooding in areas further south in Peel (which is already a concern, see Figure 17 for locations of flood vulnerable areas in Peel Region), and poorer water quality could be found in Peel's rivers and streams.

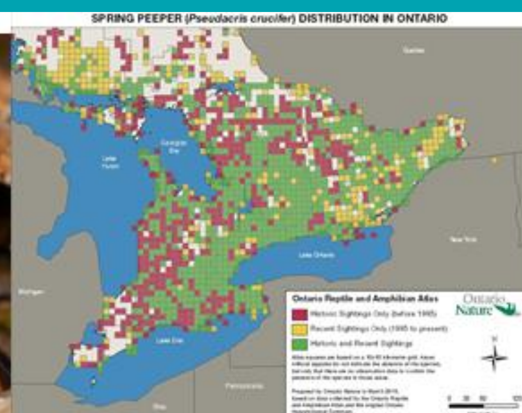
Implications to Ecosystem Services

The headwaters of the Etobicoke Creek, while small, still support much of the species diversity for the Etobicoke watershed. As services are impacted as a result of warmer, drier and more extreme rain conditions, the regulation of erosion could be altered or lost in the watercourse causing channels become more simplified and a decline in habitat diversity. Accompanying this could also be the change in the ability of the watercourses to perform the same level of water quality regulation services they had previously. It is likely also currently providing 'moderate quality,' important ecosystem services and functions, such as some tree canopy along valley corridors, which provide thermal refuge for species, and attenuation of water through the pervious cover present from agricultural and natural lands.

Box 6A: Will We Lose Our Local Amphibians to Climate Change?

Amphibians are so-called because they are found in wet and dry habitats in different parts of their life cycle. That there are at least fourteen species in Peel Region, each with different ecological needs and sensitivities, increases the challenge of anticipating climate change impacts on their populations. Amphibians in Peel Region are categorized as *forest-specific* (e.g., Red-backed Salamander), *wetland-to-forest* (e.g., Wood Frog, Spring Peeper, Jefferson Salamander), *wetland-to-meadow* (e.g., Northern Leopard Frog), *wetland-to-upland* (e.g., American Toad), and *wetland-to-wetland* (e.g., Green Frog, Bullfrog, Mink Frog).

The fourteen amphibian species were likely distributed throughout Peel Region prior to the contact era and all have responded to land use conversion in some way. Wetland-to-forest species are not generally found within the urban envelope because of the lack of association of quality forest and wetland. Bullfrogs and Mink Frog require high quality, large wetlands and are not generally found south of the ORM in Peel. But four of fourteen species, namely American Toad, Green Frog, Northern Leopard Frog, and Red-backed Salamander find habitat in both rural and urban situations, and are distributed throughout Peel Region. Climate change may further affect the distribution of these species either uniformly or in different ways according to their habitat dependence.



Winter

Wetland-to-forest species (and Chorus Frogs and Red-backed Salamander) overwinter in upland forest under leaves, logs and snow; whereas wetland-to-wetland species (and Leopard Frogs and Eastern Newt) overwinter underwater in deeper wetlands; and American Toads burrow underground below the frost line. All three strategies aim to maintain their body temperatures above freezing; therefore, length of winter and cold temperatures are important. If increasing winter precipitation coincides with increases in temperature then that precipitation will come in the form of rain, which would reduce the amount of snow accumulation. Amphibians may fare well in an extreme cold event as long as increased precipitation increases snow depth sufficiently for added insulation. However, increasing temperatures above freezing could result in a lack of insulating snow depth in uplands and wetlands, and reduced ice thickness in wetlands. Deep freeze that reaches the forest floor or wetland bottom would cause winter kill for wetland hibernators. On the other hand, if freeze-thaw cycles increase and extreme cold is followed by melting conditions, snow accumulation might be insufficient for insulation following the next cold snap and this may actually disrupt amphibian life cycles. The health of our local amphibians will depend on how future winter conditions manifest.

Box 6B: Will We Lose Our Local Amphibians to Climate Change?

Spring

Spring begins in late March or early April while snow is still on the ground and ice in wetlands. Jefferson's Salamander, Spotted Salamander, Blue-spotted Salamander, Wood Frog, Chorus Frog, Spring Peeper, Leopard Frog, and America Toad, travel on rainy nights to marshes and swamps where they breed. Other amphibians overwinter in the same wetlands where they breed. It is anticipated that increasing temperatures will signal an earlier start to the season, faster larval development, earlier dispersion (emergence) and greater productivity. Synchrony between frog emergence from hibernation and insects as a food source may also be important and changes in climate which effect these differently may lead to less survival in frogs.

All spring-breeding amphibians are wetland dependent. Increasing amounts of rain may create more days of optimal weather for migration to breeding wetlands and potentially more breeding sites available. Amphibians most often breed in "off-line" wetlands (avoiding fish predation of eggs) and therefore many populations would not suffer problems associated with flooding, such as blowout, except in oxbow situations, for example.

Summer

Spring breeding amphibians return to forest or meadow for the summer (and winter eventually). Summer breeding amphibians tend to breed from mid-May to late July, starting with Gray Treefrog. Many Green Frogs migrate on rainy nights from winter wetlands to breeding/summer wetlands. Red-backed Salamanders live in upland forests all year long, under logs, laying eggs in moist, spongy dead wood. By May and June, the young of spring breeding amphibians "emerge" from wetlands and travel to upland forests and meadows for the summer and winter. Increases in air temperature in summer would not be a problem by itself, allowing for earlier start to the season, faster larval development and dispersal, and increased productivity. However, an increase in evapotranspiration, were it to overwhelm the current or increased precipitation, may reduce wetland cover and species distribution. Forest-dwelling species may experiences changes in moisture regimes, but it is difficult to anticipate the impact on forest salamanders and frog species. In general, increasing precipitation overall increases the availability of breeding sites, thereby increasing species distribution and facilitating resilience. However, wetter weather may affect the ecology of ephemeral wetlands, especially if increased flows introduce fish (as a predator of eggs and larvae) into isolated wetlands.

Overall, increased precipitation and humidity at the time of migration and juvenile dispersal (emergence) would assist in successful migration and colonization of habitats. If increases in temperature overwhelm increases in precipitation, populations in isolated wetlands may not persist due to heat stress or drying. Perhaps the most important aspect, and limiting factor, would be a widening range of winter temperatures, from above freezing to extreme cold, whereby more rain and less snow would result. This may affect all amphibians in Peel Region.

West Humber Subwatershed

The West Humber subwatershed is located in the east of Peel in the Humber watershed, and stretches 43km across Caledon and Brampton to eventually drain into the City of Toronto (see Figure 11) (TRCA 2013c). Given the urban land use in the southern portion, the agricultural land use in the north portion and the urbanizing context in the middle reaches, this subwatershed is comprised of a diverse range of land use and is rapidly changing. Current additive terrestrial vulnerability in the West Humber illustrate this trend, with the majority of the subwatershed rated highly vulnerable south of Mayfield Road and the north portion ranging between low, moderate and high vulnerability depending on local conditions (e.g. high vulnerability near Bolton due to a few specific vulnerability factors: lower recharge, higher land surface temperatures, and low habitat connectivity. Bolton also has known flood vulnerable areas and is a special policy area due to flooding concerns) (see Figure 17). Central to this storyline are the upper and east branches of the subwatershed within Brampton and Caledon which still support the provincially endangered fish species Redside Dace (see Figure 43). These reaches and their surrounding valley corridors have been characterized as having a number of existing stresses, particularly within the aquatic and hydrologic ecosystems.

A future climate scenario focusing on conditions in the summer season was identified as being particularly important for impacts that may occur in the West Humber (see Table 22). Specifically, it is predicted that warmer temperatures will produce drier conditions in the summer that may be worsened depending on how precipitation is distributed throughout the summer months. It is assumed that on average the summer season will be drier, but punctuated with heavy rainfall events.

Table 22: Components, Vulnerability Factors and Vulnerability Indicators Discussed in the West Humber Subwatershed

Components	Vulnerability Factors	Vulnerability Indicators
• Groundwater • Wetlands • Rivers, Streams and Valley Corridors	• Aquifer Maintenance • Area-to-Depth Ratio (Aquifer Depth) • Hydrologic Connectivity • Water Taking • Topography and Grade • Tree Canopy • Thermal Gradient • Community Range	• Recharge • Groundwater Levels • Wetland Type • Soil Drainage • Baseflow • Urban forest canopy • Water Temperature

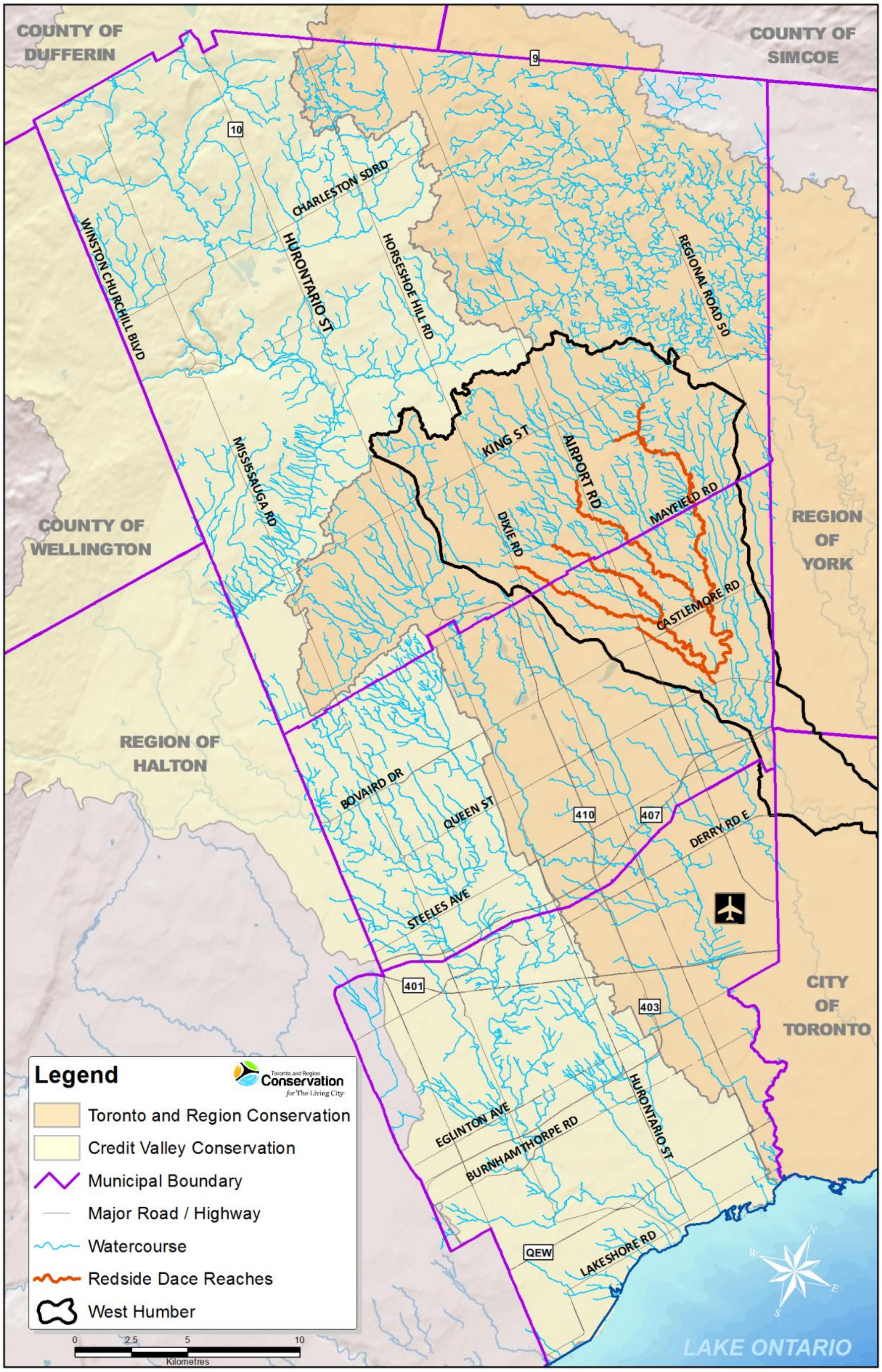


Figure 43: West Humber Subwatershed in Peel Region, including the Upper and East Branches which support the Provincially Endangered Fish Species Redside Dace

Current Conditions in the West Humber

The West Humber subwatershed is located in two physiographic regions, both with smooth gradual sloping topography (Puric-Mladenovic *et al*. 2013). Its headwaters are found in the South Slope and the majority of the remaining subwatershed lies within the Peel Plain. Soils tend to be poorly drained clays and clay tills with relatively low infiltration capacity (Hoffman and Richards 1953; TRCA 2008b). Modeled recharge in Peel Region indicates that areas in the West Humber in general contain less recharge to aquifers than those found in north Peel on the hummocky terrain of the ORM (aquifer maintenance). For instance, recharge in the upper Humber is consistently greater than 200mm/yr and even reaches 360mm/year, whereas recharge in the West Humber is much more variable, ranging from 0.3mm/yr to greater than 200mm/yr (see Figures 12A and 12B). Pockets of higher recharge in the West Humber are mostly found in the headwaters; however, these are beyond the redside dace reaches which are of interest.

Beneath the surface of the West Humber subwatershed lies a shallow groundwater system (aquifer depth), consisting of short flow paths and in some areas no aquifers being present (TRCA 2008b). Groundwater levels observed through Provincial Groundwater Monitoring Network (PGMN) wells in the Humber watershed as a whole imply a stable groundwater condition (groundwater levels fluctuated less than 1.5m over the period of record from 2001 to 2010) (TRCA 2008b). However, previous urbanization that has already occurred in the south portion of the West Humber, and in particular where the lower reaches of the Redside Dace reaches are located, has demonstrated some declines in groundwater levels underlying this area. Declines in groundwater levels due to urbanization were the result of decreasing pervious cover, which when present allow for water to infiltrate into soils (TRCA 2008c). Current groundwater levels in the West Humber are considered to have no significant trend either increasing or decreasing (TRCA 2008b).

The health of the groundwater system and specifically groundwater discharge at the surface is incredibly important in maintaining the health of surface features, such as rivers and streams in the West Humber (TRCA 2015b). The amount of groundwater discharged at the surface depends on water levels in underlying aquifers (storage capacity) and in the amount of recharge that is maintaining the aquifer system, which may in fact be originating from areas outside the West Humber subwatershed. A case study analysis conducted in the West Humber examined mean annual groundwater discharge from the groundwater system to the surface, which was selected as an indicator since it is commonly used in ecological vulnerability analyses (e.g., (AquaResource Inc. and EBNFLO Environmental 2010; Huntington *et al*. 2009). Using climate information from a thirty-year climate normal period (1981-2010) at the Orangeville climate station, mean annual groundwater discharge (MAGD) was modeled for every segment of the redside dace reaches in the West Humber. The distribution and quantity of mean annual groundwater discharge is presented in Figure 44.

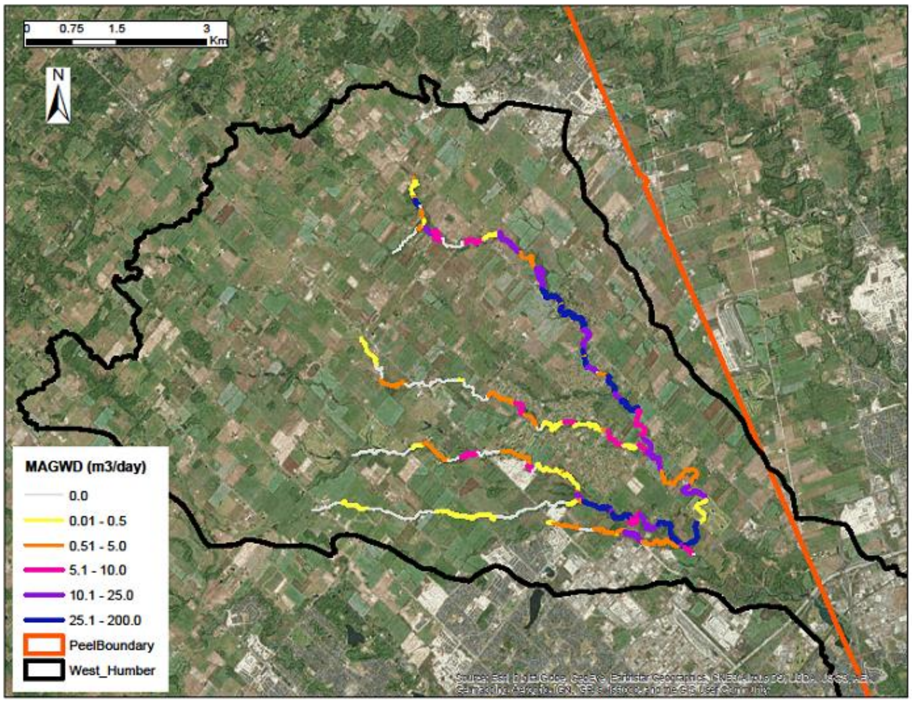


Figure 44: Mean Annual Groundwater Discharge (MAGD) simulated in Redside Dace Reaches in the West Humber.

The amount of groundwater being discharged in a particular stream segment indicates the level of hydrologic connectivity. Specifically, groundwater discharge alters the thermal regime of reaches keeping them cooler and provides baseflow. As illustrated in Figure 44, discharge varies substantially across the Redside Dace reaches in the West Humber, from less than 5 or 10m^3/day in many of the west and central tributaries to 200m^3/day in the West Humber River (easternmost tributary). These results are consistent with findings from existing reporting in the West Humber, where the majority of baseflows are described to be originating in the West Humber River main branch, and are much lower on average in reaches north of Mayfield Road (see Figure 43) (TRCA 2008b). A comparison of average groundwater discharge in the West Humber with two hydrological thresholds (see Figure 45) demonstrates that groundwater discharge seems to be fairly resilient to climate conditions, where only in the early 1980s did discharge reduce to below 30% of mean annual discharge. However, this does not capture the sensitivity of particular reaches in the West Humber which could be receiving intermittent flows, such as some reaches north of Mayfield Road which have been observed to dry up in the summer months (TRCA 2008b). Furthermore, the ratio of baseflow to total surface flow has been found to be particularly low in the West Humber River (a baseflow index of 0.47 was measured at a flow gauge at Highway 7 from 1997 to 2003), indicating that over 50% of total annual flow is being derived from surface runoff (TRCA 2015a; TRCA 2008b; TRCA 2008e). This low ratio is known to be consistent where seasonal variations in baseflow have not changed significantly over the period of record since the mid-1950s (TRCA 2008b). This subwatershed has also been noted to be of particular concern with sediment trapping (TRCA 2008b) which may reduce flows and exacerbate the issues of hydrologic connectivity. This implies that **hydrologic connectivity** may currently be vulnerable in some reaches but this is a locally specific pattern.

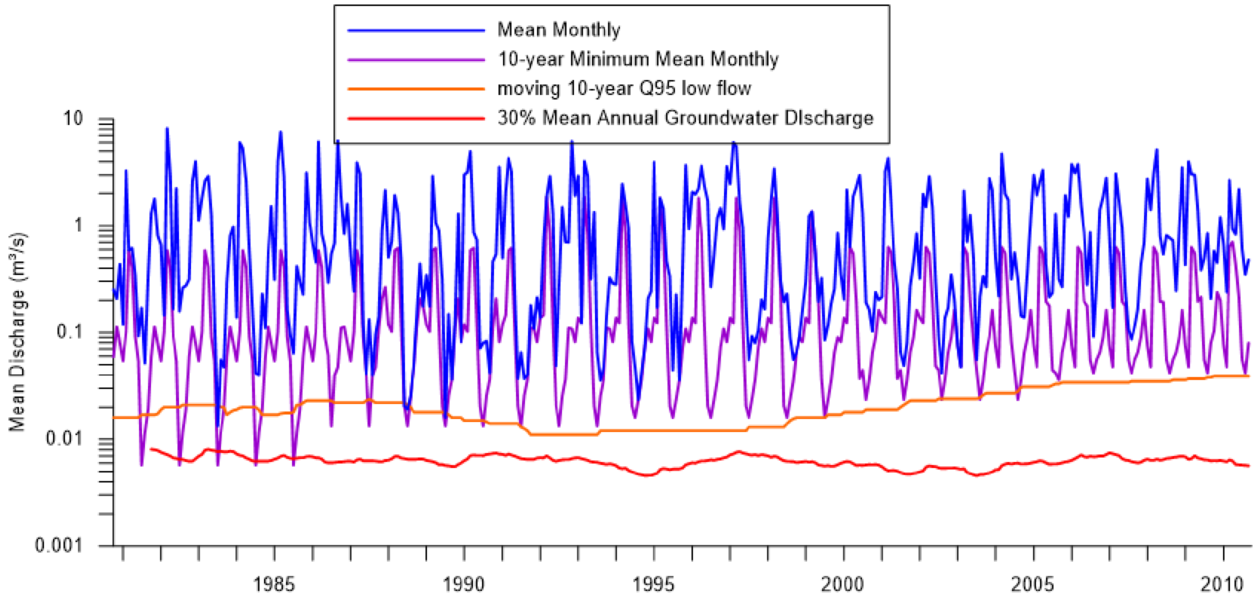


Figure 45: Average Monthly and Minimum Groundwater Discharge in the West Humber from 1981 through 2010 associated with Two Low Flow Thresholds

Hydrologic connectivity is also an important vulnerability factor for wetlands found in the West Humber. Currently, some wetlands exist throughout the West Humber (see Figure 26) although many are small in areal extent and are found along the southwest subwatershed boundary and in the northwestern portion of the West Humber. Of these, most are marshes and swamps (e.g. thicket swamp, deciduous swamp, and coniferous swamp).

Tributaries in the West Humber rely on surface water flows originating from precipitation and from overland flow (TRCA 2008b). Water taking from surface features and from the groundwater can stress these systems depending on how much water is being used compared to how much water is available. The West Humber subwatershed is rated to be most at risk of negative impacts in the Humber watershed as a whole due to surface water use, with more than 18% of the average annual baseflow allocated for withdrawal (TRCA 2008b). A water budget assessment (tier 1) completed in 2010 identified that the east half of the West Humber is significantly stressed at the surface in the summer months due to low flow conditions (TRCA 2015a). On the other hand, withdrawals from the groundwater system represent approximately 6% of total annual recharge over the watershed. This is considered low stress, but given that the withdrawals are concentrated, local rates may be higher (TRCA 2008b). The same water budget assessment (tier 1) completed in 2010 identified that groundwater stress is considered low throughout all of the West Humber (TRCA 2015a).

At the surface, the West Humber is described as very flat with little gradient (topography and grade) associated with South Slope and Peel Plain soils (TRCA 2008b). The total length of major West Humber tributaries is approximately 43km (TRCA 2013c). The subwatershed is considered to have low gradient streams with a fairly uniform drainage network in the northwest-southeast direction (TRCA 2008c). It is also considered to have been highly modified in the transition from forested conditions to agricultural and urbanized land use, such as culvert and bridge construction, agricultural drain construction and channel re-alignment (TRCA 2008c). Soil drainage ratings in the West Humber are almost entirely classified as “imperfectly drained” (see Figure 23). This is indicative of the flat, sloping surface features in this area.

Tree canopy in the West Humber consists of both urban forest canopy and natural forest cover. Natural forest cover in the south slope is described as highly fragmented which is contrast with well-forested areas further north in Peel Region (TRCA 2008c). Compared to the entire Humber watershed (which contains 17% of its total area with natural forest), the West Humber contains among the lowest (7% of the total area contains natural forest as of 2013) found in the watershed, and the majority of any that remains is found along stream and valley corridors (TRCA 2013c). An analysis on natural forest cover indicates that in no area of the West Humber do natural forests exceed 30% total coverage, implying limited thermal refuge or shading functions present (see Figure 28). Urban forest canopy information was only available for the lower half of the West Humber south of Mayfield road and in the northeast portion near Bolton. In general, urban forest canopy is highest along valley corridors and in urban areas in the form of street trees, but most do not contain as much as other areas in Peel (see Figure 27).

Water Temperature is a major factor that determines which aquatic species, fish or benthics, live in a particular stream (thermal gradient/regime). For example, a thermally stable stream is an important factor for the survival and reproduction of cool and cold-water species such as Redside Dace. Toronto watersheds were historically dominated by coldwater stream conditions; however, the more urbanized the surrounding landscape becomes, the higher the water temperatures (TRCA 2015b). Temperature fluctuations beyond what is considered the natural range are measured in the highly urbanized areas (TRCA 2008b). A thermally stable stream is one that has a temperature that does not experience any large fluctuations throughout the warmer season (i.e. late summer). At stable sites, water temperature is controlled more by groundwater than by air temperature or the heat from the sun (TRCA 2015b). Thermal stability in the tributaries containing Redside Dace is mostly rated moderately stable, with some tributaries rated as extreme (see Figure 1 in Appendix G). Maximum weekly stream water temperatures (or spiking temperatures in the summer season) in the Redside Dace tributaries range from 17˚C to 24˚C, from north to south where the main branch of the West Humber reaches summer spikes of 23˚C (Chu 2015). The present fish community (community range) in the West Humber reflects its thermal and sediment regime with tolerant species such as white sucker, common shiner, blacknose dace, longnose dace, fathead minnow, creek chub, brook stickleback and rock bass widely distributed through the subwatershed (TRCA 2008b). Currently, the West Humber only supports a small, confined population of the provincially endangered Redside Dace. This fish species prefers low gradient headwater streams with high water clarity and riparian habitat consisting of abundant overhanding vegetation (TRCA 2008b; Committee on the Status of Endangered Wildlife in Canada 2007). Redside dace are considered to be a coolwater species (with temperatures between 20 and 21˚C), which avoid warm water as well as very cold water (Committee on the Status of Endangered Wildlife in Canada 2007).

Future Vulnerability in the West Humber

The highly variable recharge rates exhibited throughout the subwatershed (see Figures 12A and 12B) (aquifer maintenance) may also shift due to changes in the timing, distribution and frequency of future precipitation (Allen *et al*. 2004). Numerous studies cite that changing precipitation, particularly how much falls in the spring time during the freshet and how much is available at the surface throughout the summer, could change aquifer recharge rates; although there is little agreement as to whether it will increase or decrease recharge since it likely requires scenario modeling exercises to determine the influence of local conditions (i.e. (Eckhardt and Ulbrich 2003; Allen *et al*. 2004; Doll 2009; AquaResource Inc. and EBNFLO Environmental 2010; Mishra and Singh 2010; Green *et al*. 2011). Changes in recharge in general; however, may be the result of flashy recharge periods associated with extreme rainfall events (Jyrkama and Sykes 2007b) or extended dry periods with warmer temperatures and inadequate precipitation. If lands in the upper half of the West Humber are not urbanized, the recharge window may widen thereby enhancing infiltration and aquifer maintenance.

The degree to which changes in recharge will ultimately impact the groundwater system depend on soils present in the area, the underlying aquifer depths, and a number of other factors. In general, shallow groundwater systems like those in the West Humber are understood to be more vulnerable to climate change (Bovolo, Parkin, and Sophocleous 2009; Dove-Thompson *et al*. 2011; Green *et al*. 2011). This is because shallow systems typically have shorter flow paths from where groundwater is infiltrated into soils and where it is ultimately discharged at the surface and thus may be subject to poorer water quality inputs due to warming, more sediment mobilization or increased salt use. Shallow aquifer systems, which are considered those with a depth up to 15 metres below the surface (D. Ford personal communication, November 3, 2014; Carter, Fortner, Skuce, & Longstaffe, 2014), will particularly respond faster than deep systems which have a large lag time from when they exhibit a response (Green *et al*. 2011; Mishra and Singh 2010). Studies have also shown that groundwater temperatures in these shallow systems track average annual air temperatures. For instance, a study conducted demonstrated that groundwater temperatures may be affected by thermal warming due to climate change that can lead to thermal signals up to 100m beneath the surface (Bovolo, Parkin, and Sophocleous 2009).

Given that changes in the hydrologic regime are expected under a changing climate (AquaResource Inc. and EBNFLO Environmental 2010; Dove-Thompson *et al*. 2011), this will likely include disruptions to water source and the hydrologic connectivity of surface features. Tributaries north of Mayfield Road within the West Humber are particularly vulnerable, given that they are currently intermittent and receive little to no baseflow support in the summer months (see Figure 26).

A modeling case study conducted on the West Humber analysed the influence of drought on groundwater discharge. Specifically, historical records at Orangeville and Toronto Pearson climate stations were used to examine ranges of plausible drought that could occur in the West Humber, since existing climate modeling in the region remain inconclusive on the future trend of drought (Auld *et al.*, 2015). Moisture indices ranged from a deficit of -747mm over three years (recorded at Toronto) to a surplus of 931mm over three years (recorded at Orangeville). Given that drought was the particular climate driver of interest in this case study and the focus was groundwater discharge support, the wettest climate scenario was selected at a value of 63mm from 2003 to 2005 (over three years). Modeling using the coupled Groundwater-surface water flow model, GSFLOW, estimated groundwater discharge with a range of scenarios using historical drought conditions. Specifically a vulnerability index was produced for each Redside Dace stream segment in the West Humber, which combines the number and severity of twelve drought scenarios. Essentially, the higher the vulnerability index, the more drought scenarios reduced groundwater discharge to less than 30% of its average annual amount over a 7-day consecutive period (see Figure 46). It should be noted that these results have been produced as a proof-of-concept of the quantitative kinds of analyses that can be undertaken and thus only present an illustration of system sensitivity.

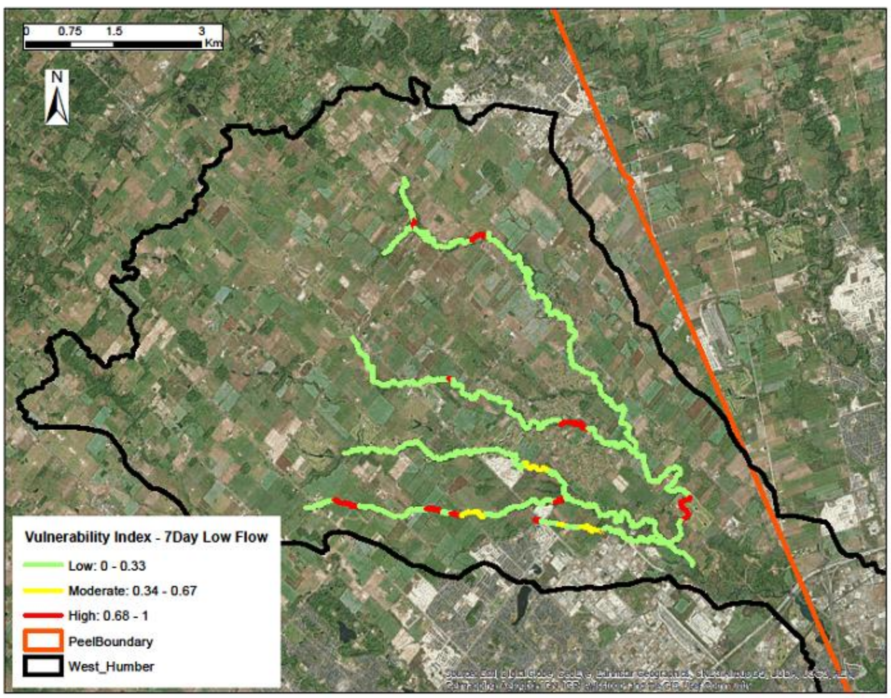


Figure 46: Vulnerability Index Illustrating Where in the West Humber Groundwater Discharge is less Than 30% MAGD Over a 7-day consecutive period

It is evident that some stream segments are highly vulnerable, indicating that they are sensitive to reduced baseflow support under many drought scenarios. However, the majority of segments appear to have stable groundwater discharge under an array of drought scenarios. In particular, the westernmost tributary shown in Figure 46 appears to be the most vulnerable (where less discharge occurs currently), and the main branch (where more discharge occurs currently) is less vulnerable. The upper segments of the Redside Dace reaches that currently become intermittent in the summer season appear to be less vulnerable than initially anticipated. According to literature, future climate change is likely to change the timing of baseflow at the surface and increase its variability in accordance with precipitation events throughout the year (AquaResource Inc. and EBNFLO Environmental 2010; Dove-Thompson *et al*. 2011; Tomalty and Komorowski 2011). Given the sensitivity of the system (i.e. the few segments that are highly vulnerable to low flow conditions of all durations) (30-day and 90-day vulnerability indices were also examined but are beyond the scope of this report), it is important that sufficient tree cover and pervious cover exist within the system to facilitate recharge and thus facilitate increased baseflow to the streams (Green *et al*. 2011; Kumar 2012). It would be prudent to begin increasing riparian corridor along the lower and east branches of the West Humber where Redside Dace are present prior to any additional urbanization upstream.

Hydrologic connectivity is also an important vulnerability factor for wetlands found in the West Humber. Depending on the size of a wetland, its functional type and where it is located in relation to a watercourse the vulnerability will differ. For instance, marshes, which are largely the dominant wetland type in the West Humber, are anticipated to exhibit between low and moderate vulnerability depending on their proximity to a watercourse. For the purposes of analyses conducted in this assessment, marshes within 30m of a watercourse are assumed to have low vulnerability since they have at least two water sources: precipitation and groundwater. Marshes further than 30m from the watercourse are likely not supported by groundwater input and thus are considered moderately vulnerable. Swamps on the other hand (some of which do exist in the upper West Humber), are considered highly vulnerable due to the fact that if drying occurs, swamps may act like a bog and be disconnected hydrologically from their groundwater source (Zedler and Kercher 2005; Environment Canada 2013). Drying or shrinking of wetlands may in fact occur around the edges leaving the middle of the wetlands intact (Desta, Lemma, and Fetene 2012; Ngaio Hotte, Kennedy, and Lantz 2009b). A similar analysis of wetland vulnerability to drying identifies that wetlands in the West Humber are anticipated to almost entirely moderately vulnerable to 2050s climate conditions (Chu 2015). Notably, this analysis did not account for functional type of wetlands and as a result the gradient in wetland vulnerability in the West Humber identified by the TRCA (see Figure 26) adds a level of detail in terms of which wetlands may be more or less vulnerable based on the type of wetland and its water sources.

In the future, it is not anticipated that water taking in the groundwater system will increase significantly in the West Humber since new developments will continue to rely on water from Lake Ontario for their needs. However, the West Humber is currently identified as stressed at the surface due to highly variable flow and baseflow throughout the tributaries, particularly those which support Redside Dace. Based on these current levels of stress at the surface, climate change may pose a risk to groundwater support to aquatic features. Periods of low precipitation may prolong low flow conditions at the surface and lower the groundwater table particularly in the shallow West Humber aquifer system (TRCA 2010a; Tomalty and Komorowski 2011).

Future climate impacts at the surface may be stressed in the West Humber given its very flat slopes and meandering streams which are vulnerable to increased evaporative losses (topography and grade). Soil drainage ratings in the West Humber are almost entirely classified as “imperfectly drained”, which correspond to a moderate vulnerability. This is indicative of the flat, sloping surface features in this area that may experience increased evaporative losses. For example, under a particularly warm and dry summer in the 2050s the upper reaches of the Redside Dace reaches may receive little precipitation and be entirely reliant on baseflow support. In these cases, this baseflow may be more vulnerable to evaporation due to increased levels of sun (radiation) exposure and slow flowing waters (Bolund and Hunhammar 1999; Winter 1999; Schindler 2001; Erwin 2009). This vulnerability can become exacerbated in the absence of sufficient tree canopy to provide shading over Redside Dace reaches in the West Humber. For example, flat meandering streams which contain little tree canopy will experience much higher evaporation directly from the water surface, whereby a more steeply sloped stream water would remain less stagnant and thus flow through areas of shade and be less exposed. Urban forest canopy in the West Humber (analysed south of Mayfield Road and northeast to Bolton) is considered moderate to highly vulnerable implying more heat stress at the surface due to lesser amounts of canopy (see Figures 26 and 27). Further, hotter and drier conditions in the future summer season is likely to stress trees themselves and the composition of which trees remain in the landscape (e.g., seedlings could be most impacted) (Beck *et al*., 2011; Choat *et al*., 2012; Joyce *et al*., 2014; Staudinger *et al*., 2013; Staudinger *et al*., 2012). Depending on the future moisture regime, foliage and leaf-area-indices may become reduced if dry conditions dominate. On the other hand, increasing temperatures may actually extend the leaf-out window and stimulate plant growth, but this will ultimately depend on how climate conditions manifest. Should leaf areas become reduced, this could impact important shade and thermal refuge in Redside Dace reaches in the West Humber (Clean Air Partnership 2007; TRCA *et al*. 2011). On the other hand, trees growing in valley corridors may be less vulnerable to summer drought to some extent because of the shallow underground water supply in this area, and that combined with warmer temperatures may stimulate growth in these areas; the directionality of change will ultimately depend on how the future climate manifests and how specific tree species along valley corridors respond to these changes.

The direct warming of surface waters due to increasing temperatures is also a concern in the West Humber (thermal gradient/regime), particularly in how it influences survival and growth requirements of Redside Dace (community range). The role of atmospheric warming will help to shape the ecology and function of rivers and streams; defining where aquatic communities will be able to find habitat (Dove-Thompson *et al*., 2011; Manomet Center for Conservation Sciences & National Wildlife Federation, 2013; van Vliet *et al*., 2013) and altering the nutrient and contaminant pathways, as well as nutrient and chemical cycles affecting aquatic life (Wisconsin Initiative on Climate Change Impacts 2011). If climatic conditions throughout the summer season yield less precipitation and potentially less groundwater discharge to surface features, surface waters may exhibit decreasing alkalinity (Schindler, 2001) or lower water quality (Eckhardt and Ulbrich 2003; Mishra and Singh 2010) due to inadequate baseflow support and/or thermal heating. Further, under periods of low flow and lesser baseflow support, there may be a further reduction in coldwater summer refuge (Dove-Thompson *et al*. 2011). Increasing temperatures throughout the winter and spring seasons may also advance the spring freshet (Jyrkama and Sykes 2007b; Green *et al*. 2011), which could increase sediment loads to surface waters (Bruce *et al*. 2008; Environment Canada 2013) and alter chloride loading to groundwater due to changes in salt uses on roads throughout winter. If Redside Dace reaches are drying up more frequently under climate change, this poses a large problem for connectivity for this provincially threatened fish species. Stresses to Redside Dace will likely be attributed to increased variability in flows, higher turbidity, and water temperatures warming beyond their optimal range which can cause the fish species to shift northward in search of colder temperatures for spawning (which occurs between 16 to 18°C) (Committee on the Status of Endangered Wildlife in Canada 2007; MNR 2010). Chu (2015) examined future maximum weekly streamwater temperatures in the West Humber, and identifies that they could range from 23 in reaches in the north to 29˚C in the southern branches such as the main West Humber River (see Figure 18) (Chu 2015). Redside Dace have an upper preferred thermal tolerance of 24˚C and a lethal water temperature of 26˚C. This implies that future spikes in water temperatures within the West Humber may significantly stress Redside Dace and may even eliminate them from the subwatershed, depending on the manifestation of climate drivers.

Implications of Future Urban Growth in the West Humber

It is expected that the West Humber will be threatened under future urban growth associated with conventional development. Specifically, modeling using GSFLOW in a separate assessment found targets to maintain natural levels of baseflow would not be met under business as usual growth (TRCA 2008b; TRCA 2008c). In fact, it is likely that reductions to groundwater levels and support to surface features in even under the less extreme, conventional official plan urbanization will affect the availability of surface water for summer in the West Humber. Furthermore, the greatest increase in urbanization in the entire Humber watershed will occur in the West Humber leading to a direct loss of habitat and reductions in quality (TRCA 2008d).

Areas further north contain some of Peel Region’s highest recharge zones associated with permeable limestone bedrock from the Niagara Escarpment, or sand and gravel from the ORM. However, under future urbanization it is predicted that recharge will decrease on average across all of Peel, and be particularly pronounced in the West Humber. This may be buffered to an extent through the widening of the recharge window where natural cover still persists, but not enough to reduce vulnerability from urbanization. For example, cumulative impact of low magnitude decreases in recharge where urbanization occurs is predicted to have some local impacts on baseflow in the West Humber tributaries. In fact, more reaches may become intermittent streams and cease to flow during extended periods of dry weather if future urban growth occurs as business-as-usual. This will reduce ability for species to move and create further impairment (i.e. specifically in the westernmost Redside Dace tributary). For example, across the TRCA’s jurisdiction, regional watershed monitoring found that healthier aquatic sites are typically located in the upper reaches of a watershed, have low levels of urbanization (less than 10% urban cover) and relatively high levels of natural forest (between 12 and 40%) (TRCA 2015b).

Future urban growth has important implications on wetlands as well. If wetlands are lost entirely due to urbanization, downstream flooding of the West Humber could become a significant concern due to inadequate natural areas and wetlands to attenuate waters upstream. This is particularly important for tableland wetlands in the West Humber in the middle reaches scheduled for development under the conventional official plan development.

Implications to Ecosystem Services

Ecosystem services in the West Humber that are likely to be most impacted by climate change include habitat diversity (baseflow support), regulation of erosion, water quality regulation and flood attenuation. For instance, rivers and streams in the West Humber will likely need to adjust both structurally and biologically to the new climate conditions in the 2050s. These changes will alter many of the ecosystem service values provided to society, such as regulation of erosion and water quality regulation.

Depending on how summer conditions manifest in the 2050s, drier conditions may become more frequent and more prolonged (Auld *et al.*, 2015). If future conditions stress wetlands in the West Humber to the point where drying occurs, this could influence a wide range of ecosystem services as well. For instance, the drying of wetlands could significantly reduce water quality regulation in the subwatershed thereby worsening water quality downstream. Similarly, this could implicate habitat support for aquatic species, reduce erosion regulation and reduce the moderation of invasive species in the natural system. Terrestrial species may also be affected if the remaining natural cover in the West Humber is eliminated or reduced, through a reduction in patch size or quality thereby reducing habitat connectivity for movement. On the other hand, if drying occurs, flood attenuation may actually be slightly improved (to an extent) if wetlands are dried to the point where soils can infiltrate and store more water.

Upper Mimico Creek Subwatershed

The Mimico Creek watershed in its entirety covers an area of 77km^2 with 34km of creek. Its headwaters are located in Brampton, and flow through Mississauga in the middle Mimico where it ultimately drains outside of Peel into the City of Toronto before discharging to Lake Ontario. In 2013, land use in the entire Mimico watershed was classified as 96% urban with the remaining 4% urbanizing (TRCA 2013d). Natural areas cover 11% of the entire watershed, 8% of which are meadows, 2% is natural forest and less than 1% is wetlands (TRCA 2013d). The Upper Mimico, which is the subwatershed examined as part of this storyline, stretches from the headwaters of the Mimico just north of Bovaird Drive in Brampton to just south of Derry Road (TRCA 1998) and is approximately 20.5km^2 in area. This municipal focus area will focus on a vulnerability characterization for select terrestrial conditions in the Upper Mimico subwatershed.

Table 23: Components, Vulnerability Factors and Vulnerability Indicators Discussed in the Upper Mimico Creek Subwatershed

Components	**Vulnerability Factors**	**Vulnerability Indicators**
• Natural Forest • Urban Forest	• Tree Canopy • Thermal Gradient • Community Range	• Urban Forest Canopy • Land Surface Temperature • Climate Sensitive Native Vegetation

Current Conditions in the Upper Mimico

As mentioned earlier, the majority of the Upper Mimico has been developed. This urban land use has resulted in higher than average land surface temperatures (thermal gradient) in this subwatershed compared with Peel Region. Land surface temperatures observed through satellite imagery at 10am on August 23, 2009 (a cooler year relative to the climate normal average, Environment Canada, 2015) identified that the almost all 30 hectare catchments in the Upper Mimico reached between 29 and 36˚C by 10am, with only a few other 30ha catchments along the valley corridor of the creek showing temperatures below 29˚C (see Figure 28). This implies that the urban heat island effect in the subwatershed is very high. For comparison, the average *air temperature* collected at 10am on August 23, 2009 at Pearson Airport (which is just southwest of the Upper Mimico is 19.4˚C (Environment Canada, 2015). Land surface temperature observed through satellite imagery collected mid-afternoon on June 18, 2014 (also a cooler year relative to the climate normal average from Environment Canada, 2015) identified almost all catchments reaching above 36˚C by mid-afternoon (see Figure 30). In the raw data, this range can be refined to show that above 36˚C actually means almost all of the Upper Mimico is above 40˚C and may even reaches 50˚C where little canopy and natural cover is present. For context, the average *air temperature* collected in mid-afternoon on June 18, 2014 at Pearson Airport was 24˚C. Comparatively with the rest of Peel Region, the Upper Mimico is among the hottest areas during the morning and afternoon in terms of land surface temperatures, with other regions outside this watershed cooler as a result of natural cover and tree canopy (i.e., in the west along the Credit River is significantly cooler as a result of its valley corridor).

One factor that could theoretically reduce the severity of the land surface temperatures found in the Upper Mimico is the amount of tree canopy in natural areas (natural forest) and in the urban matrix (urban forest). However, only 2% of the Upper Mimico contains natural forest, none of which is deeper interior forest habitat (TRCA 2010a). This implies that these natural forest areas provide very limited thermal regulation. According to the City of Brampton’s urban forest study (TRCA 2011a), existing urban forest canopy covers about 5% of the subwatershed or around 100ha. Across Peel Region as a whole, this represents among the lowest amount of urban forest canopy at the subwatershed scale (TRCA *et al*. 2011). On a more positive note, there is potential space for additional tree canopy to be planted (TRCA, 2011). Specifically, six times (600ha) and seven times (700ha) the amount of current urban forest canopy could be planted over natural areas and urban areas in the Upper Mimico, respectively, to increase its tree canopy substantially and potentially offset the urban heat island effect.

Given the significant development within this subwatershed, little diversity in vegetation communities remains (community range). Climate sensitive native vegetation specifically comprises less than 1% of the Upper Mimico, as determined through GIS analyses in this assessment. Ecosites that do exist as part of this total include swamps (e.g., ash mineral deciduous swamp, mineral thicket swamp), marshes (e.g., mineral meadow marsh), and shallow aquatic ecosites (e.g., submerged shallow aquatic, mixed shallow aquatic). These generally exist in proximity to the branches of the Mimico Creek.

Future Vulnerability in the Upper Mimico

Thermal gradients in both the morning and afternoon in the Upper Mimico exhibit extreme land surface temperatures as a result of the urban heat island effect. From a vulnerability to climate change perspective, the majority of catchments are rated as highly vulnerable in this subwatershed. The high urbanization level combined with low natural cover and tree canopy in natural areas as well as in urban settings compromises the regulation of UHI in the Upper Mimico. Even though some areas of Mimico creek, being a valley corridor, have relatively higher natural cover it is still low (and narrow / disconnected) compared to what is needed to mitigate the overall impact of heavy urban land use around it. Future warming by the 2050s will likely increase the urban heat island effect in Peel Region (thermal gradient) (Auld *et al.*, 2015), thereby making natural systems more vulnerable. Given that the Mimico Creek has very high heat stress and low natural cover both in natural areas as well as urban matrix, the tree canopy is highly vulnerable to drying and heat stress under warmer dryer conditions.

On the other hand, the application of urban forest strategies that seek to increase tree canopy both in natural areas and urban matrix may provide opportunities to mitigate the UHI effect to some extent, if implemented effectively, and if maintained properly under a future climate.

As mentioned earlier, only 1% of areas in the Upper Mimico contain climate sensitive native vegetation. Of the type of ecosites that exist, the majority are rated as moderately vulnerable to changes in hydrology conditions (e.g., the marshes and swamps), with a couple areas of shallow aquatic ecosites being rated as highly vulnerable to shifts in hydrology and fertility. The reality is; however, that this limited extent of native ecosites in general may be further stressed under climate change due to warming temperatures and less moisture availability – particularly in the summer season. It is likely that these ecosites in the Upper Mimico will exhibit the same impacts as diverse and widespread climate sensitive vegetation further north in Peel; but also be further exacerbated by 'edge' effects associated with the urban matrix they are found in. For instance, climate sensitive native vegetation (what remains following historical development) in the Upper Mimico clearly already experience higher land surface temperatures (thermal gradient), reducing moisture and availability, and are more susceptible to the spread of invasive species due to lower diversity of species present and lack of competition in the urban environment (Cregg and Dix 2001).

Implications of Future Urban Growth

Given the extent of historical development that has occurred in this storyline area, it is not anticipated that significant impacts will occur given the remaining small portion still urbanizing. However, there are opportunities for improvement in the Upper Mimico terrestrial ecosystems that were describe here, including potentially improving ecosystem services that are delivered there.

Implications to Ecosystem Services

There are currently few ecosystem services being delivered by terrestrial natural systems in Upper Mimico, with the exception of minimal benefits contained to where natural systems components still exist. For instance, habitat provisioning for biota is likely occurring in what natural cover remains, but for a limited diversity of species. It appears that what natural cover and tree canopy exists throughout the subwatershed is not significantly regulating the urban heat island being exhibited there to date. Finally, water quality regulation and flood attenuation is likely insignificant given the little natural cover and wetlands present to attenuate flows or reduce stormwater inputs to branches of Mimico creek. It is unknown to what extent ecosystem services may be worsened under future climate change in this subwatershed; or if the Upper Mimico is a form of a ‘snapshot’ for what the consequences of climate change and business-as-usual (future) development may cause on ecosystems. Regardless, examining resilience from the regional perspective is vital to ensure that upstream and headwater areas of Peel’s watersheds are conserved and enhanced to avoid larger scale loss of ecosystem function and quality.

Box 7: Ice Storms and The Urban Forest

Why are ice storms a concern?

Ice storms typically occur between December and March when warm air systems collide with cold Arctic air masses to produce a mix of rain, snow and freezing rain. During these storms ice accumulates on trees, increasing branch weight by a factor of 10 to 100 times the normal amount. As a result branches may break or trees may fall – potentially breaking power lines, damaging homes, blocking roads, and creating public safety hazards. Under a changing climate, southern Ontario may see more freezing rain events in winter months as temperatures fluctuate around freezing more often. This means we need to be well prepared for major ice storms that are similar to those experienced in 2013 and 1998.

Why are trees vulnerable to ice storm damage?

The severity of damage caused by ice storms is determined by the amount of accumulated ice, the degree of wind exposure and the duration of the storm. However, the response to these three factors will vary from one tree to the next. Trees that are more susceptible to major damage are those with weak or poorly formed branch junctures, decaying or dead branches, and unbalanced crowns. In most cases, these structural problems can be addressed through regular and proactive pruning by a certified arborist. In particular, pruning young trees will help them to develop a strong form that is more resistant to wind and ice loading.

Deciduous species with wide, open crowns and fine branches are more vulnerable to the effects of ice loading. In Peel Region hackberry, honey locust and Siberian elm are among such vulnerable species. In contrast, many conifer species such as hemlock and spruce are more resistant to damage caused by ice accumulation due to their conical form and narrow crowns. We can reduce the risk of safety hazards and power disruptions by planting trees that are better able to withstand ice storms along busy streets, next to buildings and adjacent to power lines. In addition, planting for greater species diversity is always wise when facing more unpredictable weather conditions. A tree’s root system can also determine its capacity to withstand damage. Tree species that naturally establish shallow roots as well as those with restricted, damaged or unbalanced root systems are more likely to tip over when loaded with heavy ice. Providing space and protection for large, healthy root zones is critical for proactive urban forest management.

What can we do to decrease vulnerability?

We can’t prevent all damage caused by ice storms, but there is much we can do to ensure that a greater number of trees survive and thrive. Regular pruning by qualified tree care professionals creates healthier, more structurally resilient trees that can survive storm events. Pruning early in a tree’s life is essential in this regard. Careful urban forest monitoring will allow us to spot and respond to trees with health problems, thereby reducing the likelihood that they will become hazards during an ice storm. We can cultivate a more resilient urban forest by planting a more diverse mix of trees, and planting the right tree in the right place.

6.2.3. Watercourse Storylines

Upper Main Credit River to Cheltenham

The Credit River originates north of Orangeville and flows into Peel Region through the Upper Zone of the Credit Watershed, which is described as areas above the Niagara Escarpment (CVC 2007a). This storyline in particular focuses on the upper main branch of the Credit River as it flows through two subwatersheds from north to south: (1) Melville to Forks of the Credit and (2) Forks of the Credit to Cheltenham (notably the Credit River receives water from other subwatersheds as well, such as Shaw's Creek). Despite historic and present land use changes, many parts of the Credit River watershed remain in a relatively healthy condition. The beauty of the area is enjoyed by thousands of hikers, tourists and sportsmen throughout the year and many parts of the northern section of the Credit Watershed support self-sustaining coldwater fish populations (CVC 2007a).

The Upper Watershed is generally comprised of till plains, moraines and glacial spillways. The soils in this area have moderate to highly permeable, and are able to permit a significant amount of infiltration to support the regional groundwater system (CVC 2007b). The ground surface topography is undulating, and this region is generally well drained. Baseflow to rivers and streams is maintained predominantly from springs and groundwater discharge, and water quality is generally good (CVC 2007b). Approximately 60% of the upper watershed is heavily forested and 12% of lands are classified as urban. Dominant vegetation associations include deciduous forest and white cedar swamps. The river valley varies from a complex and highly developed system around the upper end of the Escarpment to flat marshy areas in the headwater regions (CVC 2007b). In comparison to areas lower in the watershed, the Upper Credit has relatively higher amounts of pervious cover, forest cover, wetland cover, sufficient connectivity in many places and a higher species diversity (CVC 2013b).

However, a number of localized and characterized issues have triggered the identification of this storyline. In Shaw's Creek subwatershed where water flows into the Credit River from, these concerns include the presence of aggregate extraction in the area (and the potential for more), increasing development pressures, thermal gradient issues in the watercourses associated with online ponds upstream, and water chemistry issues as a result of this area being one of the most active agriculture areas in the Credit River watershed (CVC 2006). Downstream in Melville to Forks of the Credit subwatershed, similar concerns exist such as increasing development pressures including extraction activities and related land uses of existing pits as well as expansion of licensed areas (CVC 1998). Brook trout populations are also notable within the Upper Credit and their community range may be of concern based on current conditions worsening under climate change (i.e., in the absence of interventions).

Table 19 illustrates the components, vulnerability factors and vulnerability indicators that have been flagged for potential issues arising in this focal area. Additional discussion surrounding non climatic stressors (i.e. aggregate extraction) is provided in section 6.1.2.

Table 24: Components, Vulnerability Factors and Vulnerability Indicators Discussed in the Upper Main Credit River to Cheltenham

Components	Vulnerability Factors	Vulnerability Indicators
• Rivers, Streams and Valley Corridors	• Thermal Gradient • Water Chemistry • Community Range	• Water Temperature • Total Phosphorus • Brook Trout Tolerances
• Groundwater	• Aquifer Maintenance • Area-to-Depth Ratio	• Recharge • Aquifer Depth

Current Conditions in the Upper Main Credit River to Cheltenham

While detailed information on aquifer depth and groundwater flowpaths are unavailable in this storyline area, existing subwatershed studies characterize relevant hydrogeological conditions that have been described in portions of it. In Shaw's creek subwatershed, there are three bedrock formations that subcrop beneath the subwatershed (from deepest to shallowest): the Manitoulin, Amabel, and Guelph Formations (CVC 2006; CVC 2012c). The first underlies northwestern Peel and is described as a grey, dense weathered limestone and dolostone unit that exists only underneath the Town of Alton. The second overlies the Manitoulin Formation and is the uppermost bedrock unit beneath the eastern two-thirds of the Shaws Creek subwatershed. It is described as a grey crystalline dolostone capable of yielding large quantities of groundwater due to secondary porosity features such as fractures and dissolution cavities. It is considered a very significant local and regional aquifer. Finally, the third formation overlies both the Manitoulin and Amabel Formations and is described as a cream to brown crystalline dolostone, which is also capable of yielding large quantities of groundwater in some areas due to secondary porosity features such as fractures and cavities. As you travel downstream of Shaw's Creek into Melville to Forks of the Credit, bedrock in this area continues as the Amabel Formation, which is described as a significant aquifer unit in Southern Ontario (CVC 1998). Further south into the Forks of the Credit to Cheltenham subwatershed, information on detailed groundwater and hydrogeological conditions is not yet available.

Groundwater flow beneath Shaw's Creek is generally from the north and west to the east and southeast as it flows through bedrock aquifers like the Guelph and Amabel formations (CVC 2006). Overburden groundwater flows also appear to follow surface topography where the highest groundwater elevations coincide with coarse-grained deposits of the Orangeville Moraine. For instance, the highest groundwater elevation of around 470 masl is found where the surface elevation is approximately 490 masl (CVC 2006; CVC 2012c). From these areas of topographic high, localized groundwater flows away from these areas following the topographical slope. In Melville to Forks of the Credit, groundwater flows radiate from a 'groundwater high' area located in a till unit just east of the subwatershed in Caledon Creek. Groundwater originating from this area provides baseflow to Caledon Creek, the Credit River and in fact to the Humber River in TRCA's jurisdiction as well (TRCA 1998). Thus, interactions and impacts that occur in the upper Credit could be linked to those occurring in the Humber River through recharge-discharge processes.

At the subwatershed-scale, areas of high topographic relief and high permeability deposits (i.e., sand and gravel) are associated with high rates of recharge (and aquifer maintenance) (e.g., in Shaw's Creek: >250 mm/yr), while lower permeability deposits (i.e., silt tills) are associated with lower recharge rates (e.g., in Shaw's Creek: <150 mm/yr). Where the Orangeville Moraine and glaciofluvial outwash sediments exist (see CVC, 2006 for mapping), significant recharge areas are expected due to the broad spatial distribution of high permeability soils and flat to hummocky topography ('dead-end storage'). Downstream in Melville to Forks of the Credit, groundwater is similarly recharged across much of the northern portion of the subwatershed as evidenced by the highest water table elevations in this area (CVC, 1998). Groundwater is recharged by the extensive ponds and wetlands found within the topographic high where geological a moderately permeable till is present and forms part of the Singhampton Moraine (CVC, 1998).

The headwaters of the Credit, although a coldwater ecosystem (thermal gradient) are influenced by the South Dam associated with the Island Lake (reservoir); although just north of Peel, it is close enough to influence temperatures and baseflows in the main Upper Credit as it flows through north Caledon. Based on the fish communities and thermal targets, all monitored streams in the Upper Watershed are managed as coldwater systems. Coldwater systems contain fish which are impacted (e.g. thermal stress) when water temperatures generally rise above 20°C (CVC, 2013a; MNR and CVC, 2002). The Upper East portion of the Credit (in Caledon) has been noted to be above absolute max summer temperature targets for the river system; exceeding average daily max summer temperature target (CVC, 2013a). This condition places stress on the fish communities and aquatic ecosystems found here. According to monitoring stations information (see Figure 15 – Current Max Weekly Stream Temperature), 6 monitoring stations exceed the summer thermal targets in this portion of the Credit. Recent thermal aquatic habitat modelling by Chu (2015) suggests temperatures spike between 18-21˚C.

There are three water quality monitoring stations that exist in the Upper Credit (Credit River at Hwy10 north, Hwy 10 South and at Melville); that can be drawn upon to determine the levels of total phosphorus concentrations in the river (CVC, 2012b). Of the samples collected, 31% exceeded PWQO guidelines for this parameter. The Upper Credit is described has having exceedances "much" higher than main credit – tied to high agricultural land use in these subwatersheds. As mentioned earlier, since the construction of the Island Lake Reservoir to augment low flows and the Orangeville Wastewater Treatment Plant that artificially augments total flows north of Peel Region, low water conditions have been rare in the Credit River (CVC 2012b). While there can be ecological impacts from low water conditions such as reducing available aquatic habitat for species, potentially raising stream temperatures, and affecting overall water chemistry in the water column; total low flow issues is not expected to be a concern in Peel Region. There has only been one formal level 1 low water condition in 2012, and this pertained to voluntary water use reductions of 10% by residents and not ecological impacts (CVC, 2013a). Notably, the sensitivity of the river and these conditions may change over time in response to changing climate.

As a result of some of the current conditions listed above, the loss of Brook Trout species has been cited as a concern in upper Credit watershed. Notably, Brook Trout do not occupy the river from just downstream of the Forks of the Credit to Cheltenham where Brown Trout and Atlantic Salmon are dominant. Where Brook trout are found; however, are a sensitive coldwater species that generally need water temperature below 20°C to survive. Generally, in hot summers (e.g. 2011) the majority of stations within the main credit exceed both targets for Brook Trout. The Upper East Credit has similar temperature issues as well (CVC, 2002; CVC, 2013a). Based on 24 monitoring sites with sampling from 2011; 2004-2012 available fisheries scoring (Index of Biotic Integrity (IBI)) in the Upper Credit has been rated as fair (but declining) (CVC, 2013a), which suggests aquatic habitat conditions are currently stressed, and thereby likely limiting some of the aquatic communities overall range (community range) in this portion of the watershed under certain climate/weather conditions. The current level of baseflow support appears to be potentially buffering Brook Trout populations by helping to reduce stream water temperatures and their overall temperature variability. This baseflow condition might offer some future resilience for aquatic ecosystems found here, as stream temperatures are projected to increase in response to rising air temperature. However, in addition to Brook Trout there are other cold and cool water species that will be similarly affected as environmental conditions change over time.

Future Vulnerability in the Upper Main Credit River to Cheltenham

The degree to which the groundwater system may be disrupted to climate change depends on the level of aquifer maintenance that exists into the future. Based on modeled recharge across the Credit watershed, this storyline area from Shaw's Creek subwatershed to Forks of the Credit to Cheltenham contains some of the highest areas of recharge in Peel (i.e., in the upper third of recharge rates or >333 mm/yr). These significant recharge rates are particularly located in Shaw's Creek and Melville to Forks of the Credit. High recharge rates in these subwatersheds not only implies that the underlying groundwater system may be less vulnerable into the future due to increase water supply or maintenance into aquifers but also is likely regionally significant for the entire regional aquifer system, given the urban and urbanizing land uses further south in Peel. Evidence to this effect is that as you travel downstream in the Credit River into the Forks of the Credit to Cheltenham Subwatershed, recharge becomes less significant and in fact rated moderately vulnerable based on the GIS analyses completed in this assessment. Furthermore, some areas are highly vulnerable in the southwest of this subwatershed and further southwest in the Cheltenham to Glen Williams subwatershed (just north of the Etobicoke Headwaters). In general, as you traverse from north to south in this storyline area, aquifer maintenance becomes increasingly restricted as a result of a number of factors: physiography, soil type, topography and grade, and current land use. It is likely that a higher degree of resilience exists in the northern areas of the Credit (Shaw's Creek and Melville to Forks of the Credit) particularly as a result of the amount of low vulnerability areas that exist, and where increasingly pervious cover maintains and recharges the regional aquifer systems more sufficiently.

The recharge rates exhibited throughout this storyline (see Figures 12A and 12B) (aquifer maintenance) may also shift due to changes in the timing, distribution and frequency of future precipitation (Allen *et al*. 2004). Numerous studies cite that changing precipitation, particularly how much falls in the spring time during the freshet and how much is available at the surface throughout the summer, could change aquifer recharge rates; although there is little agreement as to whether it will increase or decrease recharge since it likely requires scenario modeling exercises to determine the influence of local conditions (i.e. (Eckhardt and Ulbrich 2003; Allen *et al*. 2004; Doll 2009; AquaResource Inc. and EBNFLO Environmental 2010; Mishra and Singh 2010; Green *et al*. 2011). Changes in recharge in general; however, may be the result of flashy recharge periods associated with extreme rainfall events (Jyrkama and Sykes 2007b) or extended dry periods with warmer temperatures and inadequate precipitation. The recharge window may widen thereby enhancing infiltration and aquifer maintenance, if significant recharge areas are protected. Specifically, for instance, in Shaw's Creek, where interbedded high and low permeability deposits exist, this could cause horizontal groundwater flow, which could increase discharge to surface water features in these areas. Should the recharge window widen, and pervious cover is maintained, some surface water features may receive additional baseflow support.

As mentioned earlier, the extent to which changes in recharge will ultimately impact the groundwater system depends on soils present in the area, the underlying aquifer depths, and a number of other factors. In general, shallow groundwater systems are understood to be more vulnerable to climate change (Bovolo, Parkin, and Sophocleous 2009; Dove-Thompson *et al.* 2011; Green *et al*. 2011). This is because shallow systems (or those with a depth of up to 15m below the surface) typically have shorter flow paths from where groundwater is infiltrated into soils and where it is ultimately discharged at the surface and thus may be subject to poorer water quality inputs due to warming, more sediment mobilization or increased salt use. In the case of this storyline, comprehensive flowpath modeling was unavailable to make an inference on the level of vulnerability based on aquifer depth.

According to the available monitoring stations (see Figure 15 – Current Max Weekly Stream Temperature), there are already a number of stations exceeding summer thermal targets (thermal gradient). This is likely to increase with higher summer temperatures and with higher intensity shorter duration storm events in the summer. Future MWAT modeling by Chu (2015) suggests temperatures could spike in the 2050s under business as usual to 26 and 27˚C (well above the coldwater threshold) and thereby dramatically reducing species ranges or potentially eliminating species from portions of the watershed altogether. Fish requiring coldwater will suffer from a reduction in suitable available habitat and an increase in stress (Poff *et al*. 2002; Browne and Hunt 2007). Generally climate change is likely to warm existing water temperatures further (Chu, 2015)

Depending on the extent of water temperature warming and duration, other interrelated aquatic environmental factors may also begin to change, such as water chemistry parameters (e.g., changes in nutrient loadings to the Credit). Oxygen concentrations for example may also decline in these warmed waters, further degrading aquatic habitat during the stressful summer months (Poff *et al*. 2002). Should warmer temperatures increase to the point of causing coldwater streams to shift to mixed/coolwater streams, this could cause an influx of coolwater fish species and the possibility of exotic species expanding their ranges northward and altering angling opportunities (Dove and Lewis, n.d.). In the Credit River, coolwater species already share habitat with non-native salmonids below the Niagara Escarpment and these shifts would essentially continue coolwater species being unable to access the watercourse upstream. Should thermal impacts be mitigated through existing opportunities such as the removal or upgrading of on-line and stormwater management ponds, there is potential for retaining more coolwater habitat in the near future, though climate change independently may cause warming of waters by the 2050s in these headwater areas.

It is uncertain if total phosphorus concentrations in the Upper Credit will continue to trend downwards (as is the case currently), or if warming of temperatures, nutrient inputs from urban expansion, agriculture and thermal gradients may worsen conditions. Proposed and ongoing expansion of wastewater treatment plans and septic systems that drain into the Upper Credit from the Village of Erin, Town of Alton and Town of Orangeville may contribute to nutrient loading in the future. The changing nature of precipitation over the seasons may affect how total phosphorous responds in the watercourses. There are also other factors at play such as atmospheric deposition of nutrients and other nutrients and/or metals etc.

Long term increases in temperature may also alter other aquatic parameter such as the pH and dissolved oxygen available for aquatic species and communities (Allerton 2010; Great Lakes Information Management & Delivery System 2014) which in some cases can exert a controlling influence on aquatic ecosystems. However, stream warming that affects chemistry can also be affected by changing landscape conditions, where warmer surface runoff inputs from future development (in this case – particularly to the north and outside of Peel) may compound impacts of climate change, further stressing cold and cool water aquatic ecosystems found here. Whereas atmospheric warming tends to be a slow controlling variable, the surface water runoff tends to be more stochastic in nature, and also adds potentially habitat degrading constituents directly to the water column from the overland flow. As such, water quality may become degraded by higher temperatures, water quality changes made worse or better by changes in water flow volume changes such as baseflow contributions as well as more frequent extreme rainfall events (Gitay *et al.,* 2011).

There is a risk of losing overall Brook Trout community range and potentially portions of the population due to thermal warming of watercourses in the future – particularly if there are thermal regime shifts and/or stochastic events. Areas that are more likely to be resilient are those that are supplied heavily by groundwater discharge, and from deeper groundwater sources. The steady supply of ground water and at a relatively consistent temperature will help these systems withstand stress from both high summer temperatures, and increasingly dynamic temperatures. In addition to summer heat extremes, thought needs to be given to the changing dynamics of winter climate as well, and milder winters with a smaller or no snowpack (Campbell *et. al.,* 2014). These changing winter conditions are changing nutrient discharges to watercourses and altering flow regimes like the spring freshet. These environmental changes can be problematic for many cool and cold-water species like Brook Trout, but advantageous to changes in the community range of warmwater species and to new non-native and/or invasive species (Dove-Thompson *et. al.* 2011). Warming overall has been more significant in winter and in spring and (Dove-Thompson *et. al.* 2011) as these are critical ecological timeframes for many cool and coldwater species. This should be an area of focused study if there is a desire to minimize the effect on the overall aquatic community composition and recreational fishing opportunities.

Implications to Ecosystem Services

It is estimated that ecosystem services currently being delivered in this upper area of the Upper Credit River are of high integrity, and are vital for the surrounding and lower watersheds where urban growth has occurred and is occurring. The amount of pervious cover in the Upper Credit and relatively good ecological function implies that higher species diversity is being supported on average across Peel thereby providing areas of recreational activity and ecological health for well-being for humans. Furthermore, these areas as a whole are likely provided an important and valuable buffer against extreme events, such as extreme precipitation, and maintaining the regional aquifer system implying that water supply needs (potable and non-potable) are met. Therefore, they assist in bolstering the resilience of the natural system as a whole in the Upper and lower regions of the watersheds throughout Peel Region.

Box 8: Where Have All The Brook Trout Gone?

Rivers and Brook Trout are born in the same locations: the headwaters of our Watersheds, and they are ecologically linked (Meyer *et al*. 2003). Groundwater enters the river system as cold stable flow, giving rise to specialist species, like Brook Trout, so well adapted to these unique habitats. Brook Trout are viewed by some outdoor enthusiasts as an iconic coldwater gamefish, while others view them as an important symbol of river health, representing the integrity of the watershed ecosystem. Brook Trout in particular are sensitive to a changing climate, and exhibit physical stress to even small increases in summer maximum temperatures (Trumbo *et al*. 2014). Brook Trout already live at the upper edge of our urban aquatic ecosystems; where will they go if their home streams warm further? As the ecosystem responds to climate change, in particular increasing air temperatures, and warmer surface and shallow groundwater temperatures,

coldwater species like Brook Trout will have to retreat north, finding colder places to live or hunker down in any remaining deep, cold pools; but being in the headwaters they can only go so far. Historically, populations and fish biomass have declined in the Credit watershed for instance, with the longer stretches of remaining habitat found in Black Creek, upstream of Stewarttown and in the West Credit, Erin to Belfountain (CVC, 2012c).

The more the air, and subsequently water temperature rises, the more stress they feel, and the more their populations will be affected (Chadwick *et al*., 2015). Dams that exist along watercourses are a barrier and impact brook trout, thereby reducing their ability to find refuge under climate change. Future magnitude and frequency of extreme weather events, including drought and extreme heat days, and landscape changes will largely dictate how long Brook Trout will be able persist in Peel Region, and where we might find them. Thankfully, some viable populations of Brook Trout still exist in and around Peel Region and have managed to survive previous impacts and population bottlenecks. In a future climate, local subpopulations could be considered to naturally reconnect restored areas and expand the species' range. Traditional protection and restoration methods will increase their overall resilience, but additional methods may be required under a changing climate to help Brook Trout persist. Continuing to expand Conservation Authority efforts such as dam mitigation and removal, buffer plantings and groundwater protection to improve thermal regimes and reconnect populations. A focus should be specifically be on maintaining and enhancing areas of recharge to facilitate groundwater connections to the headwaters of our watersheds.

Centreville Creek

Centreville Creek is a headwater tributary system of the Humber River (Figure 11 Peel storyline mapping). The creek flows from the Niagara Escarpment and ORM, through the rural service area of Caledon East, and into the main Humber River at Albion Hills Conservation Area (TRCA, 2008c). In comparison to southern, urban portions of Peel Region, this system contains high concentrations of natural components such as large forested areas, one of the highest concentrations of wetlands in the TRCA jurisdiction and coldwater stream habitat (TRCA, 2008a; TRCA, 2008c; TRCA, 2015a). While most of the lands in the Centreville Creek subwatershed are rural and/or protected by the *Niagara Escarpment Plan,* 1994; *Oak Ridges Moraine Conservation Plan*, 2002; and *Greenbelt Plan*, 2005, all these plans, the provincial Growth Plan amendments are now in effect and the expansion of urban settlements in Caledon East is already in progress. To support the latter, the eventual expansion of municipal water supply infrastructure was identified (TRCA, 2008c) but events in very recent years - unrelated to providing more water to new residents - accelerated the need to drill another, deeper groundwater supply well.

The selection of Centreville Creek as a focal area of more detailed discussion was based on available groundwater and surface water monitoring data that strongly suggests changes to seasonal stream discharge and thermal habitat are occurring (linked to high demand-period for water supply) and water quality impairment (phosphorus) is broadly experienced. The story is of further climate interest given the presence of deep and shallow aquifer systems and fisheries management objectives to maintain the population of native Brook Trout at its current range or greater. Climate projections of hotter summers with extended dry periods, coupled with higher evaporation rates, are relevant to understanding how vulnerability factors in Centreville Creek (see Table 25) may increase the system's future vulnerability to climate change.

Table 25: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Centreville Creek

Component	**Vulnerability Factors**	**Vulnerability Indicators**
Rivers, Streams and Valley Corridors	• Water Supply • Thermal Gradient • Water Chemistry • Community Range	• Water Temperature • Groundwater Levels • Total Phosphorus

Current Conditions in Centreville Creek

Centreville Creek subwatershed is characterized by the ORM Aquifer Complex, which is a mix of confined and semi-confined aquifers, and shallow in comparison to the underlying regional systems (Thorncliffe and Scarborough) (TRCA, 2008a; TRCA, 2010a). This subwatershed is also described as having High Vulnerable Aquifers and Significant Groundwater Recharge Areas which reflects the presence of many shallow aquifers that are naturally vulnerable (TRCA, 2015a). Not surprisingly, a large portion of the water supply to Centreville Creek and its tributaries is groundwater discharge from these ORM deposits as measured by a relatively high Base Flow Index (BFI) of 0.72 (TRCA, 2008a; TRCA, 2015a). BFI equals the ratio of baseflow to total flow and is a measure of coldwater habitat.

The coldwater fish species Brook Trout and Atlantic Salmon (the latter is part of a reintroduction program) are both managed as target fish species in the Centreville Creek system. Based on known sampling activity, Brook Trout are collected in good abundance in the upper most tributaries (e.g. Boyce's Creek) around Caledon East but not in the furthest downstream reaches that flow through Albion Hills Conservation Area (TRCA 2015b). The main branch of Centreville Creek, flowing through Caledon East, is not characterized as a strong trout spawning stream (too much sediment, low grade) but is used as nursery and adult trout habitat (TRCA 2015f). Although there are no fish collection records for much of the main branch that flows down through Innis Lake (and other on-line ponds) but it is assumed that adult Brook Trout move more or less through the network of tributaries, occupying the most suitable reaches.

In addition to groundwater providing high quality fish habitat, it is also extracted for municipal supply to support the growing community of Caledon East. Other significant groundwater users on the area include golf courses and aggregate extraction operations (TRCA 2008a). The Caledon East municipal water supply was originally provided by 3 wells (since the early 2000s), one drawing from the deeper Thorncliffe (CE4) and 2 from the more shallow ORM aquifer complex (CE2 and CE3) (TRCA 2015a). During 2014 – 2015, it was decided by the Region of Peel, for reasons other than immediate water supply requirements, that wells CE2 and CE3 would be decommissioned once the drilling and testing of a deeper well (CE4b) was completed; this deeper well would come on-line to service the existing and, to a large extent, future development. The CE4b well is now completed but the exact status of its operations and services are not confirmed.

Implications of municipal supply water taking to the natural system, including to the resident Brook Trout community, are determined through the Natural Heritage Monitoring Program (NHMP), which is a collaborative effort between the Region of Peel and TRCA. The NHMP has been implemented annually since 2007 but monitoring the potential effects of increased water taking has been confounded by significant sediment deposition into the creek (since 2012 and occurring, periodically, into 2015) spatially coincident with NHMP monitoring sites. However, monitoring prior to sediment issues (2007 - 2011) had already started to identify an increase in the frequency of stream temperatures spikes above the one day lethal threshold for Brook Trout (24°C) in both Centreville Creek and Boyce's Creek (tributary to Centreville Creek) (TRCA, 2015e).

Findings from the most recent NHMP report (2014 monitoring year) raised the following issues: measured aquatic habitat changes and aquatic community responses are indicative of impacts at the ecosystem level (i.e., dominance of larger adult Brook Trout but overall decreased abundance and distribution of fish community; decreased young-of-the-year Brook Trout abundance, and shifts in spawning activity). The 2014 NHMP report further stated that groundwater pumping rates have continued to increase beyond 2010 rates, when no temperature spikes were recorded, but more detailed analysis of surface water flow and groundwater levels and annual climate variation (hot-dry vs cool-wet years) are required to better understand what role water taking may be having on coldwater stream habitat in the summer when water demand is highest and thermal stress to the resident fish community is of most concern (TRCA, 2015e). Note that reporting 2010 pumping rates as not having impact on stream temperature is generally consistent with the Source Water Protection 2010 Tier 1 Water

Budget Assessment that identified Centreville Creek subwatershed as ‘low stress’ for both surface and groundwater supply and demand (TRCA, 2015a).

It should also be noted that the periodic sediment release very likely impacted Brook Trout spawning habitat and, to an extent, survival/growth of young fish. Monitoring of the fish community is part of the NHMP and specific sampling of young-of-the-year confirmed only low and declining numbers of Brook Trout survived sediment releases which threatened egg survival (over winter) and hatching (in early spring). The sedimentation issue has largely been resolved (2015) and stream recovery is expected from a physical habitat perspective given sufficient time. Using the available data sets, it is not possible to quantify the relative roles of sediment release versus changes in summer water temperature and/or flow on the observed changes in Brook Trout community between the years 2012 – 2015.

For this assessment, TRCA regional monitoring data at 3 stations (HU032, HU031, HU033) in 2013 (similar annual climate conditions to 2011 for comparison to CVC monitoring data) were analyzed to determine if summer maximum stream temperatures exceeded the thermal target set for absolute summer maximum of coldwater streams of 26°C (see Table 13, Section 6.1.2). The stations are located in sequence along Centreville Creek starting upstream after the confluence with Boyce’s Creek in Caledon East (HU032), further downstream at the Gore Road crossing (HU031) and furthest downstream within Albion Hills Conservation Area (HU033) just before Centreville Creek joins the Main Humber River. Results from this analysis indicated 2 out of the 3 stations exceeded the summer maximum target of 26°C with temperatures reaching 27.7°C and 29.5°C at stations HU031 and HU033, respectively. As noted in Section 6.1.2 of this report, monitoring station HU033 recorded chronic stream temperatures unsuitable for adult Brook Trout occupation and the sampling record confirms no Brook Trout are collected at this station. There is an on-line pond located upstream of HU033 (called the “Albion Hills Dam”) which is identified in the Humber River Fisheries Management Plan (MNR and TRCA, 2005) as the likely cause for elevated downstream temperatures. In the fall of 2016, TRCA will be removing the dam structure below this pond and restoring the original watercourse channel, complete with riparian wetlands. It is anticipated that the removal of the dam and associated pond, summer stream temperatures will cool down and fish, including Brook Trout, will have improved connectivity between more suitable coldwater habitat upstream in Centrevillle Creek and within the Main Humber River (and tributaries).

Surface water quality in Centreville Creek is flagged for historical and current impairment, particularly for total phosphorus (TP). There is some evidence to suggest elevated TP concentrations are coupled with rain events that produce overland runoff, which would not be surprising as the dominant land use in the subwatershed is agriculture (TRCA 2008a). For example, prior to 2008, exceedances of the PWQO for total phosphorus (TP, 0.03 mg/L) at station 83104 were reported 50% of the time in 2002 (0.04 mg/L median; 0.06 mg/L max) (TRCA 2008a); water quality data collected at this same station from 2009 – 2013 showed the median TP concentration met the PWQO and the 75th percentile of samples measured similar exceedances as in the past (0.04 mg/L; 0.05 mg/L max); TP at this station did NOT exceed PWQO in 2013, which was a drier year than normal.

Other water quality issues point to high levels of manure and metals (such as lead) (TRCA 2008a). Nitrogen compounds in groundwater, based on PGMN well monitoring data for the Centreville Creek subwatershed, are generally less than 1 mg/L, clearly below the ODWQS of 10 mg/L.

The connections to water quality and wetlands improving nutrient issues (through assimilation and uptake) maybe an important one for this system, but no data are available to understand this relationship. Similarly, the extent to which the presence of abundant wetland complexes may be contributing to flood water attenuation and providing benefit to downstream communities is not currently known.

Future Vulnerabilities in Centrevillle Creek

Future vulnerabilities are expected to revolve around exacerbated stream temperature, less flow and stream connectivity and water quality impacts. Stream temperature modelling predicts many reaches within Centreville Creek to have summer maximum weekly average stream temperatures above the Brook Trout tolerance threshold of 24°C, increasing dependence on thermal refuge habitat that maybe more limited (e.g. deep pools or high discharge areas with sufficient flow). If the increases to evaporation rates and/or potential disruption in groundwater discharge from shallow, unconfined aquifers are significant enough, new summer low flows may prevent fish movement into areas of more suitable thermal habitat, including temporary refugia. Additionally, there are large swaths of highly vulnerable climate sensitive vegetation across this subwatershed (see Figure 31); the shade and specific infiltration properties associated with the current vegetation may decline or somehow shift under the hotter and seasonally drier climate scenario, further impacting thermal and/or stream flow conditions.

Issues of water quality, particularly pertaining to TP concentrations may also become exacerbated by warmer water, less stream flow and increased loadings due to more severe rain events. The potential for intense and more frequent algal blooms presents itself, which can ultimately cause fish kills (due to anoxic conditions in ponds), destabilization of the aquatic food web and aesthetic impacts within streams that flow through populated areas like Caledon East and recreational venues like Albion Hills Conservation Area.

Implications of Future Growth in Centreville Creek

The municipal water supply needed to support the urban expansion for Caledon East has not been flagged as vulnerable (TRCA 2015a) given water taking is from deep, aquifers. However, it is unclear if seasonally high water demands (i.e., summer) will increase to a level such that measured stream response is conclusive with respect to causing (temporary) decrease in surface stream flow and elevated stream temperature; also the full implications of tapping the deeper CE4b well is not yet realized and it may indeed provide sufficient buffer for surface features needing groundwater to support habitat.

Implications to Ecosystem Services

The greatest known implications are to the services that support important and valued coldwater fish habitat and regional species diversity. Implications to surface land temperature regulation in high quality natural areas (i.e. via shading); water cycle regulation (i.e., infiltration, flood attenuation) and water quality (nutrient uptake) are all unknown at this time.

Spring Creek

Spring Creek is found in the Etobicoke watershed and joins the main creek approximately 13.5km upstream from Lake Ontario and has its source within the Heart Lake complex of wetlands near Mayfield Road and Heart Lake Road in Brampton (TRCA, 2010a). The subwatershed that drains into Spring Creek is approximately 46.6km^2, 48.2% of which is considered impervious, 14.3% is covered by trees, 36.6% is grass and shrub and 3.2% is bare soil. Tree cover in the subwatershed consists of mostly urban forest canopy, with little natural forest patches remaining. Across the entire Etobicoke watershed, less than 5% of natural forest cover remains, due to historical development, with the highest amounts found in the headwaters and south to Heart Lake Conservation Area where some sensitive bird and plant species still exist (TRCA, 2013b). Spring Creek itself can be considered extensively channelized and hardened with only species that have adapted to more urban conditions found in the valley corridor and surrounding areas.

Table 26 illustrates the components, vulnerability factors and vulnerability indicators that have been flagged for potential issues arising in this focal area.

Table 26: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Spring Creek

Components	Vulnerability Factors	Vulnerability Indicators
Rivers, Streams &Valley Corridors	• Pervious Cover • Flow Variation • Thermal Gradient • Community Range	• Natural Cover • Baseflow • Water Temperature

Current Conditions in Spring Creek

In-stream ecology in the urban stream context that Spring Creek is in refers to the quantity and quality of fish habitat, and fish community distribution. Spring Creek is located in a highly urban area, where stream channel erosion, scour and flooding are major issues (TRCA, 2010a). Historical urbanization in the 1960s and 1970s (TRCA, 2015d) has resulted in a phenomenon commonly known as the “urban stream syndrome,” whereby hydrographs become flashier (i.e., increased flow variability), water quality is degraded, channels are homogenized and incised, and biological richness declines (Hughes *et al.,* 2014). In-stream ecological impairment has been shown when percent impervious cover of a watershed exceeds 10-15% (Carlson *et al*., 2004; Baron *et al*., 2003), which is the case in Spring Creek where impervious cover is almost

50%, although the actual threshold for impairment will depend on how much impervious area is connected to drains (i.e., effective imperviousness) rather than drains to pervious land features (Walsh *et al*., 2005).

As a result of the historical urbanization that has occurred (reduction in pervious cover), flow variation has been altered, and causing fluvial-geomorphic processes to have been disrupted (e.g., channel erosion). Furthermore, the channel has been incised in many reaches and is currently in a transitional geomorphic state, which is not stable, and is disconnected from its natural floodplain. These high levels of alteration have impacted ecological quality and function in Spring Creek. Fish and benthic community studies have indicated that Spring Creek shows signs of fair to poor habitat quality (TRCA, 2006a). Fish species that have been collected in Spring Creek through monitoring are dominantly non-jumping species such as brown bullhead, golden shiner, central mudminnow, blacknose dace, and green sunfish (among others) (TRCA, 2010). The Etobicoke Creek in-stream barrier assessment confirmed the presence of 152 instream structures along Spring Creek, 59 of which are barriers to non-jumping fish passage and of those 36 also prevent the movement of jumping fish species (TRCA, 2010a). Weirs are the dominant structure restricting passage along Spring Creek, followed by road crossings, damaged infrastructure and a dam.

The dominant fish community through Spring Creek is comprised of cool to warm water tolerant species that can occupy many different types of habitat (i.e., they are generalists) (TRCA, 2010a). Based on monitoring stations in the subwatershed, thermal stability is considered extremely unstable (TRCA, 2006a), meaning streamwater temperatures are highly variable and spike frequently based on extreme rainfall events. Based on modeling conducted by Chu (2016), maximum weekly streamwater temperatures range between 20˚C and 22˚C in Spring Creek. The fisheries community in Spring Creek exhibits very limited species diversity, an indication of poor ecological integrity, as well as low Index of Biotic Integrity (IBI) scoring (TRCA, 2006a). Spring Creek used to support both redside dace and slimy sculpin. While both density and diversity of invertebrates found within the subwatershed are relatively low, this can be considered typical of urbanized streams.

Baseflow support to Spring Creek from groundwater may assist in cooling water temperatures and creating habitat for fish, but can also exacerbate flood events if the contribution of baseflow in the creek increases. The Brampton Esker feature in Spring Creek has been deemed an important source of groundwater inputs with local contributions to baseflow from Esker Lakes and stormwater management ponds (former aggregate pit operations) located within the Esker feature (TRCA, 2010a). Future groundwater contributions in this area are expected to increase (TRCA, 2010a) further highlighting the need for re-naturalization to re-connect reaches to their natural floodplains. However that level of connection may not be possible in the more urban areas of Spring Creek as adjacent lands consist of private properties and public parks. The in-stream ecological integrity of the watercourse stands to gain significant quality under the opportunity of re-naturalizing reaches of Spring Creek as well.

Future Vulnerability in Spring Creek

Urban streams with low pervious cover, like Spring Creek, face additional challenges in the future because they are already stressed. Wetter conditions in general, and extreme precipitation events, will degrade such streams where a higher percentage of land is impervious. Stormwater inputs, under flashier conditions and entering Spring Creek faster as a result of the low pervious cover in the subwatershed are likely to cause higher water conditions as a result of extreme precipitation events. Climate change is anticipated to cause flashier urban streams, as extreme events become more frequent and more extreme rainfall events (Paul and Meyer, 2001; Konrad and Booth, 2005). This flashiness is driven by the higher amount of impervious surface in the subwatershed. Instead of water infiltrating into soils (which are driven by topography and grade in a natural system) and recharging the hydrologic system, the water moves quickly off of impervious surfaces and is delivered into rivers and streams where they may exceed the tributary's conveyance capacity. Spring Creek is not anticipated to become more developed (or urbanized) than its current conditions; however, increasing climate variability may drive flow variation that may lead to further degradation of the natural systems (e.g., erosion, scour, and water quality reduction).

In terms of thermal gradient vulnerability to climate change, water temperatures are expected to warm further causing 'spikes' in water temperatures in Spring Creek from 20-22˚C (currently) to 26-27˚ (based on maximum weekly streamwater temperature modeling by Chu 2015). Monitoring stations located in Spring Creek as well are anticipated to exceed thermal tolerances for coldwater fish species, implying that habitat for these species will be significantly reduced and coldwater fish species may seek refuge further upstream, if barriers do not impede their ability to do so.

Implications to Ecosystem Services

Understanding current conditions of Spring Creek in the face of climate change may in fact present an opportunity to buffer the worst of potential impacts that may occur in the future of Peel Region. In the case of Spring Creek, many of the same planning strategies and implementation projects to reduce ecological impacts of urbanization can be used to reduce climate change vulnerability (Denault *et al.,* 2006). This, in turn, will increase ecosystem services that are currently being under-delivered in the creek such as water quality regulation, regulation of erosion, flood attenuation, recreational benefits to Peel Region residents and habitat diversity. For instance, re-naturalization of the hardened stream portions of Spring Creek could bring benefits to the in-stream ecology. If instream barrier removal is considered within the re-naturalization of reaches, this could improve aquatic connectivity throughout the watercourse for some fish species seeking cooler temperatures upstream, and foster a higher biotic integrity in Spring Creek. It is expected that naturalization yields positive improvements in flow velocities (reduces 'flashiness' of flows, increases habitat quality and cover, increases in fish and aquatic vegetation richness).

Fletcher's Creek

Fletcher's Creek subwatershed is located in the City of Brampton and City of Mississauga, and encompasses natural systems of largely successional features in CVC's jurisdiction. Specifically, Fletcher's Creek is found in the Lower Credit physiographic region and stretches from south of the 401 to north of Mayfield Road. The catchment is 4251 ha in size of which 66% has been classified as urban, and the remaining portions being classified as natural area (14%) and agricultural (20%) (CVC 2012a). In the northern portion of Fletcher's Creek catchment, agricultural lands do still exist and play an important role in regulating the hydrology of the system and water quality which then flows downstream into the urban areas that are already considered currently stressed in the absence of climate change (CVC 2012b). For example, Fletcher's Creek has been identified as having surface water quality concerns based on poor monitoring results from high nutrients, chloride, metal and E.*Coli* levels (CVC 2012b). It is best described as an urbanizing watercourse, but transitioning from more agricultural to predominantly urban lands, which differs when compared with some land area in south Peel (e.g. Cooksville Creek) (Table 27).

Table 27: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Fletcher's Creek

Components	Vulnerability Factors	Vulnerability Indicators
• Rivers, Streams and Valley Corridors	• Pervious Cover • Topography and Grade • Flow Variation • Community Range • Tree Canopy • Thermal Gradient • Water Chemistry	• Recharge • Soil Drainage • Baseflow • Climate Sensitive Vegetation • Water Temperature • Total Phosphorus

Current Conditions in Fletcher's Creek

Fletchers Creek is located where pervious cover, while already relatively low is gradually decreasing over time; the rate at which this is occurring is not insignificant. A large majority of the catchment's natural cover which only accounts for (14%) of its total area, is successional habitat (9.7%), which minimizes some of the drainage areas overall attenuation and infiltration abilities. There are, however, some areas of higher infiltration capacity (abilities) in the rural headwater portions of the subwatershed (CVC 2012a) owing in part to the non-uniform nature of its underlying geology. Despite these facts the subwatershed's storm events can currently be clearly distinguished from its baseflow conditions by its rapid flow response (CVC 2012b; CVC 2013a). This response is in part a subwatershed condition, where the soils are associated with a clay parent material. The dominant soil type is clay, allowing for less infiltration during precipitation events when compared to sandier soils. This condition, along with a lack of vegetation in agricultural areas and impervious surfaces in urban areas, are contributing to high stormwater runoff in this subwatershed. As a result, relatively high portions of rainfall tend to run off into surface channels.

It is not unexpected that the subwatershed does not support very much in the way of climate sensitive vegetation. Low amounts of forest (3.1%) which forms the catchment's tree canopy and wetland cover (0.2%), combined with small very fragmented tableland woodlots offer very limited levels of pervious cover, and is similar to other urban areas in the Region. As well, an examination of climate sensitive vegetation found there was no climate sensitive vegetation present (CVC 2012b). The current subwatershed landscape conditions are not conducive to supporting a diversity of climate sensitive vegetation communities. Infiltration and attenuation processes for water are no longer functioning to the degree that these ecosystems require for their continued persistence in landscape.

Fletchers Creek already has a significant degree of flow variation that has been identified in background reports. The river is described as having moderately flashy flows and impaired quality but possibly better than more urban streams such as Cooksville Creek (CVC *et al*. 2009). This variation in flow has been noted as being related to both the soil type of the catchment, being largely made up of low porosity clay, as well as the catchment being a largely urban and urbanizing landscape (CVC 2012b). However, there are other contributing facts in addition to paved surfaces, such as soil compaction which serves to reduce infiltration and discharge to the river. Activities like grading have also changed overland flow paths, and reduced the attenuation and storage of water within the area. As well, the process of river channelization (hardening) where the watercourse has been lined with concrete has decreased the discharge of groundwater into the watercourse and reduced baseflow levels (CVC 2012b). Finally the addition of storm sewers to the landscape facilitates the rapid transfer of water from the landscape directly to watercourses after storm events, and reduces shallow groundwater discharge to the river.

The changes in the watercourses main stem flow regime over time are expressing themselves in the physical nature of the channel of the river itself. The result being that the large majority of the main river system is either in transition or adjustment (CVC 2012b). In transition means that the watercourse has been assessed using a "stability" index and was rated in transition (which implies a stressed condition); while in adjustment means the stream course is full on changing (typically in response to aggradation, degradation, or widening) implying a really stressed state. The large majority of the river is also widening in response to these current flow regime changes and are being exacerbated by other factors such as channel armouring and stormwater outlets (CVC 2012b).

Topography and Grade was examined to better understand surface runoff volumes independent of urban factors, and includes more variables than simple soil porosity, which are known from geology and soil classification to be largely low permeability clays (CVC 2012b). This additive analysis illustrates that almost the entire catchment has a moderate vulnerability to climate change factors, which is lower than what might be inferred by the examination of soils type and geology alone. This examination illustrates that the value of the non-urban portions of the headwaters of Fletcher's Creek might be higher than anticipated, though the value these portions hold will be eliminated in the near future. This is due to non-urban areas (e.g., the headwaters) being completely developed currently and in the short term, which is expected to make Fletcher's Creek more vulnerable to climatic changes.

The thermal gradients in Fletchers Creek may be characteristic of how systems with ephemeral or intermittent headwaters usually function, and have likely been shaped by historical wetlands that existed (e.g., clay plain swamps) and current agricultural practices in the subwatershed. In the case of Fletchers Creek, the watercourses are warmer in the headwaters and appear to vary the most in daily temperatures (CVC 2012b), when compared to some lower reaches of the watercourse. It should be noted; however, that the headwaters above Highway 7 are intermittent and difficult to characterize using continuous data loggers. Potential headwater temperature instability appears to be in part a result of landscape condition, with low levels of natural cover being present; where there are only a few small very fragmented tableland woodlots and much of the riparian area is meadow. The watercourse is also only seasonally connected to a shallow groundwater table which helps to stabilize both flow volume and temperature. Fletcher's Creek is also cooler between Highway 7 and Highway 407, but is at its warmest around Second Line and upstream of the confluence with the Credit River. The influences of urban infrastructure are also evident as water temperatures tend to increase around stormwater ponds (CVC 2012b).

Water chemistry appears to be an issue in Fletchers Creek, however the levels of phosphorus while of concern are not currently increasing within the river system. The phosphorus issue seems to be a whole subwatershed issue, as high concentrations were identified at all monitoring stations and were well in excess of the PWQO. "The long-term MOE data indicates that the Fletchers Creek is a Policy 2 watercourse in terms of Total Phosphorus as even the 25th percentiles exceeded the PWQO in most years and 81% of all samples exceeded guidelines" (CVC 2012b; MOE 1994). The phosphorus concern is primarily tied to rain events where concentrations are regularly measured at more than 30 times the provincial guideline, and is highest in the spring and then the fall season. Analysis of this problem has illustrated that the levels of phosphorus are tied to total suspended solids, and are a good indication most phosphorus is bound to sediments. This indicates the phosphorus problem is likely related to stormwater runoff (CVC 2012b).

Future Vulnerability in Fletchers Creek

Fletcher's Creek is on track to suffer from the same impacts of other fully urbanized river systems, such as Cooksville Creek, should development continue its business as usual path into the future (C. Zimmer personal communication, June 14, 2015). The effects from continued increases in impervious cover levels and the resulting loss of pervious cover surfaces are well established and well known. Typically referred to as urban stream syndrome the river becomes increasingly flashy (flow variation) (Paul and Meyer 2001) compared to existing climate conditions. Furthermore, ephemeral streams in the headwaters of northwest Brampton have historically been (and continue to be) replaced by pipes and stormwater management ponds, the implications of which have caused what watercourses that remain to be permanently flowing and transitioned to autochthonous energy driven systems. The implications of this when applied with a climate change lens are less positive. Already identified as a stressed surface flow system (CVC 2015c) the implications of extreme precipitations events, and longer durations of no precipitation between events is very likely to push the system past an ecological tipping point. Exacerbating these impacts will be other factors related to topography and grade. A headwater system already experiencing issues with warming and seasonal drying due to its poor connection to groundwater resources is likely to increase with less infiltration into the soil. Even if all pervious surfaces are retained into the future in the headwaters, increases in short term intense rainfalls punctuated by longer periods of drought will create soil conditions less conducive to water infiltration, and generate higher rates of runoff. These higher rates of runoff will also generate increased pulses of sediment and phosphorus, further changing water chemistry. With predicted changes in the seasonal distribution of precipitation events, it is likely there will be increased loadings of phosphorus in the rivers. The increased phosphorus input may cause increased algal issues within the river system itself, particularly when examined with the changing seasonal nature of precipitation and increased number of growing days as a result of warmer winter temperatures. For example, without a strong spring freshet, phosphorus is not moved downstream and may build up increasing algal problems.

Changes in infiltration rates and overland flow will affect baseflow levels, increasing the amount of water in the river system on average. In fact, baseflows have been increasing since 1998 likely as a result of urbanization. This trend is expected to continue under climate change as precipitation increases annually. With these changes will likely come a change in thermal gradients of the river system as well, and related shifts in aquatic habitat conditions. In response to these flow and temperature changes, and to a lesser degree changes in phosphorus levels, will come changes in overall aquatic community range; and likely the loss of elements within the community (Baron *et al*. 2003). Community range within Fletchers Creek will be restricted based on several of the above described factors, such as temperature, channel alteration, altered flow regime as well as urbanization impacts. For example, cool water communities will only be able to persist in the lower reaches of the watercourse as water temperatures warm even further with further urban inputs and warmer air temperatures; although this is already the case to some extent so fish distribution may become limited even further exacerbated by climate change and increasing urbanization.

The species that will be able to persist in the watercourse will also need to be tolerant of the altered flow regime and habitat. The upper watercourse will only be able to support a warm water fish community during the summer months, but its composition will be shaped by seasonal factors such a watercourse drying (CVC 2012b). The species that will be able to persist in the warmest reaches of the watercourse are those likely to tolerate very high temperatures, and lower oxygen levels. Because the seasonal connection of the groundwater system in the spring and fall acts to both cool the watercourse and add volume, there is will be some opportunity for seasonal overlap between the cool and warm water communities. For example, cool water communities may take the opportunity to move into the headwaters in the spring to find spawning opportunities.

This subwatershed has been evaluated as being highly vulnerable to the effects of predicted climate change, when examined for its recharge and aquifer maintenance functions (CVC 2012b; CVC 2013a). This fact is supported by recent subwatershed studies where it has been identified that despite standard SWM practices, in-stream levels of erosion and flows are increasing within Fletchers Creek (CVC 2012b; CVC 2013a). However, with the likely increase in urban development within this catchment area, there may come some degree of increased riparian and tree canopy cover along the river. This will serve to help shade the watercourse but it is unknown if the degree of canopy cover will be able to offset corresponding changes from a loss in baseflow volume, and increased air temperature. It is highly unlikely that there will be the re-establishment of a climate sensitive vegetation community, particularly without a large investment of resources and sustained long term management activities.

Implications to Ecosystem Services

Fletchers Creek has already experienced substantial changes as a result of urban development, and under climate change, more significant changes in its valued ecosystem services could occur. The watercourse is very likely to continue to experience significant increases in flow volumes during rain events, particularly as climate change exacerbates the intensity and frequency of these events. This will continue to act to increase erosion in the watercourses of Fletchers Creek. The result will be further degradation and change in the form and function of the watercourse, as the channel begins to lose its structural integrity. As the channels integrity is lost, the rivers capacity to regulate erosion and improve water quality will be eliminated. As the channel is simplified in response to the rivers flow regime, there will be less diversity of habitat for all forms of life, and this problem will cascade into more simplified ecosystems that will be less efficient at processing nutrients and contaminants. As result services like water quality regulation are likely to decline which in turn will affect other services like water use and may facilitate the entry, and the creation of suitable habitat for aquatic invasive species and new aquatic ecosystem diseases.

Cooksville Creek

Cooksville Creek subwatershed is located east of the Credit River in the community of Mineola, Mississauga. This second order, warm water tributary drains directly into Lake Ontario and has a 16 km x 2 km (3390 ha) drainage catchment that is highly urbanized with 60% residential lands, 34% industrial and commercial lands and 6% other surfaces (Kennedy and Wilson 2009; Aquafor Beech Limited 2012). Riverine and urban flooding issues affect 4.5% of the subwatershed area, resulting in the highest number of flood vulnerable structures (309) in southern Peel (CVC 2013a; GHD Consulting 2015). A quantitative vulnerability assessment of water infrastructure systems in Cooksville Creek is currently being led by CVC and findings will be used to inform interactions of vulnerabilities across the natural and built systems.

The high amounts of urban land cover in this subwatershed, and its known riverine and urban flooding issues led to the selection of this storyline area. Specifically, how climate change impacts the highly altered Cooksville Creek will be particularly important (see Table 28). It was determined that a climate scenario of warmer temperatures, wetter conditions overall throughout the year and increasing extreme precipitation events may produce a series of impacts which could increase the vulnerability in the natural systems of Cooksville Creek.

Table 28: Components, Vulnerability Factors and Vulnerability Indicators Discussed in Cooksville Creek

Components	Vulnerability Factors	Vulnerability Indicators
Rivers, Streams &Valley Corridors	• Pervious Cover • Flow Variation • Topography & Grade • Water Chemistry	• Natural Cover • Climate Sensitive Native Vegetation • Soil Drainage • Baseflow • Total Phosphorus

Current Conditions in Cooksville Creek

Cooksville Creek is located in a highly urban area, where pervious cover comprises a minimal 6% of the area and stream channel erosion, scour and flooding are major issues (Aquafor Beech Limited 2011a). Historical urbanization has resulted in a phenomenon commonly known as the “urban stream syndrome,” whereby hydrographs become flashier (i.e., increased flow variability), water quality is degraded, channels are homogenized and incised, biological richness declines, and disturbance-tolerant and alien species increase in prevalence (Hughes *et al*. 2014). In Cooksville, little climate sensitive vegetation is present simply because there is little pervious cover for a diversity of vegetation communities to thrive. Thus, there is clear evidence that ecosystem services such as infiltration and attenuation of water no longer function in the subwatershed as a result of high amounts of impervious cover. Ecological impairment has been shown when percent impervious cover of a watershed exceeds 10-15% (Carlson *et al*. 2004; Baron *et al*. 2003), although the actual threshold for impairment will depend on how much impervious area is connected to drains (i.e., effective imperviousness) rather than drains to pervious land features (C. Walsh, Fletcher, and Ladson 2005). Further, this area of Peel has been documented as one of the hardest-hit for common flood-related issues associated with both urban and riverine flooding. Figure 47 illustrates the locations of known urban flood related issues in Cooksville Creek.

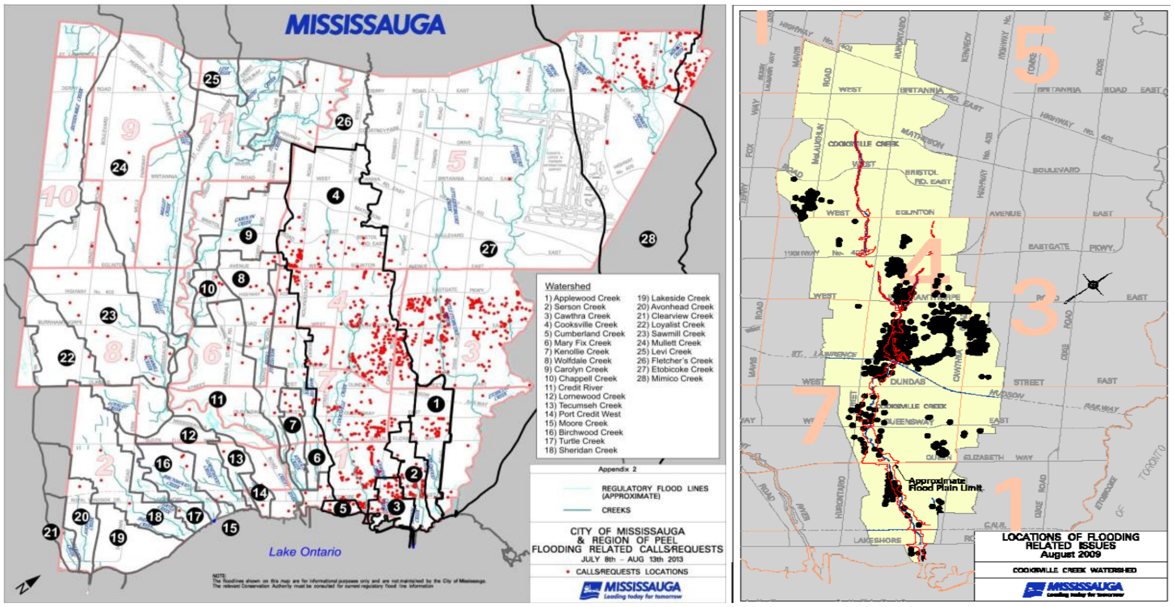


Figure 47: Locations of Flood Related Issues in the City of Mississauga from the July 8th, 2013 storm (left) and in Cooksville Creek from the August 4th, 2009 storm (right)

As a result of the historical urbanization that has occurred, flow variation has been altered. This in turn has caused fluvial-geomorphic processes to have been disrupted. For example, channel erosion processes and flood regulation in urban streams are altered from their natural state, and this is exacerbated in areas where this condition is coupled with insufficient SWM like in Cooksville Creek. The majority of Cooksville Creek's channel has been straightened and hardened (using gabion and armour stone). From 1977 to 1990, the channel width increased by 14-60% and the length decreased by 2-30% (Aquafor Beech Limited 2011a). This decrease in the channel length has resulted in an increased channel gradient. Active erosion and downcutting into the shale bedrock is found in multiple reaches (Aquafor Beech Limited 2011a). Furthermore, the channel has been incised in many reaches and is currently in a transitional geomorphic state, which is not stable (Center for Watershed Protection 2003), and is disconnected from its natural floodplain. Ultimately, Cooksville Creek is moderately vulnerable in its current conditions given its high levels of alteration.

Other factors contributing to vulnerability in Cooksville Creek are less definitive. For instance, topography and grade was examined through the indicator of soil drainage, and particularly to understand the processes of increased surface volume runoff. In the upper and lower portions of the subwatershed, Cooksville is dominated by well drained soils and in the middle portion of the subwatershed it contains imperfectly drained soils (Hoffman & Richards 1953). If Cooksville Creek was not found in an urban area, one could expect higher amounts of surface runoff in the middle portion of the subwatershed. However, this factor has limited applicability in the urban context since soils have been largely developed over. It is still known that due to the high level of impervious cover and little SWM in Cooksville Creek, this area is generating increased amounts of surface volume runoff, but due to an anthropogenic cause. Thus, this factor contributes to a higher level of vulnerability in the natural system, whereby larger amounts of runoff can inundate the system under the current climate, especially due to a lack of attenuating and infiltrating vegetation and natural cover.

Cooksville Creek has been characterized as of particular concern for water chemistry as well. Specifically, in historical extreme events sanitary sewers have been overflowed leading to overland flooding of untreated water that drains into Lake Ontario worsening water quality (CVC 2009b). Notably, there are no combined sewer systems in Cooksville Creek that could exacerbate the issue of stormwater and untreated sewage entering Lake Ontario under extreme rainfall events; however, there have been incidents where illegal cross connections have occurred resulting in raw sewage entering storm sewers and ultimately flowing through storm outfalls entering into Lake Ontario (P. James personal communication, August 25, 2015). However, illegal cross-connections are likely minor in comparison to the impacts of combined sewer outfalls (CSOs) and a lack of stormwater management as contributors of Total Phosphorous loading into Lake Ontario. Better water quality controls are needed. For example, in the spring of 2014, a number of telling trends were documented in Cooksville Creek following a warmer winter season. Algal blooms associated with higher levels of total phosphorus and the warmer preceding season were observed (Singh and Murison, n.d.), but these are not well studied. Monitoring data suggests that with increased precipitation and melting snow in 2014, turbidity of waters in Cooksville Creek increased, and dissolved oxygen content of the waters consistently exceeded Ontario's Provincial Water Quality Objectives (4 mg/L) ranging between 6 and 15 mg/L (obtained from CVC real-time data). Streamwater temperature; however, remained below CVC's upper thermal target (30˚C) ranging from -0.65˚C to 23.7˚C. Ultimately, water chemistry is considered moderately vulnerable to climate change in Cooksville given that exceedances are occurring under the current climate.

Future Vulnerability in Cooksville Creek

Urban streams with low pervious cover, like Cooksville Creek, face additional challenges in the future because they are already significantly stressed. Wetter conditions in general, and extreme precipitation events, will selectively degrade such streams where a higher percentage of land is impervious (Wisconsin Initiative on Climate Change Impacts 2011). Here, changes in stormwater are likely to cause high water conditions from heavy rainfall over relatively small areas even when events last only minutes to hours. Urban streams are expected to become more "flashy" (flow variation) in response to increasing extreme events with more frequency and higher rainfall (Paul and Meyer 2001; Konrad and Booth 2005). The major reason for this flashiness is the greater amount of impervious surface in the watershed. Instead of water infiltrating into soils (which is driven by topography and grade in a natural system) and recharging aquifers or being transpired by vegetation, the water moves quickly off of impervious surfaces (CCSP 2008) and is delivered directly to Lake Ontario via storm drains and pipes. While Cooksville Creek is not expected to become increasingly urbanized, shifting patterns in precipitation will likely increase the vulnerability of the system from flow variation to potential infrastructure damage, natural systems degradation and increased flooding (Denault *et al.*, 2006; Staudinger *et al.*, 2013). The implications for streams and rivers could be significant. For example, in a historical reconstruction of flood histories for upper Mississippi River tributaries over the last 7,000 years, it was found that small shifts in temperature (1-2°C) and precipitation

(10-20%) caused sudden changes in flood magnitude and frequency (Knox 1993). These sudden changes in flood magnitude and frequency could also cause a shift in aquatic species composition and perhaps eliminate many species, although the degree of change in Cooksville Creek could likely be less significant due to its existing altered state in the urban area (Denault, Millar, and Lence 2006; N LeRoy Poff, Brinson, and Day 2002).

Future changes in climate will also heavily influence water chemistry in Cooksville Creek. For example, more heavy rainfall increases the movement of nutrients and pollutants to downstream ecosystems like Cooksville Creek, thereby worsening water quality, restructuring processes, biota, and habitats (Staudinger *et al*., 2012). These heavy rainfall events can release pollution and contaminant runoff from sewer systems, treatment plants, and waste storage facilities (Staudinger *et al*., 2012). This is particularly important due to any cross connections that may exist between sanitary and stormwater sewers occurring in Cooksville Creek's sewer system (P. James personal communication, August 25, 2015). Similarly, a modified seasonal pattern in precipitation, which is translated into surface runoff that feeds into Cooksville Creek could further alter species composition and aquatic productivity (N LeRoy Poff, Brinson, and Day 2002). Increased amounts of pollutants and contaminants, such as heavy metals, nutrients, petroleum products and pesticides can enter the aquatic system, thereby increasing biological oxygen demand and stimulated nuisance algal growth (Paul & Meyer 2001). This in turn, could reduce the amount of available dissolved oxygen for invertebrates, fish, and other aquatic life.

Climate change presents society with choices about how to respond with management and operations: buffering impacts, tracking change through time, or anticipating transitions to new ecological states and adaptively updating management actions through time (Baron *et al*. 2003). However, the same planning strategies that can reduce the impacts of imperviousness may also help to reduce the effects of climate change (Denault, Millar, and Lence 2006). For instance, widespread application of low impact development across Cooksville Creek provides an opportunity to reduce these impacts (Hatt *et al*. 2004).

Implications to Ecosystem Services

Cooksville Creek will continue to experience changes in its valued ecosystem services as we experience future climate scenarios. The watercourse will likely experience increasingly erosive forces which will continue to shape the form and function of the watercourse itself, as the projected rainfall intensity and distribution of precipitation are delivered. The altered flow regime caused by the catchment's high level of impervious cover will continue to generate larger amounts of runoff, particularly as more water falls in the future as higher intensity rainfall events. As there will be no apparent additional attenuation or infiltration services that will manifest through the climate change process, there will be no additional buffering capacity to deal with increase overland flow within the subwatershed. In fact it is likely that the existing pervious cover components of this system will change over time, likely decreasing their capacity for attenuation. This could alter the very limited degree of infiltration and attenuation capacity within the system currently. Ultimately, it is likely to exacerbate flooding issues already experienced along the river and valley corridor, and continue to produce water quality issues that could be made worse under drought conditions and be ecologically damaging to aquatic life.

The increasing flow variation, and altered flow regime of the watercourse will act to simplify the watercourses of Cooksville Creek in terms of both structure and function, through the fluvial geomorphic response of the new climate conditions. So while increased water volumes generated by higher intensity rain events carry more nutrients and contaminants to the watercourse, there will be a reduced capacity for the ecosystems to process, store and deal with the extra volume of these nutrients and contaminants. The lack of aquatic ecosystem function and habitat diversity to process additional nutrients and contaminants will increase the primary productivity experienced in the downstream and lake front aquatic ecosystem.

Other ecosystem services are also likely to change in response to the new climate conditions; including supporting services (e.g. habitat diversity), and recreational activities. These services are already very limited in this watercourse and it is likely that this will continue to be the case. There is also a risk of further decline. The synergistic nature of the vulnerability factors identified here, will act to mutually reinforce each other as the changes manifest themselves within the catchment.

7. SUMMARY OF KEY FINDINGS

The following section presents a summary of key findings based on the Peel climate trend analysis (Auld *et al.,* 2015) and the characterization of current and future vulnerabilities of natural system components to climate change and additional stressors.

7.1. Future Climate Conditions

Climate Change is very likely to increase temperature in all seasons, bringing hotter summer days and more days in the winter around 0˚C. Auld *et al.* (2015) project a mean annual air temperature increase of 2˚C by the 2050s (from 7.4˚C to 9.4˚C). Correspondingly, increasing air temperatures have already warmed, and will continue to warm, water temperatures in the Great Lakes. Chu (2015) found that from 1968 to 2002, August surface water temperatures in Lake Ontario warmed 1.6˚C and Lake Huron warmed 2.9˚C.

Climate Change is also likely to produce more rain falling throughout the year, but not necessarily in the summer season where drier conditions could dominate but be punctuated by heavier rainfall events. Likewise, extreme events like heat waves and extreme rainfalls are likely to become more severe and more common.

Snowmelt conditions in the spring could shift, but the amount and duration of snow melting (controlling the spring freshet) is uncertain and depends on the amount of precipitation falling as snow in the winter. Finally, the growing season is expected to increase in length, with frost free conditions beginning earlier in April and ending later in October or November.

7.2. Influences of Additional Stressors

Urbanization, in general, exacerbates many of the direct impacts of climate change on the natural system (e.g., drying of wetlands, heat stress to sensitive vegetation communities, warming of in-land lakes, rivers and streams, more frequent algal blooms) and conversely, climate change will amplify impacts that are driven by existing urbanization (e.g. urban flooding and urban heat island). This implies similar and potentially overlapping signals of impact between climate change and urbanization; however, land use change is expected to dominate future, short-term impacts to the natural environment as growth planning requires new development and intensification in the Region of Peel to occur over the next 30 years, or so. The outcome, which is highly dependent on how development proceeds, including addressing cumulative impacts, is likely a new baseline condition for the natural system once urbanization activity slows and may become limited to cycles of localized re-development or renewal. That new baseline will determine how resilient the natural system will be to the climate conditions and extremes predicted for 2050s and beyond.

Other land use practices that can disrupt ecological processes may also amplify the negative impacts of climate change. In the Region of Peel, evidence presented in this assessment suggests current water taking activities associated with aggregate extraction, agriculture and other non-municipal water supply users are impacting headwater and cold water streams from a quantity perspective which in-turn can contribute to stream temperature and water quality issues, particularly in the upper watersheds. For instance, proposed expansions of wastewater treatment plants and/or septic systems in the upper watersheds may increase nutrient loading and worsen water quality, depending on future precipitation patterns.

Disruption to the groundwater supply to surface features (e.g. wetlands and streams), particularly in the upper Credit watershed, has been flagged as a potential future concern specifically related to municipal water supply required to service urban growth beyond the borders of Peel Region.

Both terrestrial and aquatic invasive and non-native species already exist in the watersheds of Peel Region, their presence recorded over many years (even decades) through various inventory and monitoring programs undertaken by the province, conservations authorities (e.g. wetland species inventory in Rattray Marsh and annual terrestrial and aquatic monitoring programs) and municipalities (e.g. urban forest tree species inventory). The pathways of introduction for these existing invasive or non-native species are not all verified but are largely attributed to human factors (e.g., beetle larvae or adults transported in packaging from international sources, ballast water release, ornamental garden trade and intentional releases for purpose of ecological control). Climate change may, in some cases, create an even more favourable environment for invasive or non-native species already established in Peel watersheds, particularly those that are more aggressive and/or appear hardier to hotter, drier conditions (e.g. the shrubby buckthorn or warm water carp) than our native species. Episodic but extensive inundation of floodplains and coastal wetlands, a potential result of more frequent and intense rainfall events, may facilitate the spread of both aquatic plant and animal movement, including the highly invasive European phragmites. The changing climate itself is also the suspected driver behind more recent occurrences of “southern” species moving up into our ‘northern’ habitats (e.g., opossum) or rapidly expanding beyond their typical range (e.g. wood ticks and smallmouth bass). As the climate further warms, the trend of new introductions and/or expanding populations of more tolerant species are predicted to increase and with that exert greater competitive pressure on native species that are more vulnerable due to lower adaptive capacity and higher sensitivity to climate and other existing stresses.

7.3. Terrestrial System

Approximately 55% of the terrestrial system in Peel Region is currently considered 'highly' vulnerable to the effects of increased air temperature and longer summer dry periods. This is an additive score, representing multiple indicators. There is a tight coupling between extensive areas of high terrestrial vulnerability and urban/urbanizing areas, reflective of the discussion points in Section 7.2. More specifically, 4.1% of the natural cover within urban areas contains climate sensitive native vegetation (including tree species intolerant of drier conditions). The implication is a loss or decline of tree species that contribute to the urban forest canopy and with them would go some of the service of regulating land surface temperatures as evidenced by cooler temperatures found coincident with canopy and natural cover (ranged between 25˚C – 35˚C in mid-afternoon June, 2014) versus areas with no canopy and natural cover (ranged between 36˚C and 54˚C in mid-afternoon June, 2014).

Vegetation communities in the northern portions of Peel Region, which currently exhibit less overall vulnerability (reflective of less pressure from the urban matrix), also contain climate sensitive vegetation (mostly to changes in hydrology). The implication is one day needing to manage potentially significant declines and complete shifts in vegetation communities in parts of the terrestrial natural heritage system that have, to date, been the healthiest, most connected and the reason sensitive bird and wildlife species (refer to L-ranks) still persist on the landscape.

Poorly connected terrestrial components, such as woodlots or 'urban wetlands' are more vulnerable to climate change and may be more stressed due to increased 'edge effects' caused by urban heat island and invasive species expansion.

The type of wetland matters when determining the degree of vulnerability to drying and potential desiccation. The most vulnerable are isolated, precipitation-fed wetlands, including the remaining swamps located in the upper half of Peel Region. These types of wetland features are commonly located near headwaters and on tablelands; they provide the greater flood attenuation services compared to riparian wetlands located along streams and shorelines. Although the result of seasonal drying may indeed increase the flood attenuation capacity, should climate change induce conditions of severe and extended drought, sufficient to cause wetland soil desiccation, the attenuation properties may no longer function (extent of recovery and associated response time is not well understood).

7.4. Aquatic System

Nine highly vulnerable stream reaches across Peel Region were identified for the aquatic system under current conditions, defined by summer low flows and elevated summer stream temperatures (beyond maximum summer targets set for aquatic habitat). Areas of existing vulnerability were not confined to only urban centres thus measured impacts to flow and temperature are assumed to be caused by some combination of urbanization, other land uses (as discussed in Section 7.2) and natural variation, with their respective extent of influence considered location-dependent.

Future climate modelling for stream temperature in Peel Region helped quantify the increasing vulnerability expected for the aquatic system. Key findings are:

- Summer stream temperatures, on average, are expected to warm as much as 2˚C. Some stream monitoring stations would record unsuitable habitat conditions for both cold and warm water fish species; unsuitability could be chronic or occur as more frequent and extreme thermal spikes. Implications of these 2 types of impacts are not identical but both serve to stress fish populations and/or cause local mortality at the community or individual level.
- With increasing air temperatures, the areal extent of at least four of the nine highly vulnerable stream reaches are predicted to expand for both cold and warm water habitats.
- Coldwater fish habitat in rivers and streams is very likely to warm with some areas warming sufficiently to shift to coolwater habitat and drive sensitive coldwater fish species (e.g. Brook Trout) northward to where, in Peel Region, suitable habitat is already limited (this is a Great Lakes Basin wide prediction).
- Specific focal area storylines that include details on stream temperature vulnerability are: Centreville Creek, Upper Main Credit River to Cheltenham, West Humber River, Spring Creek, Fletcher's Creek, Albion Hills CA, and Heart Lake CA.

Available surface and groundwater monitoring data helped qualify local conditions and/or watershed scale trends in stream flow (water quantity). Key findings are:

- At the watershed scale, stream flows are not exhibiting any significant changes over time.
- At the local level, both too much and too little surface water flow is currently experienced at numerous locations across Peel Region.
    - Too much water coincident with storm events aggravate and accelerate rates of stream erosion, and can cause urban flooding (see Section 7.2). The predicted increase in storm frequency and intensity is expected to exacerbate these impacts.
    - Too little water appears to be more of a complex interaction of natural variation (e.g., shallow groundwater connections to surface features that respond to annual climate cycles), habitat conditions and water taking (see Section 7.2). Implications of warmer atmospheric temperatures to water quantity include a shift in when and how and how much precipitation falls (hydrologic processes are expected to be disrupted and contribute to lower seasonal flows) and increased rates of evaporation, also lowering seasonal water levels in watercourses and in-land lakes, especially where no riparian or canopy cover exists.
- Experiencing lower summer flows than at present, and for potentially longer periods (whether due to climate change alone or combined with other stresses), is expected to

further reduce aquatic habitat connectivity (via stream drying and/or more in-stream structures become impassable) and thus compromise fish movement and survival in vulnerable subwatersheds.

- Specific focal area storylines that include details on stream flow vulnerability are: Centreville Creek, Upper Credit, West Humber Subwatershed, Spring Creek, Fletchers Creek, Etobicoke Headwaters and Cooksville Creek.
- Monitoring data and assessment of current winter stream hydrology as not been undertaken (traditionally not a season of concern either ecologically or hydrologically/hydraulically) but future climate projections for warmer, wetter winters have raised a 'red flag' that winter stream conditions may be higher energy and less ecologically and hydraulically stable. Emerging vulnerabilities associated with fish biometrics (respiration, metabolism, etc.), over-wintering egg survival, and higher erosion potential in the winter months (linked to lack of ice cover, higher flows, semi-frozen banks and no live vegetation) may result in a need to broaden current fish management and stormwater management considerations.

Quantifying and defining current spatial vulnerabilities associated with water quality was less precise than temporal understanding with exceedances of common parameters (e.g. total phosphorus) most often measured during late spring and summer months. Both urban and rural areas are currently impacted by these periodic increases in nutrients and climate change is expected to amplify this cycle and result in more intense and frequent algal blooms in lakes, ponds and stream depositional areas.

Specific focal area storylines that identified water quality (nutrient) issues are Heart Lake CA, Etobicoke Headwaters, Upper Main Credit River to Cheltenham, Centreville Creek, Cooksville Creek and Fletcher's Creek.

7.5. Groundwater System

Based on available information, a higher degree of buffering and resilience appears to exist in the deeper groundwater system that underlies Peel Region; however, there may be a decadal lag in response time of the aquifers to historic climate conditions that is not currently detected but may heavily influence groundwater discharge to surface features at some point in the future.

Shallow, unconfined aquifers are more vulnerable to climate stress, including direct and indirect warming, than deeper regional aquifers; numerous such shallow groundwater systems exist and support aquatic features across Peel Region. Future climate conditions may reduce the amount of water discharging to surface as baseflow, contributing to predicted impacts on thermal stream habitat, flow/connectivity and non-municipal water supply.

Specific focal area storylines that identified shallow groundwater vulnerability are Centreville Creek, West Humber River Subwatershed, Upper Credit and Etobicoke Headwaters.

8. MANAGEMENT CONSIDERATIONS

The target audience for the technical details and management considerations presented within this assessment report is the Conservation Authorities in Peel Region. By understanding the anticipated implications of climate change on natural systems within Peel Region, TRCA and CVC can identify and prioritize alternative ecosystem management responses that represent effective adaptations designed to achieve desired outcomes. The information in the report does not prescribe the management priorities or outcomes but offers information to formulate a range of rationales, such as protecting or enhancing when loss of ecological complexity is likely not recoverable and identifying ecosystems services that current management or restoration practices can replicate and benefit human communities (discussed in Section 2.2). Of additional mention is the precautionary principle, foundational to CA policies and practice, and important context for addressing the uncertainties inherent in climate change projections.

Beyond the target audience, the plain-language summary of technical findings, together with the larger body of evidence amassed through other sector-based vulnerability assessments and climate trend reporting for Peel Region, should inform current but evolving strategic policy discussions, adaptation planning and implementation amongst a broader set of players. Two ways to inform these next stages include: 1) effective communication (*of evidence-based vulnerabilities*) with the local government leaders and policy makers whose direction will influence the future condition of natural systems either directly or indirectly and 2) meaningful engagement and collaboration with the sector-based practitioners whose current daily operations affect or are affected by the state of the natural environment.

There is significant opportunity today, through the land use planning process, to embody, embolden and implement the principles of integrated watershed planning, adaptation action, and a low-carbon society, to ensure the future baseline condition for our natural systems minimizes climate change vulnerability and maximizes resiliency to extreme weather events. As a starting point, it is recommended that all municipalities, including Peel Region, identify natural heritage systems in their official plans in line with provincial policy. The recently amended (May 2017) provincial Growth Plan, Greenbelt Act, Oak Ridges Moraine Act and Niagara Escarpment Act are moving us in the right policy directions. Specifically, the updated plans recognize the importance of addressing climate change and include new policy directions aimed at more effectively responding to and mitigating its effects by 1) requiring municipalities to implement climate policies in their Official Plans; 2) requiring stormwater management plans in settlement areas and for major developments, and 3) requiring municipalities to assess infrastructure risks and vulnerabilities caused by the impacts of climate change when planning or replacing infrastructure and identify options for further enhancing resiliency.

The information and evidence summarized in this document can be a tool to enable further discussions around implementing these policies at the watershed and regional scales, including coordination, roles and responsibilities. The collective impact of such a coordinated effort being a resilient region situated within a high functioning natural landscape that delivers the suite ecosystem services which cannot be replicated at either the needed scale and/or degree of effectiveness. With recognition of this broader guidance and planning context, the following is a series of management considerations which largely speak to the opportunities for Conservation Authorities to have these vulnerability assessment results inform their strategic work:

1. Protect, enhance or restore regional species diversity through strategic increase in the habitat connectivity of natural areas including forests, meadows, wetlands, major valley corridors and watercourses with focus on enhancing or expanding areas with current high function and low to moderate vulnerability in Peel Region.

Rationale: Recognizing that diversity at the genetic, species, community, and ecosystem level are the foundation of a resilient landscape, a comprehensive review of ecosystem management identified maintaining habitat quality and its connectivity as one of the most important and effective adaptation action to undertake in the face of climate change (Heller and Zavaleta, 2009). Emerging science about addressing climate change vulnerability in natural systems, presented and discussed at the 2016 National Adaptation Conference in Ottawa, corroborated the importance of connectivity and further advised that connecting high quality, functional and complex habitats, where species vulnerability is relatively low, should be a management priority; the premise being ‘maintain and enhance the source(s) of overall diversity. This is under the premise that such habitat will maintain and enhance the source(s) of diversity in the landscape which allows it to be resilient to undesired changes in climate and land use. This perspective also acknowledges the limits of current best practice in the ecological restoration and our ability to fully replicate the diversity and complexity of natural systems. Based on this notion, and results from terrestrial and aquatic systems vulnerability assessment shows that the northern portions of the watersheds, the headwater areas, and major valley corridors down to Lake Ontario within Peel Region offer strongholds in community diversity, habitat function and ecosystem services (i.e. low vulnerability). These areas should be the focus of climate change action to protect and enhance in terms of habitat connectivity both across the east-west and north-south corridors. This will ensure that these community diversity source areas can contribute to the overall resiliency of the entire landscape where and when needed. Further information presented in this report in Sections 6.1.2 and 6.1.3 on terrestrial and aquatic habitat connectivity (TRCA 2015) provides greater detail on where restoring or expanding habitat connectivity will provide the greatest benefit for ecosystem diversity across the TRCA jurisdiction of Peel Region.

2. Protect existing and restore or create new natural features including forests, meadows, and wetlands across Peel Region with near-term focus on protecting, restoring or creating wetlands (swamps) across the landscape.

Rationale: Climate change scenarios predict drier summers punctuated with extreme rainfall events that will increases the risk and magnitude of flooding (riverine and urban). Wetlands, forests, and meadows across the landscape (including urban areas) intercept, store, and slow the speed of surface runoff which decreases the risk and magnitude of urban and riverine flooding. As extreme rainfall events become more severe and frequent protection of existing and creation of new natural features such as wetlands, forests, and meadows in strategic locations as part of broader Green Infrastructure or Low Impact Development initiatives will reduce the risks associated with flooding events. Natural features not only provide protection from short term riverine and urban flooding, they also provide long term cumulative benefit to maintaining and enhancing the ecosystem functions and services provided structural connections (e.g. connected forest patches) and functional linkages (e.g. hydrological linkages among forests and wetlands) are maintained. These connections allow the natural features to be resilient to the disturbances in the landscape such as climate and land use change. Specifically speaking, some natural features such as precipitation-fed swamps are one of the most valuable natural features in terms of providing specific ecosystem service such as flood attenuation especially in urban areas. However, these are also one of the most vulnerable wetland types to climate. The thrust of this management consideration highlights that such natural features that provide high levels of ecosystem service over short and long term (e.g. protective measures from urban flooding and increase water quality polishing to streams/shoreline) but are more vulnerable to climate change need to be the focus of protection and creation across the landscape, especially in urban areas where such services are needed more. There is also a need to maintain or improve fundamental abiotic conditions (e.g., soils) that support these natural components across the landscape. Another example of features needing high level of protection and enhancement are coastal wetlands, which are efficient at accommodating potential water level changes, enhancing overall diversity (CVC 2009), as well as to potentially increasing important carbon sequestration opportunities (greater scientific understanding and management direction required on carbon flux cycles and conditions that drive carbon sink and source mechanisms).

3. Prioritize support, including technical guidance and research, to municipalities to maintain and enhance urban forest canopy with near-term focus on areas that currently lack or have limited ability to effectively regulate summer land surface temperatures.

Rationale: Heat stress to humans (particularly where vulnerable populations live), fish, wildlife and sensitive vegetation is already a clear issue in urban areas and is expected to become worse with climate change. Urban heat island effect and the direct effects of increased radiant heating on land surface temperature can effectively and sufficiently be reduced through shading by the urban forest canopy. Areas of highest land surface temperatures (mid-day, summer) are identified in this report and should be used to inform existing urban forest planting program. Development of intensive urban forest management activities such as introducing assisted migration of the southern species that already have GTA as their northern boundary well as usage of more resilient local genetic pools of native species should be considered. This will help off-set the risks to urban canopy that are generally associated with poor growing conditions, invasive species, and disease occurrence within urban areas. To ensure that there is no undesired effects and that expected outcome are achieved; a rigorous monitoring of such novel approaches should be included in the urban management initiatives.

4. Increase efforts to lower summer maximum stream water temperatures with near-term focus on coldwater stream networks and warmwater reaches that currently have elevated average summer temperatures or exceed biological targets.

Rationale: Coldwater habitat is effectively defined by stream temperature with strong agreement in the literature, and corroborated by modelling results presented in this report, that significant decline or loss of this habitat type is entirely possible due to the level of thermal impact that could be caused or exacerbated by climate change. Similarly, warmwater habitat may increase in temperatures to the point where even tolerant fish species cannot occupy or move through the available habitat to either complete life cycle requirements or access thermal refuge areas. Thus, this management consideration is intended to address a limiting biological factor for many fish species and ultimately support the maintenance of regional ecosystem diversity. Beyond a focus on the spatial priorities for thermal vulnerability reduction presented in this report, further consideration should be given to how thermal impact management can be more coordinated amongst CAs and integrated into various restoration, retrofit and stewardship programs to aggressively address cumulative thermal impact using best practice (e.g. riparian planting for shade, reduction in thermal load by infiltrating runoff or increasing evapotranspiration as part of an LID or Green Infrastructure treatment train, etc.). Existing thermal mitigation guidelines (CVC 2011b) should be used as an important reference in these discussions and in addressing this management consideration.

5. Maintain or improve stream baseflow to meet the appropriate seasonal ecological flow targets at the most effective scale to minimize aquatic system vulnerability, with near term focus on coldwater networks (reach, watercourse or subwatershed).

Rationale: These aquatic system components rely on baseflow contribution to maintain critical ecosystem functions and are at highest vulnerability to habitat decline or loss due to climate change and additional stressors (see Management Consideration #4). Further, the maintenance of baseflow in the coldwater networks will contribute to reducing downstream vulnerabilities in cool and, to an extent, water habitats. In addition to continuing existing operations of dams designed to augment baseflow (e.g. Island Lake Dam) or introducing/investigating such management operations where existing infrastructure might allow (e.g., Claireville Dam), there should be consideration for updating and prioritizing the implementation of existing management and public communication plans for water conservation at the subwatershed and watershed scale, and develop and/or integrate ecologically-based low flow summer targets with existing low water response programs (also see Management Consideration #9). As a point of further investigation, it would be valuable to document how close we are under existing conditions to cool and warmwater temperature thresholds being crossed - specifically considering dissolved oxygen concentrations in addition to baseflow.

6. Increase/intensify management efforts to reduce nutrient loadings and prevent the exceedance of PWQO for total phosphorus concentrations in water bodies and shorelines across Peel Region with near-term focus on areas currently experiencing spring and summer PWQO exceedances and/or have reported/observed algal bloom issues.

Rationale: As reported in this assessment, climate change is expected to exacerbate existing water quality issues with excessive nutrient loadings leading to more frequent, intense and/or chronic algal blooms which in turn can significantly destabilize aquatic food webs, foul recreational/aesthetic areas and cause damage/disruption to drinking water filtration infrastructure. Nutrient abatement is not a new management focus but it continues to be a complicated issue given the nature of multiple, non-point sources of phosphorus (and nitrogen) across the watersheds in Peel Region. Conservation Authorities have been an integral player in encouraging and enabling best practice for stormwater quality and rural land drainage water quality through a variety of mechanisms from outreach/education to testing LID effectiveness to working with municipalities and land owners as part of the development review process; but with the phosphorus-algal impacts growing in magnitude, posing more serious consequences to aquatic life and ecosystem services, management efforts should increase and innovate, including strong support for enabling policies and evolving practices that optimize distributed, treatment-train approaches at the watershed and subwatershed scale (e.g. living green infrastructure networks incorporating effective/proven LID designs for infiltration, evaporation and nutrient uptake by vegetation). Furthermore, CAs could also consider options such as phosphorous trading and increasing assimilative capacity through other forms of restoration (e.g., wetlands) and dam removals. Advocating for the best available technology to be used in new and proposed wastewater treatment plants on a watershed basis including those outside and draining into Peel Region could also be an important method to reduce phosphorous loadings.

7. Protect local, shallow groundwater flow paths to ensure protection of important recharge – discharge functions from shallow, unconfined aquifers to surface water features (e.g., streams and wetlands).

Rationale: While there is a growing understanding of the important spatial and specific groundwater to surface water connections (i.e., flow paths) that support the range of stream and wetland habitats, gaps in knowledge remain in Peel Region for where specifically these critical connections are, despite current understanding marking them as highly vulnerable to climate change and additional stressors. CAs have played a major role in assisting the Province with defining and modelling/mapping important recharge and discharge areas (e.g., through Sourcewater Protection programs). As a result, we have a decent level of understanding of priority groundwater areas and drinking water wells (TRCA 2015a; CVC 2015c), however, a comprehensive understanding of local critical connections in Peel Region have not been specifically studied. Thus, it is important to advance this knowledge by undertaking further reverse particle tracking to map shallow groundwater flow paths (this has occurred in some subwatersheds based on concern but is not yet available for the region). This information would also advance current CA-led research and inform requirements to achieve wetland water balance in new development areas.

8. Review current natural system related monitoring and reporting programs through a climate change lens and, if necessary, revise monitoring and reporting programs such that changes to known vulnerabilities are tracked using appropriate metrics at appropriate temporal and spatial scales, or adaptation action effectiveness is evaluated and reported in a cycle that supports a meaningful adaptive learning process to achieve watershed resiliency outcomes and objectives.

Rationale: CAs are leaders in natural system data monitoring, reporting and management but some of these important programs were designed at a time when climate change vulnerabilities were not considered. On the other hand, different CA programs were initiated at different points in time over the previous decade; some are more or less focused at being able to address climate change indicators. Most work is currently focused on objectives around ambient monitoring and reporting (trends over time) more so than performance monitoring of management activities. Reviewing current monitoring programs is a timely action that can well situate CAs and their partners with providing the local ecosystem response data needed to guide existing and innovative climate change adaptation actions. It is important to do this in a context of adaptive management, which is a management intervention tool used to probe the functioning of an ecosystem by identifying uncertainties and establishing methods to test hypotheses around uncertainties. In this manner, adaptive learning is iterative and appealing due to its ability to be anticipatory to change. As a practical example, the TRCA has undertaken an adaptive management approach to its creation of wetland habitat in Tommy Thomson Park. Active adaptive management (which included experimental design, rather than simply learning from mistakes, or passive adaptive management) was successful in this case in developing new processes and continued learning through constructing two phased wetland cells, the latter eventually being improved based on lessons learned from the first wetland cell's construction and monitoring. More generally, CA emphasis should also be on how best to monitor and report on cumulative effects related to climate change – both the negative impacts (i.e. increasing vulnerabilities) and positive effects (e.g. distributed, treatment-train management actions or systematic, regional scale implementation of single action such as planting climate change tolerant tree species). In this regard, CVC and TRCA have produced with Peel Region a climate change risk budget assessment framework that will be used to screen funding available for climate change projects. Furthermore, TRCA is undertaking an overhaul of their corporate-wide internal monitoring through the creation of a Centralized Planning and Reporting database (CPR) built upon the Theory of Change, which will allow for the creation of more effective key performance indicators, many of which will be directly relevant to climate change.

9. Continue to implement sustainability and other important natural heritage system management recommendations from existing strategies, plans, studies and assessments that are effectively 'adaptation actions', while undertaking specific implementation plan updates to explicitly incorporate new science, evidence and approaches to reducing natural system vulnerability to climate change and extreme weather – starting with results presented in this and other vulnerability assessments.

Rationale:

While numerous high level frameworks exist to undertake vulnerability assessments generally (e.g., Gleeson *et al*. 2011), the collection of available technical and guidance documents relevant to Peel Region was largely developed at a time when climate science and data were not well understood, accessed or incorporated into natural system/watershed planning and management. Some of the more obvious and important strategy, plan, study or assessment updates include:

- Urban Forest Strategies, Studies and Planting Programs: Locations of climate sensitive vegetation and 'gaps' in the urban forest canopy where land surface temperatures are extreme are provided in this report. This knowledge can be used to update priority planting locations to 1) meet canopy targets while serving to lower maximum land surface temperatures and further manage UHI and 2) anticipate where more climate-tolerant species will likely be needed in the future.
- Update the natural heritage system, restoration strategies and associated mapping to incorporate new information about natural system vulnerability, particularly where climate sensitive vegetation exists and likely requires more proactive management to minimize lag time in vegetation regrowth and/or prevent invasive species movement should large swaths of natural areas decline. Strong integration of terrestrial, groundwater and aquatic system functions and processes is also an important update to consider as this report specifically illustrates how and where vulnerabilities in one system cascade and effect vulnerabilities in another.
- Prioritize the implementation of stream and shoreline protection or restoration (form and function) plans based on locations of stream-based vulnerabilities identified in this assessment (and other vulnerability assessments related to water infrastructure, the Lake Ontario shoreline for Peel Region) and incorporate the climate change rationale when delivering erosion and sediment control training courses (i.e., the link to exacerbated water quality and increased stream form vulnerability due to more frequent or intense rainfall).
- Complete or update in-stream barrier assessments and prioritization exercises (including connectivity modelling) to ensure highest species diversity gains will be achieved through in-stream barrier removal or mitigation project implementation. Valley and stream crossing reports published to date (e.g., TRCA 2015e) are important references in this work.
- Consider increasing and enhancing terrestrial connectivity in plan input and review processes at the CAs, in restoration and stewardship programs and other relevant aspects of CA work.

The following is a list of existing natural system related management documents that contain synergistic recommendations for achieving adaptation outcomes and should continue to be implemented:

- Watershed Plans (Humber, Credit, Etobicoke and Mimico) and CVC Subwatershed Plans
- CTC Source Protection Assessments across the Region
- TRCA Terrestrial Natural Heritage System Strategy and CVC Natural Heritage System Strategy
- Watershed-based Fisheries Management Plans (TRCA and CVC)
- A variety of other TRCA and CVC strategies and plans (e.g., Water Management Plans, Conservation Areas Master Plans, Valley and Stream Corridor Crossing Guidelines by TRCA and CVC)
- Water Balance for Protection of Natural Features (TRCA and CVC)
- Peel Region Urban Forest Strategy
- Town of Caledon Urban Forest Study
- City of Brampton Urban Forest Study
- City of Mississauga Urban Forest Study
- Brampton Grow Green Environmental Master Plan
- Natural Heritage and Environmental Management Strategy (Brampton)
- Natural Heritage and Urban Forest Strategy (Mississauga)

10. Ensure effective collaboration, appropriate coordination and streamlined information sharing between CAs, amongst the Peel Community Climate Change Partnership, with other adjacent or upstream municipalities, and with the provincial and federal governments.

Rationale: Climate change is everyone's issue; no single group has all the answers, resources, capacity or responsibility to manage natural systems and transform our watersheds and communities into a resilient region. Identifying shared outcomes and objectives that can be achieved through both collaborative actions and coordinated knowledge mobilization of more group-specific activities should be central to how we do business and select priority work. An important example of this type of collaboration could be applying the concept of Integrated Watershed Management. Collaboration, analysis and partnership between CAs, regional municipalities and municipalities upstream may make for effective and beneficial results to implement adaptation upstream. Likewise, similar vulnerability assessments should be undertaken across CVC and TRCA jurisdictions to further enhance the resilience of our natural systems and to promote knowledge sharing and increase uptake. Peel Region is a leader in conducting vulnerability assessments and in watershed protection; this should be shared to increase mutual benefits.

9. LIST OF RESOURCES TO SUPPORT ADAPTIVE CAPACITY IN PEEL REGION

There are numerous resources in Peel Region at the regional and municipal level that can increase adaptive capacity within the natural heritage system. The assessment framework employed in this report identifies adaptive capacity as an attribute of the natural systems that can reduce vulnerability to existing and potential future climate impacts. There are specifically five main categories of resources that can be regarded as determinants of a system's adaptive capacity (ICLEI 2010): policies and regulations, human and social capital, information and knowledge, physical resources (on-the-ground programs or pilots), and financial resources. Table 30 summarizes examples within all of these categories which incorporate natural systems into planning and decision making. Notably, this information was collected in the summer of 2014 and should be updated to ensure the most recent policies and programs are included. While it was beyond the scope of the current assessment to conduct an in-depth analysis of each of these policies, adaptation strategies could benefit from this information.

Table 30 demonstrates that there are a large number of adaptive capacity resources present and that this can assist in reducing the vulnerability of the natural systems in Peel Region. These policies and programs provide ways to innovate what stakeholders are already doing in the region. For example, the City of Mississauga's stormwater charge will help reduce the risk of flooding while protecting water quality. Beginning in January 2016, residents and businesses will be required to pay a fee to the city based on the amount of hard surface on their properties. Thus, this program seeks to incentivize pervious surfaces and the use of capturing stormwater onsite through permeable pavement and other such applications to reduce higher amounts of water flowing overland. It is through the effective use of the resources in Table 30 that adaptive capacity can be built to reduce the vulnerabilities in the natural systems to climate change.

Table 29: Synthesis of Resources for Adaptive Capacity in Peel's Natural Systems

Resource Category		Resources in Peel
Policies and Regulations (e.g., Natural Heritage, Urban Forest, and other policies which incorporate natural systems components like Built Form and Planning)	Policies and regulations – targeting and Focusing on Improving Peel's Natural Heritage Explicitly	• Official Plans (Peel Region, Caledon, Brampton, Mississauga) • Environmental Progress Action Plan (Caledon) • Credit River Watershed and Peel Region Natural Areas Inventory • Open Space & Parks: Regional Official Plan • Peel Region Urban Forest Strategy • Town of Caledon Urban Forest Strategy • Woodlands By-Law (Caledon) • Brampton Grow Green Environmental Master Plan • Natural Heritage and Environmental Management Strategy (Brampton) • City of Brampton Urban Forest Study • City of Mississauga Urban Forest Study • Urban Forestry Management Plan • Woodlot Conservation By-Law (Brampton) • Natural Heritage and Urban Forest Strategy (Mississauga) • Urban Forest Study and Management Program (Mississauga)
	Policies and regulations – Incorporating Natural Heritage as a Component of Decision Making	• Peel Climate Change Strategy • Grown in Peel: Urban Agriculture & Food Systems • Regional Sustainable Development Guidelines Project (Built Form) • Regional Stormwater Policy and Water Resources Background Paper • Storm Sewer Inventory • Sustainable Community Development Guidelines (Brampton) • Parks, Culture and Recreation Master Plan (Brampton) • PathWays Master Plan (Brampton) • Green Development Strategy (Mississauga) • Credit River Parks Strategy (Mississauga) • Living Green Master Plan (Mississauga)
Human and Social Capital	Conservation Authorities	• TRCA • CVC
	Social networks, resource sharing, community and social capacity	• Peel Adaptation Working Group • Peel Mitigation Working Group • Peel Agricultural Advisory Working Group • Halton-Peel Woodlands and Wildlife Stewardship • Alliance for Resilient Cities • Partners for Climate Protection • The Friends of the Greenbelt Foundation • Peel Environmental Youth Alliance • Community Environment Alliance of Peel • Caledon Countryside Alliance • GTA Clean Air Council • Regional Air Quality Working Group

Resource Category		Resources in Peel
	Research, technology and access to information	• Ontario Universities specializing in natural heritage adaptation research (University of Toronto, University of Waterloo, Western University, University of Guelph, etc.) • Conservation Authority research programs • Federal, provincial and municipal government and conservation authority grants supporting adaptation
Information and Knowledge	Climate Change and Natural Heritage	• Peel Vulnerability Assessments (ongoing) for Agriculture, Water Infrastructure, Natural Heritage, Public Health, Community, etc. • Watershed Plans (Humber, Credit, Etobicoke and Mimico) and CVC Subwatershed Plans • CTC Source Protection Assessments across the Region • TRCA and CVC Natural Heritage System Strategies • Watershed-based Fisheries Management Plans (TRCA and CVC) • A variety of other TRCA and CVC strategies and plans (e.g., Water Management Plans, Conservation Areas Master Plans, Valley and Stream Corridor Crossing Guidelines by TRCA and CVC) • Peel Region Urban Forest Strategy • Town of Caledon Urban Forest Strategy • City of Brampton Urban Forest Study • Brampton Grow Green Environmental Master Plan • Natural Heritage and Environmental Management Study (Brampton) • Natural Heritage and Urban Forest Strategy (Mississauga)
Financial Resources	Incentive Programs and Funding Relevant for the Natural System	• Managed Forest Tax Incentive Program • Conservation Land Tax Incentive Program • Community Green Fund (Caledon) • Stormwater Charge Program (Mississauga) • Landowner Action Fund (Credit River Watershed) • Peel Rural Water Quality Program

Resource Category		Resources in Peel
Physical Resources	Government Programs and Services in Peel	• Tree Planting Services • Ecological Gifts Program • Greenlands Securement Program • Landowner Outreach and Education Pilot Project • Peel Rural Water Quality Program • Low Impact Development Pilot Median Planter Project • WaterSmart Peel • Tree Workshops • Native Tree Seedling Program (Caledon) • Active Inventory System (Brampton) • Sustainable Neighbourhood Retrofit Action Plan Program (SNAP at TRCA) • Valley Re-Naturalization Program (Brampton) • Natural Areas Survey (Mississauga) • One Million Trees (Mississauga) • Comprehensive Programs and Services offered by Local Conservation Authorities: TRCA & CVC, such as: - Terrestrial Monitoring & Ecosystem Enhancement Programs - Wetland, Stream and Pond Management Services - Habitat Protection and Restoration - Low Flow Management Program - Low Impact Development Guidelines - Greenlands Acquisition Project - Etc.

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