VULNERABILITY ASSESSMENT

Agricultural 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

RSI RISK SCIENCES INTERNATIONAL

Action on Climate Change in Peel Region

The Region of Peel recognizes that working together with regional municipalities, Conservation Authorities, and local citizens is paramount to addressing the challenge of climate change. In 2011, the Region developed the Peel Climate Change Strategy in partnership with lower tier municipalities (Brampton, Mississauga and Caledon) and local Conservation Authorities (Credit Valley Conservation and Toronto and Region Conservation) to build resilience and adaptive capacity to climate change.

The Strategy serves as a road map for addressing climate change impacts locally 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 2016, this vulnerability assessment was completed, which studies the impacts of climate change on agricultural systems in the Region, with a focus on oil seed and grain crops. The following summary of that assessment was prepared by Hutchinson Environmental Sciences Ltd. and Shared Value Solutions Ltd., in collaboration with the Toronto and Region Conservation Authority, 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. Statistics were derived mainly from the 2011 Agricultural Census, with some comparisons to the 2006 Agricultural Census.

Suggested citation for the full technical report:

Harris, S., Hazen, S., Fausto, E., Zhang, J., Kundurpi, A., Saunders-Hastings, P. 2016. **Climate Change Effects on Agricultural Production in the Region of Peel.** An Assessment of Vulnerabilities and Potential Opportunities. 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. Efforts are underway to address the problem at all scales, from local to global. While reducing greenhouse gas emissions is clearly an essential part of this strategy, we also need to plan for how we adapt to the impacts of climate change which are already happening and forecasted to get worse in the future. Adaptation to climate change will play a critical role in minimizing negative climate impacts on our society, economy and the natural world.

The purpose of the vulnerability assessment is to understand the impacts of climate change on agriculture within Peel Region.

Calls to Action

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

- ✓ Start or continue adaptation planning, leveraging this and other community assessments and datasets to increase adoption of farming best management practices (BMPs).
- ✓ Be proactive by working with farmers to minimize harmful impacts of climate change.
- ✓ Protect ecosystem services (such as flood and erosion control, habitat diversity, water quality) as well as farming infrastructure, technologies and inputs so that natural and built resources can better cope with variable and extreme weather.
- ✓ Enable investment in new technologies and innovative approaches that consider flexibility to changing conditions (such as climate change and urbanization).
- ✓ Promote collaboration of government, farmers, community interest groups and agricultural suppliers to prioritize best adaptation approaches, seize opportunities, and avoid top down regulations.
- ✓ Encourage a holistic conversation and knowledge transfer among suppliers, farmers, markets and consumers on the future impact of climate change on the Region's agricultural systems.

DEFINING RESILIENCE AND ADAPTIVE CAPACITY TO CLIMATE CHANGE

Agriculture, by nature, is sensitive to climate and weather. The degree to which farming is vulnerable to changes in temperature, precipitation or extreme weather events will depend on its **adaptive capacity**: the ability to adjust to changing conditions over time. This in turn will result in **resilience**: the ability to cope and remain productive under a range of different and highly variable conditions. Both resilience and adaptive capacity are influenced by the ability to mobilize resources and learn from experience.

DEFINING AGRICULTURAL VULNERABILITY TO CLIMATE CHANGE

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

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

How Does Climate Change Affect Agriculture?

Climate plays a significant role in agriculture. Among other things, it influences the suitability of land for farming, what crops can grow, the availability of water for crops and livestock, and how smoothly farm operations run (such as irrigation systems and pest management approaches).

Farmers have always depended on predictable weather patterns to plan and manage their farming activities. Climate change will lead to increasingly variable and unpredictable conditions, making it difficult to forecast how long the growing season will be, or when to plant and harvest. At the same time, extreme weather, such as flooding and drought, is expected to become more frequent and severe, leading to numerous potential impacts such as the following:

- Water-logging of fields
- Soil erosion
- Pest infestations
- Leaching of nutrients
- Water scarcity

Peel's Agricultural Profile

Farming is already under pressure in Peel Region because of urban development and rising human population. Climate change will bring additional threats to the sector. It is crucial that farmers and agricultural decision-makers have the information they need both to envision the impacts of climate change on their livelihoods, and to plan effective responses to those impacts.

- Peel has some of the most productive agricultural land in Canada.
- Of the Region's farmland, 62% is considered prime, and only 25% is considered marginal.
- Based on the 2012 MPAC assessment, approximately 45% of the Region's total land base is used for farming, most within the Town of Caledon.
- Between 2006 and 2011, the number of farms in the Region declined by 8.5% and the area of land used for agriculture declined by 1.5%.
- Agricultural sectors that declined most were dairy cattle (-40%), beef cattle (-32%), and greenhouse production (-20%), while oil seed and grain farming increased the most (+42%).

The frequency and severity of extreme weather events, such as flooding and drought, is projected to increase.

- Peel farmers benefit from their proximity to a large consumer market in the Greater Toronto Area (GTA), but also face threats from urban development and high population growth.
- Peel's population is rapidly increasing, with currently 1.3 million people living in the Region, putting pressure on natural areas and farmland.
- In addition to land development pressures associated with urban sprawl, farming in the GTA faces challenges related to high capital costs, decreasing commodity prices, and fewer people choosing to farm. These factors are expected to worsen the effects of climate change on farming in the future.
- As of July 1, 2017, amendments to the Ontario Growth Plan for the Greater Golden Horseshoe (GGH) take effect and include new policies to better manage and protect farmland in GGH growth areas. These policies should be implemented as part of the response to reducing Peel's agricultural systems vulnerability to climate change impacts described in this assessment.

Possible Futures Under Climate Change

Climate Trends in Peel Region

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

Climate change will directly affect farming in several ways within Peel Region. The growing season will likely extend by between 34 and 54 days on average over the next 60 years, but unseasonal frost may become more frequent both early and late in the season. While a longer growing season and some other changes could boost crop yield and present other opportunities, more frequent heat waves and drought during the summer will be damaging for many types of crops.

Impacts on Ecosystem Services

Healthy farmland does not exist in isolation. It needs to be nested within a broader landscape that features a variety of healthy, thriving natural

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 (from 12 days/ year now to 26 days/year)
- The intensity of extreme storms will increase by 28-51%
- The growing season will be 20% longer than today (from 169 days currently to 203 days)

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 (62 days/year)
- The intensity of extreme storms will increase by 46-90%
- The growing season will be 30% longer than today (up to 223 days/year)

environments, such as forests, wetlands, rivers and lakes. These natural systems provide a number of ecosystem services that benefit farming, such as habitat for crop pollinators, regulation of water quality and quantity, and control of soil erosion. However, climate change threatens the normal functioning of the natural environment, which will have cascading effects on farming. In Peel Region, this could mean that there will be shifts in the types of crops that can grow, and changes in when and how much water is available for crops and livestock.

STAKEHOLDER ENGAGEMENT

Farmers and agricultural decision-makers are the ones directly experiencing the effects of climate change on agriculture, and thus their input for this vulnerability assessment was critical. Stakeholder engagement was a key component of the assessment process and occurred at every step to ensure that stakeholders' perspectives, experiences and knowledge were considered and incorporated.

A broad cross-section of agricultural stakeholder groups was consulted for the report:

- The Town of Caledon
- The City of Brampton
- The City of Mississauga
- The Peel Agricultural Advisory Working Group
- The Peel Federation of Agriculture
- The Peel Soil and Crop Improvement Association
- The Greater Toronto Area Agricultural Action Committee
- The Golden Horseshoe Food and Farming Alliance
- The Ontario Soil and Crop Improvement Association
- The Ontario Climate Consortium
- Conservation Authorities
- Agricultural input supply companies
- Commodity groups
- Private sector businesses
- The Ontario Ministry of Agriculture, Food and Rural Affairs
- The Ontario Federation of Agriculture
- Agriculture and Agri-Food Canada

New Challenges Ahead

Climate change will bring fundamental changes to farming in Peel Region and farmers will face many new challenges. To maximize farming success under these new unpredictable conditions, farmers will need to rethink a number of important issues:

- What land to farm
- What crops and livestock to produce
- What farming practices to follow
- What infrastructure to invest in

In Peel Region, for instance, rising temperatures, more variable rainfall, and a longer growing season will likely put significant pressures on water supply. New approaches to water management may be needed to control the availability of water for farming. Farmers are on the front lines of dealing with climate change. The innovative ways in which they adapt and respond can be a powerful example for the rest of society.

What the Storylines Tell Us

The agricultural vulnerability assessment focused on four potential impacts of climate change on farming in Peel Region, which are presented in a series of storylines. The storylines link research on climate change impacts with current conditions in Peel, to illustrate potential vulnerabilities and highlight potential ways farmers can adapt.

Storyline 1: Extreme Precipitation

Storyline 3: Extreme Heat

Storyline 2: Drought

Storyline 4: Changes to the Timing of Growing Conditions

Storyline 1: Extreme Precipitation

Climate change is expected to produce stronger storms with heavier rainfall, which will affect oil seed and grain farming in a number of ways:

- Water logging and flooding of soils
- Soil erosion and changes to the availability of nutrients
- Outbreaks of pests and disease

The severity of impacts from severe storms will depend largely on when they occur during the growing season, and on the type of crops affected.

Winter, spring and fall will likely be wetter, while summer will be drier on average, but punctuated by heavy rainfall events.

Water Logging and Flooding

Water logging of fields is a particular concern if it occurs during planting or harvest periods, as it can delay farming activities. The longer farmers have to wait to sow seeds, the greater the chance that crops won't mature in time. Water logging during harvest, meanwhile, can lead to rust and fungal infections of grain, as well as sprouting of grain before it can be harvested.

The extent of damage to crops from water logging and flooding varies by plant type and stage of development. Corn, soybeans and wheat, for example, are most sensitive to adverse weather during early growth, flowering and grain filling stages. Corn yield can drop by more than 40% if prolonged flooding happens at the start of flowering or kernel development. Soybeans can tolerate floods lasting up to two days during their reproductive stages (i.e., blooming through full maturity) without any serious decline in yield. Different plant varieties also differ in their tolerance of extreme weather. Soybean types that are sensitive to flooding, for instance, experience a 77% reduction in yield compared with a 39% reduction for flood-tolerant types during the blooming period.

Low-lying lands are most susceptible to water logging and flooding, especially if drainage is poor. In Peel Region, these areas are mainly located in the northwest and south of the Niagara Escarpment, comprising roughly 1/3 of all farmland. Peel has only a small portion of farmland with poorly drained soil (2.5%), made up of clay and clay-loam, and this mainly occurs below the escarpment. Thus, vulnerable areas to water logging and flooding are generally concentrated south of the escarpment.

Tile drainage is an important management measure to reduce the risk of water logging and flooding in poorly drained areas. Currently 5.8% of Peel farmland has tile drains, mainly in fields used for cash crops or mixed farming south of the escarpment.

Corn yield can drop by more than 40% if prolonged flooding happens at the start of flowering or kernel development.

Farming practices can play a major role in determining the overall vulnerability of land to erosion and nutrient loss. The less physical disturbance of the soil the better.

Soil Erosion and Changes to Nutrient Availability

The more rain that falls during a storm, the greater the amount of soil that washes away, taking with it valuable nutrients needed by plants. Physical factors, such as slope and soil type, influence the vulnerability of soil to erosion and leaching. For example, steep terrain is more prone to erosion than flat land. Loamy soils tend to let water drain through without erosion, while clay soils resist being swept away by water flow. Most farms in Peel Region are not very vulnerable to soil erosion, but those that are generally occur in the northeast on the escarpment.

Farming practices can play a major role in determining the overall vulnerability of land to erosion and nutrient loss. The less physical disturbance of the soil the better. For example, conservation tillage (which leaves crop residues on the soil surface) is a proven technique to retain moisture and nutrients in the soil. Approximately 35% of Peel farms currently use no-till farming as a conservation tillage practice. Hay and pasture practices are least susceptible to soil erosion and leaching.

Pests and Disease

Climate change is expected to benefit existing agricultural pests and diseases and to lead to the introduction of new ones. Increased rainfall may help spread plant pathogens, such as rusts and bacteria, as well as insect pests, such as aphids and psyllids. At the same time, excess moisture could cause some weeds to flourish and out-compete crops for light and nutrients.

Farmers will need to adapt their Integrated Pest Management Strategies to deal with the increase in pest and disease outbreaks in crops.

Storyline 2: Drought

The frequency and duration of drought events will likely increase under climate change. Prolonged lack of water during the growing season can have serious impacts on crops including the following:

- Limiting growth and development
- Increasing pest and disease outbreaks
- Exposing plants to extreme heat

Drought reduces yield in soybean, corn and grains and can increase seedling death in maize. Dry soil conditions make it more difficult for plants to receive adequate supplies of nutrients during the growing season. Some agricultural pests and disease thrive when crops are stressed from lack of water.

Aphids, for example, proliferate during drought years, while some weeds can out-compete crops under dry conditions.

Crops vary in their vulnerability to drought depending on plant type and development stage. The table below illustrates the number of days two common crops can tolerate drought conditions. Similar information is needed for other crop types to determine management options and needs (such as irrigation and alternative drought tolerant cropping systems).

Farmers will need to adapt their farming practices to cope with more frequent and severe drought in the future. One way may be through increased reliance on irrigation, which accomplishes the following:

- Provides crops with the water they need when rainfall is scarce during critical growth stages
- Increases the opportunity for double cropping in a season
- Improves the overall quality and quantity of crops produced

Irrigation, which is currently used by only 12% of farms in Peel, may become an increasingly important practice across the Region in the future. However, this practice has its drawbacks. Irrigation is expensive and can put a strain on local water supplies. In Peel Region very few water taking permits currently exist for agriculture. There are many permits already issued for other uses in the area north of the escarpment, which may mean that water is not available for agriculture under climate change.

Farmers can mitigate the negative effects of drought in other ways as well. For example, type of cultivar, tillage practices, and pest and nutrient management strategies all play a role in determining the vulnerability of crops to drought.

There are many permits already issued for other uses in the area north of the escarpment, which may mean that water is not available for agriculture under climate change.

Thresholds at Which Wheat and Soybeans Show Negative Impacts of Drought

Crop Stage of Development	Wheat Threshold	Soybean Threshold
Initial stage	30 days of reduced rain (< 9 mm)	10 days of reduced rain (< 8 mm)
Developmental stage	30 days of reduced rain (< 34mm)	20 days of reduced rain (< 35 mm)
Middle stage	40 days of reduced rain (< 119 mm)	40 days of reduced rain (< 131 mm)
Late stage	40 days of reduced rain (< 85 mm)	20 days of reduced rain (< 33 mm)
All stages	More than 8 consecutive days without rain	

Storyline 3: Extreme Heat

The frequency, intensity and duration of heat waves is expected to increase in Peel Region under climate change. Heat stress affects plants in a variety of ways:

- Reduced photosynthesis
- Scorched leaves and stems
- Dead leaves and seeds
- Reduced pollen production and viability
- Reduced grain number and weight

Most plants are more vulnerable to extreme temperatures when they are in their reproductive stage, and even short spikes of heat (a few hours long) can dramatically reduce crop productivity and yield. Farmers may need to switch to crops and cultivars that are bred to withstand higher temperatures. They may also rely increasingly on irrigation, which cools plants and reduces heat stress. Drought and extreme heat will interact under climate change to amplify damage to crops.

Farmers may need to switch to crops and cultivars that are bred to withstand higher temperatures.

Storyline 4: Changes to the Timing of Growing Conditions

Climate change will alter temperature and rainfall patterns, affecting both growing conditions and length of growing season. Farmers will likely be able to plant and harvest crops earlier than they have in the past, which will be beneficial as long conditions remain favourable for crops throughout the season. For example, if frost occurs during the earlier planting period this may damage crops early on in the season. Similarly, extreme rainfall or heat waves over the course of the summer could reduce any gains in yield from a longer growing season.

Climate change will alter temperature and rainfall patterns, affecting both growing conditions and length of growing season.

Crops respond differently to changes in conditions depending on their type and stage of development. In southwestern Ontario, precipitation in January and April could mean lower corn and soybean yields, but higher wheat yield. Precipitation in July, meanwhile, could lead to higher yields of corn and winter wheat. While drought is expected to become more common, heavy rainstorms will also be more frequent in summer. Even a modest increase in total summer rainfall (50 mm more in a season) could help counteract the damaging effects of increased heat on crops, with potential increases in yield of 5-10% for wheat and soybeans.

An extended growing season and warming temperatures could have positive impacts initially on corn and soybean yields. Climate projections suggest, however, that after a certain threshold these crops could collapse.

Where Do We Go From Here?

Climate change is real and it's happening now. This vulnerability assessment has shown that there are many potential negative impacts of climate change on farming in Peel Region. However, by taking a proactive approach to the problem, farmers and agricultural decision-makers can minimize harmful effects on the agricultural sector, while at the same time taking advantage of new opportunities of a changing climate.

Adaptive Management Considerations

Agricultural adaptation to climate change will need to occur across multiple scales, both on and off the farm. Specific approaches may differ throughout the Region, since the extent and nature of climate change impacts is expected to vary geographically based on soil type. A wide array of farming best management practices, technologies and strategies already exist that could form part of an adaptation plan for farming in Peel Region.

Farms within Peel Region have a higher rate of adoption of BMPs relating to soil conservation and environmental protection compared with other Ontario farms. However, most of these practices are used in fewer than 30% of farms in the Region, showing that there is considerable opportunity to expand their benefits. These BMPs represent a critical way to address many of the vulnerabilities highlighted in the storylines. They also provide additional benefits for farms, by conserving soil and water resources while lessening reliance on artificial farm inputs. Advancing the use of these and other innovative approaches to farming will position Peel at the leading edge of agricultural adaptation.

Select Best Management Practices and Potential Benefits for Reducing Vulnerability

On-farm Practice	Climate Resiliency Benefits
Conservation tillage/no till/intercropping	Minimize soil erosion and runoff; retain soil moisture; retain nutrients, pest management, frost protection
New rotations, harvesting schedules and varieties	Take advantage of new climate regimes by double cropping, staggering crops, and planting crops adapted to the different growing conditions
Drainage	Reduce flooding
Water reuse	Mitigate drought
Ongoing monitoring	Test field practices (timing, techniques) and climate resilient crop types to optimize best approaches under climate change
Off-farm Practice	
Funding	Provide financial support for testing of new field practices and crop types
Communication	Promote transfer of knowledge and success stories within the farming community

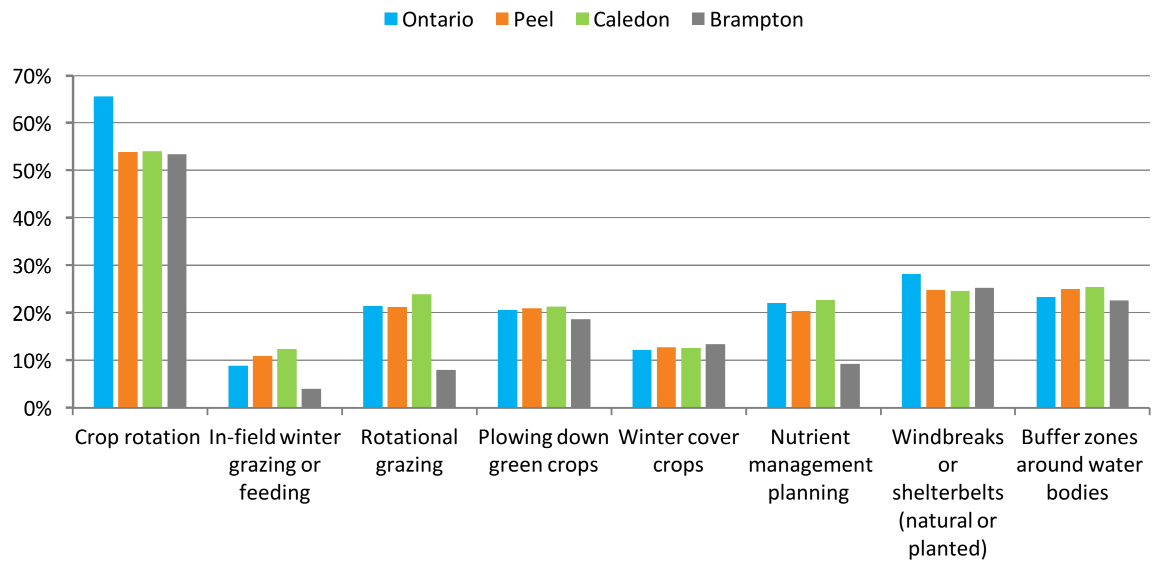
WHAT THIS VULNERABILITY ASSESSMENT IS

- Part of the research phase of the adaptive management process Peel is undertaking to respond to climate change
- Technical assessment to understand how agricultural systems in Peel respond to climate change
- Characterizes 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 agricultural systems
- Provides background information that could be used in future risk assessments
- Developed through widespread consultation with local stakeholders (farmers and agricultural decision-makers)

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 agricultural systems
- Does not evaluate resources or programs available in Peel Region to support adaptation planning and implementation

Adoption Rate of Agricultural Best Management Practices by Farms Within Peel Region and Ontario (From the 2011 Census).



Strengthening Adaptive Capacity

Climate change will bring considerable uncertainty and variability to agricultural systems. As a result, business as usual may no longer be effective. Farmers and decision-makers will need to be flexible and responsive to build resiliency under these new conditions.

Many potential approaches exist for building adaptive capacity, and it can be challenging to assess and prioritize the best way forward. At a systems scale, Agriculture and Agri-Food Canada has developed Envision, an integrated decision support tool based on scenario testing to enable adaptation planning on a landscape scale: <https://www.iisd.org/sites/default/files/publications/mainstreaming-climate-change-toolkit-briefing-note.pdf>

Farmers will need to actively engage with stakeholders beyond their farms for adaptation to be truly successful. The cooperation, knowledge and support of both upstream and downstream players will be essential. Upstream, companies that supply farmers will need to understand how to adapt to climate change, so that this information and associated products can be passed along to farmers. Downstream, farmers will need to consider the preferences of wholesalers, exporters, retailers, and consumers when they make their choices on crops, technologies and practices best suited for climate change. Also, farmers should plan to communicate with other downstream markets to let them know what climate change means for farming, and how this may affect product selection, availability and price as a result.

Climate Change Effects on Agricultural Production in the Region of Peel

An assessment of vulnerabilities and potential opportunities

Complete Technical Report

Prepared for:

Region of Peel
Working for you

Prepared By:

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

RECOMMENDED CITATION

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

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ACRONYMNS

AAFC	Agriculture and Agri-food Canada
ACRI	Agro-climatic Resource Index
BMP	Best Management Practice
CHU	Crop Heating Units
CLI	Canada Land Inventory
CMIP5	Fifth Coupled Model Inter-comparison Project
CSA	Climate-smart Agriculture
CVC	Credit Valley Conservation
FAO	Food and Agriculture Organization of the United Nations
FAO	Food and Agriculture Organization
FIPI	Farm Input Price Index
GCM	Global Climate Model
GTAAAC	Greater Toronto Area Agriculture Action Committee
GTHA	Greater Toronto-Hamilton Area
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change
IPMs	Integrated Pest Management Strategies
MNR	Ontario Ministry of Natural Resources and Forestry
OFT	Ontario Farm Trust
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
PAAWG	Peel Agricultural Action Working Group
PCCS	2011 Peel Climate Change Strategy
P-CRAFT	Peel Climate Risk Analysis Framework and Templates
RCP	Representative Concentration Pathway
RUSLE	Revised Universal Soil Loss Equation
TRCA	Toronto and Region Conservation Authority
USLE	Universal Soil Loss Equation
WMO	World Meteorological Organization

1. INTRODUCTION

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

1.1. Adaptive Management

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

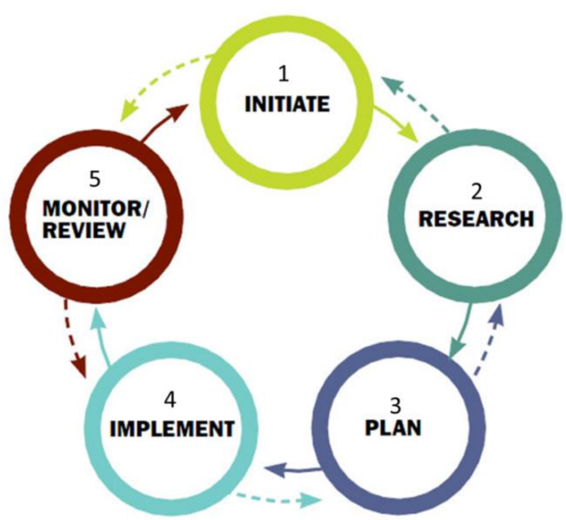

Figure 1: Five milestone adaptive management cycle (from ICLEI, 2012)

1.2. **Peel's Climate Change Planning Process and Strategy**

The Region of Peel, in partnership with the cities of Brampton and Mississauga, Town of Caledon and the Credit Valley and Toronto and Region Conservation Authorities, developed the 2011 *Peel Climate Change Strategy* (PCCS), as a roadmap for addressing climate change impacts locally (Region of Peel 2011). The original PCCS identified six major objectives to mitigate and adapt to climate change, as follows:

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

For each objective, the strategy identified specific actions that stakeholders could undertake to support effective mitigation of, and adaptation to climate change. A timeframe, thematic focus area, and set of responsible stakeholders were identified for implementing each action. In order for several of these individual activities and adaptive management more broadly to proceed, substantial work to characterize climate change impacts and system vulnerabilities was identified as important prerequisite within Objective 1.

Currently, the strategy is in the process of being updated with refined information on sector-specific climate change effects, primarily focused on risks and vulnerabilities. This information will feed into community consultation and policy analysis designed to synthesize the findings from these reports into an integrated climate change strategy update for the Region of Peel. This synthesis/update process is an important step in the adaptive management process being used to respond to climate change and other policy pressures in the Region of Peel.

1.3. **Agricultural Assessment Objectives, Scope and Limitations**

This assessment is designed to feed directly into the process of adaptive management being implemented in the Region of Peel to plan for climate change. Specifically, this report aims to contribute to PCCS's Objective 1, through the work outlined by Action 1.1[1]. More broadly, this report falls within Milestone 2 (Research) of the ICLEI framework (Figure 1), which intended to provide the information needed for developing an adaptation plan in Milestone 3. Give this context, the objective of this assessment is to understand the climatic, biophysical and human factors that influence climate change impacts and vulnerabilities within the dominant agricultural production systems in the Region of Peel.

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[1] **Objective 1 - Action 1.1** mandates the completion of "a vulnerability risk assessment of all infrastructure, of the community and of natural heritage" within the PCCS goal of "proactive and responsive planning and leadership". Together, this goal and action provide the foundation for adaptive management within the Region of Peel.

This information is then used at the conclusion of the report to identify a preliminary set of alternative options (e.g. best management practices, farming practices/technologies, broader sector strategies, and resources available to the agricultural sector) based fundamental principles in agricultural adaptation that have emerged over several decades of research in this area, for responding to major impacts and vulnerabilities presented through the report. This set of alternatives is not meant to be a prescription for addressing agricultural 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 (i.e., “Plan” step in Figure 1).

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

- What are the climate change effects relevant to agricultural production in the Region of Peel (positive and negative impacts)?
- What are the processes and factors that influence vulnerability to climate change?
- What are the current adaptive capacity resources that contribute to reducing vulnerability to climate change?
- What are some potential adaptation alternatives that could be implemented to reduce vulnerability and take advantage of opportunities?
- What key questions related to climate vulnerability and adaptation in agriculture still need to be answered?

To address the objectives and research questions posed, this assessment emphasizes characterizing current climate vulnerability in the Region of Peel in order to identify the most salient factors that influence the extent, magnitude and overall character of climate and weather impact on farming today (IPCC 2014). Future climate scenarios are also considered, and are used to assess how this current vulnerability might change under the influence of climate change. This approach of considering current vulnerability first and then using future climate scenarios to determine which climate conditions most critical to agriculture today and in the future is presented in Figure 2. It is also consistent with the approach to vulnerability assessment presented in FAO (2013) which suggests that “relationships between climate and agriculture now and in the past can be combined with future climate projections to infer associated potential impacts on agriculture” (p. 500). Other agricultural climate vulnerability assessments, such as Reid et al. (2007), Espeseth (2012) and Lim et al. (2004) have employed similar approaches.

Because climate change is also anticipated to result in conditions that are potentially advantageous to agricultural, namely increases in heat units and growing season length, these trends and the associated potential opportunities are also explored. The overall assessment approach described above is aimed at enabling the identification of factors and processes that are critical in mediating the effects of climate on agricultural production. Targeting these factors through adaptation actions is then assumed to be an effective initial starting point for addressing climate change effects.

Given time and resources available for this project, and priorities of stakeholders, a thematic focus is placed on the interaction of climate with grain and oilseed, or cash crop production systems, with an aim of understanding the processes and factors that influence crop productivity at the farm scale (see Figure 2). The rationale for selecting cash crop production as the focus is that it is the single largest form of production in terms of number of farms in the Region, land area, and farm receipts. Cash crop production also supports higher-value production systems, such as livestock through the provision of feed, and by supplementing the income of many horticultural producers. Despite this narrow focus, many of the findings on cash crop vulnerabilities are transferrable to other crop systems. In particular, detailed descriptions of climate impacts on soil health and nutrient availability, pests and disease, and the timing of farming operations will be relevant to other crop production systems. Detailed information on the characteristics of Peel's agricultural system is provided in Section 2.2 and Section 3.3 describes the scoping process in more depth. Together these report sections further rationalize the scope selected for this assessment.

Finally, it is recognized that many other systems and contextual factors contribute to the effects of climate change on agriculture, such as ecosystem health, water resources, local community characteristics, economics, government services and program, on and off-farm infrastructure, among many others. It is however, beyond the scope of this report to examine all these systems and their effects on agriculture in detail. Many of these systems are currently undergoing equivalent climate change assessments that can be consulted during subsequent planning processes that will require such information. Section 2.1 of this report does however describe the linkages of these systems to agricultural production and their influence in mediating climate change effects on farming.

This assessment does not represent a total scan of the entire agricultural sector in the region in the region of Peel. This study is focus on a single commodity group, grains/oilseeds. Additionally, this report is not a risk assessment that weights the different impacts discussed against one another. Rather it is aimed at providing the information to allow a risk assessment process to be undertaken. This is in accordance with the steps for risk and vulnerability assessment in many guidance documents, such as Gleeson et al. (2011), ICLEI (2011) and UKCIP (2003). Other prominent commodity group in Peel that were considered included the tender fruit, horticulture, livestock and equine sectors; however, based on stakeholder input, they were prioritized as being less important and in need of detailed analysis at this time. Nonetheless, it is likely that many of the findings concluded from this study will be applicable to those commodity groups. Additionally, significantly more research was available on certain impacts and system components than others. For instance, corn had a far greater abundance of information than the other crop types, and drought related impacts dominated the types of impacts where there was applicable research.

1.4. Intended Audience

This technical report is intended to be used by regional and municipal officials, decision makers and interest groups within the agricultural sector for planning purposes. It contains information relevant to the major effects of climate change on agricultural production in the Region of Peel.

Given the focus on impacts at the farm-scale, many of the findings are directly relevant to agricultural stakeholders and farmers in the Peel and other Great Toronto Area communities.

By understanding the anticipated implications of climate change for agricultural production, decision makers can identify and prioritize alternative responses that represent viable adaptations. Such adaptation measures may be implemented through farm-scale practices, broader policies and programs, or by building adaptive capacity across a range of other management contexts. Ultimately, the aim would be for such initiatives, and the role of decision makers, to foster more resilient agricultural systems and rural communities.

1.5. **Issues and Needs**

1.5.1. *Climate Impacts on Agriculture*

The most recent assessment of climate change (Box 1) by the Intergovernmental Panel on Climate Change (IPCC) concluded "with certainty" that human influence has been the main cause of recently observed global temperature increases (IPCC 2014). The IPCC found that if global GHG emissions are not significantly reduced, warming trends will continue, leading to a shift in the overall timing, magnitude, variability and frequency of temperature, precipitation and seasonality, as well as more intense and recurrent extreme weather events. Through its 2014 report, the IPCC group of scientists warned that at the current rate of warming, significant impacts to a variety of human dependent systems are likely (IPCC 2014).

Box 1: Definition of climate change

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

(IPCC 2014)

Moderate increases in precipitation and temperature during the growing season are typically viewed as potential opportunities for agriculture, and are generally projected for southern Ontario and Peel under scenarios of climate change (Auld et al. 2015; Campbell et al. 2014). Canada's national 2014 climate adaptation report, entitled *Canada in a Changing Climate,* concluded that agricultural production in many parts of the country including southern Ontario, may benefit from these trends, but only if the potential risks associated with climate change are also managed (Campbell et al. 2014). This is consistent with global-scale findings presented in IPCC (2014) and recognized through the Food and Agriculture Organization of the United Nations' *Climate-Smart Agriculture* program (FAO 2013) (Box 2).

It is projected that climate change in southern Ontario will reduce the predictability and increase the variability in agro-climate variables from year-to-year, and also increase the frequency and intensity of extreme weather events (Auld et al. 2015; Campbell et al. 2014). Such changes are of concern due to the potential direct effects of climate variability and extremes on crop yield, field management practices, livestock production, infrastructure, ecosystem services and economic environment required to support agricultural production (Campbell et al. 2014; He

2012).There are also a host of indirect climate impacts faced within the agricultural sector, that are driven by a complex web of interactions among various systems that ultimately support farmers and the agricultural sector. For instance, with a changing climate there is potential for changes the presence of natural pollinators, water supply availability and quality, shifts in crop suitability and agro-ecological zones across the landscape, and the host of economic effects of such shifts both locally and globally (Campbell et al. 2014).

At the core of agriculture is recognition of the fundamental limits of both the landscape and socio-economic context within which the production of food, fuel and fiber occurs. Farmers have always operated with an astute awareness of the feedbacks and interaction of farm systems with the hydrologic cycle, soils, natural ecosystems, global and local economies, built infrastructure and community social structures (Cabell et al. 2011). However, climate change is likely to continue altering the nature of those relationships as the profile of risks and opportunity for agricultural production and the systems with which it interacts shift. Farmers have always managed to sustain a highly productive agricultural system through natural climatic variability; however, the weight of evidence surrounding climate change suggests that the range of variability and climatic conditions are likely to exceed those experienced historically (IPCC 2014). This means that variables such as growing season length, planting and harvesting dates, and heat unit accumulation will become increasingly challenging to anticipate. While the predictability in agro-climatic variables decreases, the severity of extreme events is also anticipated to increases under projected scenarios of climate change. This has and will continue to pose new decision-making considerations for farmers and agricultural decision makers regarding land and water allocation, production system selection, best management practices, and investments in infrastructure and other assets.

Box 2: Climate-Smart Agriculture

Many of the concepts associated with climate adaptation, including vulnerability, are embedded in the FAO's recently developed concept of "Climate-Smart Agriculture" (CSA). CSA is defined as an "integrative approach to address the interlinked challenges of food security and climate change" and it aims to promote "production systems that sustainably increase productivity, resilience (adaptation), reduces/removes GHGs (mitigation, and enhances the achievement of… food security and development goals" (FAO 2013).

Effectively managing multiple and interacting effects of climate change on agriculture, as described above, benefits from knowledge of their biophysical processes at play, decision making opportunities for adaptation, and an identification of key sources of uncertainty. Such analyses can enhance collective understandings of the potential threats and opportunities of climate change to local agricultural production, so that they can be managed through adaptive strategies. This report aims to advance this understanding in the Region of Peel specifically by providing information to information adaptive management.

1.5.2. *Mitigation of Climate Change*

It is important to note that agricultural production has an important role to play in the regulation of greenhouse gas (GHG) emissions, which has been directly linked to climate change (IPCC

2014). As such, curbing of emissions is a critical aspect of global, national and local responses to climate change. Based on its 2014 assessment of Canadian GHG emissions, Environment Canada estimates that approximately ten percent of the nation's total emissions are attributed directly to agriculture, at approximately 70 Mt of CO_2 equivalents per year (Environment Canada 2014). This value has remained constant since the benchmark year of 2005 and is projected to remain unchanged through 2020 (Environment Canada 2014). Agricultural land use practices have played a role in changing the global carbon cycle and the climate as a whole through the release of emissions from soil through tillage, livestock rearing, and the direct combustion of fossil fuels in farm operations (USEPA 2014; Houghton & Hackler 2001). On a national scale, the majority of these emissions are attributed to GHG releases from livestock production (45% in 2012), crop production (35% in 2012), with a lesser amount due to on-farm fuel consumption (20% in 2012) (Environment Canada 2014). There has yet to be any work to characterize agricultural emissions in Peel specifically, however it is reasonable to assume that similar source of emissions exist at the local scale, however the exact proportion of total emissions attributed to agriculture is currently not known. Local scale agricultural emissions are based on the balance of sources and sinks of methane, carbon dioxide and nitrous oxide associated with soil nutrient cycling and management, manure and fertilizer storage, energy use and biomass decomposition (Janzen et al. 2006).

1.6. **Defining Agricultural Vulnerability to Climate Change**

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

> *"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt"* (IPCC 2015, p. 1775)

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

> "*A present inability to cope with external pressures or changes, such as changing climate conditions... a characteristic of social and ecological systems generated by multiple factors and processes"* (IPCC 2015, p. 1762)

Future vulnerability is defined as:

> *"…the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability"* (IPCC 2015, p.1769)

With respect to a managed system such as agriculture, the aforementioned definitions suggest that vulnerability can be thought of as being comprised of three categories of factors that influence the overall potential for impacts, or vulnerability (Figure 2):

(1) The climate itself;
(2) biophysical factors that influence how climatic conditions are translating into impacts; and
(3) human, or management, factors that further mediate how climate influences agriculture, and abilities to adapt to changing conditions, including climate change and extreme weather.

As the climate changes and hazardous climate events and conditions occur in greater frequency, intensity and duration, the vulnerabilities in a given system can become more severe if sources of current vulnerability are not addressed. It is often recognized in climate change adaptation guidance that vulnerabilities can be addressed by increasing the adaptive capacity of a given system. This concept is explored further in Section 1.6, but is shown conceptually in Figure 2.

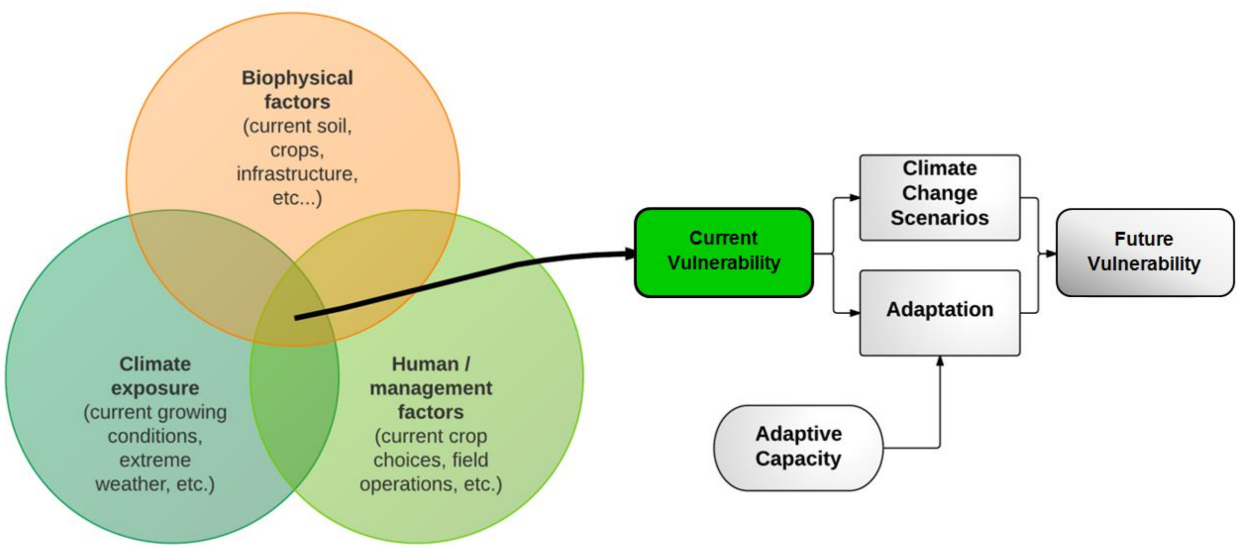

Figure 2: Conceptual diagram illustrating the factors that contribute to current vulnerability, the role of adaptive capacity in influencing adaptation, in combination with climate change scenarios that ultimately influence future vulnerability for agricultural systems.

1.7. Importance of Stakeholder Input

Given that agriculture can be fundamentally defined as the “science or practice of… growing of crops and the rearing of animals to provide food, wool, and other products” (Oxford Dictionary 2013), farm production systems can be regarded as managed natural ecosystems. As such, it is critical to consider the role and perspectives of farmers and agricultural decision makers when assessing potential climate change effects. Involvement of these groups in this research was a central element.

There are many key stakeholders that can influence adaptation, policies and programs in light of climate change locally in Peel Region and at the broader governing scale including: the Peel Agricultural Advisory Working Group (PAAWG), the Peel Federation of Agriculture (PFA), the Ontario Soil and Crop Improvement Association (OSCIA), Conservation Authorities, agricultural input supply companies, commodity groups, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), The Greater Golden Horseshoe Food and Farming Alliance, Ontario Federation of Agriculture (OFA) and Agriculture and Agri-Food Canada (AAFC) (Region of Peel Draft Agricultural Discussion Paper 2008). Throughout the development of this report, representatives from each of these stakeholder groups were consulted and provided the opportunity to comment on the final draft to ensure its relevance to the agricultural community.

1.8. **Report Structure**

This report is structured to gradually provide the reader more detailed analysis of the interaction between climate and agricultural production in the Region of Peel. Section 2 (Background) provides the necessary background on how the agricultural production system is defined and its relation to climate in general, in addition to qualitatively describing the fundamental connections between farm and supporting systems in Peel, and the policy framework(s) that may support adaptation. Section 3 (Methods) describes the detailed analytical methods used, and is supported by additional detail in several appendices. Section 4 (Results) presents the results of an analysis of the key climate effects and sources of vulnerability, as well as opportunities for the agricultural sector in the Region of Peel by first identifying and prioritizing impacts (4.1 and 4.2), then describing how climate variables relevant to agriculture are likely to change in the future (4.3), followed by an identification of the critical factors that make Peel's agricultural system vulnerable to climatic changes, including detailed descriptions of specific critical impacts through "Storylines". The report concludes by characterizing the current adaptive capacity in Peel (Section 5), in addition to identifying some potential adaptation alternative that might be considered to build the climate resilience of Peel's agricultural systems (Section 6).

2. BACKGROUND

2.1. The Climate Change Connection to Agriculture

Although advances in farming technologies and practices have successfully advanced the productivity of agriculture over time, variability and extremes in climate are still fundamental constraints within which farmers and the sector operate (FAO 2013). Climate (defined in Box 3), and therefore changes in climate, influence agricultural production both directly and indirectly and at various spatial and temporal scales. This Section introduces some of the major relationships between climate and agriculture and provides a conceptual model for understanding the vulnerability of a given agricultural region to climate change.

2.1.1. *Direct and Indirect Influences of Climate on Agriculture*

> **Box 3: Weather and Climate Defined**
>
> Weather is defined as the state of the air and atmosphere at a particular place and instant in time. Climate is a larger-scale expression of the weather conditions for a particular location and period of time, including variations and extremes.
>
> (Adapted from WMO 2011)

Climate directly influences agricultural production by regulating the amount and timing of energy and water available for farming in a given area. Additionally, climate variables such as air temperature, carbon dioxide concentration and the occurrence of extreme weather events can fundamentally limit the functioning of production systems (Mera et al. 2006) by exposing plants, animals, soil, and farm infrastructure to adverse conditions. Planting dates and access to fields for farm operations are directly tied to daylight hours, temperature and soil moisture conditions, factors that are all in-turn driven by local climate. The effectiveness of rural, on-farm and environmental protection infrastructure, such as irrigation systems, drainage canals, harvest storage structures, and runoff control facilities, are also directly tied to the precipitation, moisture and temperature regimes for which they were designed. As those regimes change, so will the effectiveness of infrastructure and operational procedures. The effectiveness of different field operations, such as nutrient and pest management, is also highly sensitive to climate conditions. Other than variables of soil, terrain, and water, climate is regarded as key physical determinant of agricultural suitability for a given area (Gagnon et al., 2014; Fischer et al. 2002), as well as market forces (Bradley et al. 2012).

Beyond the direct influences, climate influences farming through its interactions with the natural ecosystems, community infrastructure and services, hydrology and water resources, external markets, and local economies that support agriculture in a given area (IPCC 2014). For instance, climate and extreme weather can influence access to markets, including physical connections between rural and urban centres, availability of production inputs and physical access to points of sale for agricultural products. The climate also influences the functioning of ecosystems that provide important services to agriculture, such as pollination and regulation of water quantity and quality. Although assessing the vulnerabilities to these supporting systems is beyond the scope of this report, the connections between agricultural production, the supporting systems, and climate is presented graphically in Figure 3. Components in the "Systems Supporting/Influenced by Agricultural Production" box in Figure 4 are explored in greater detail in Section 2.1.2 through 2.1.5.

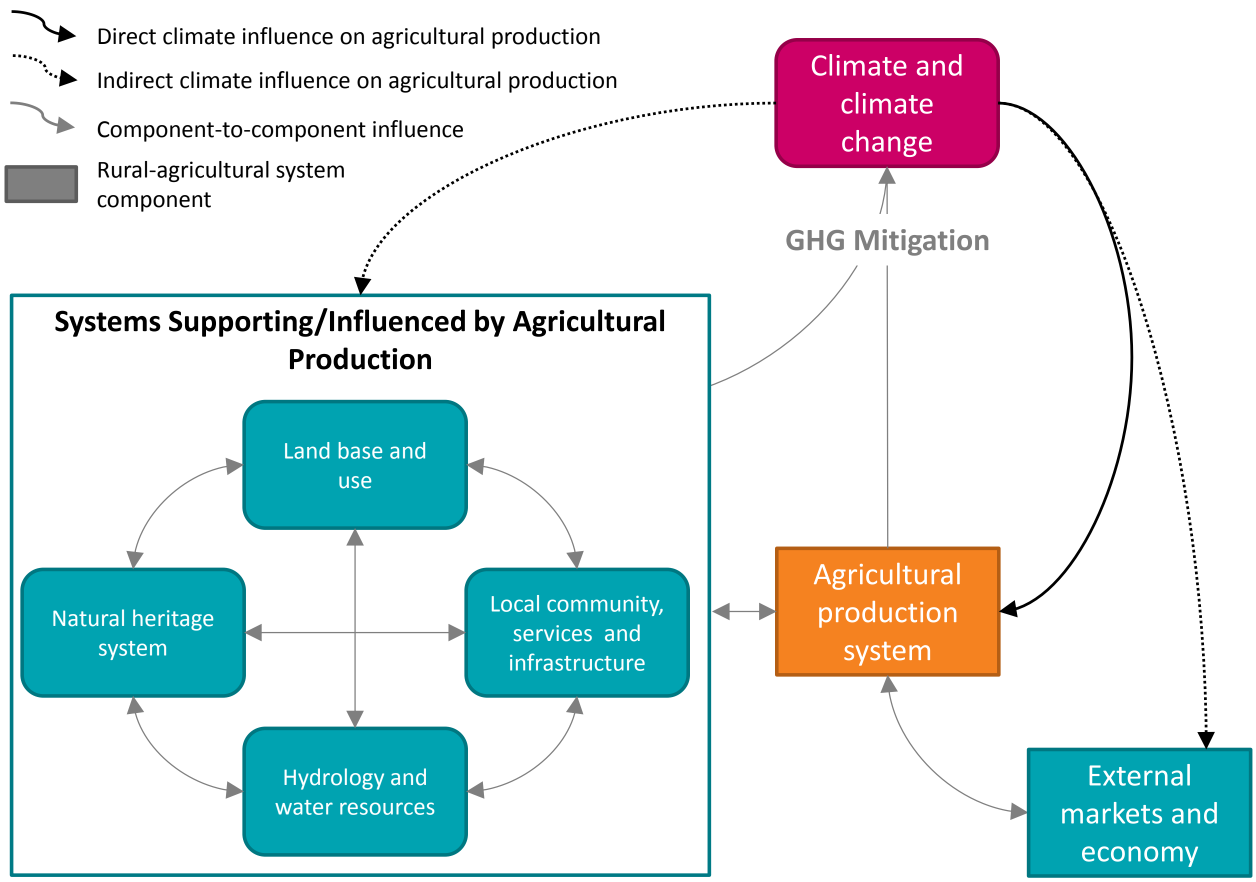

Figure 3: Conceptual model of the interconnections between climate change, agricultural production, and supporting systems such as natural heritage system, land base and infrastructure, water resources, and markets.

2.1.2. *The Role of Land base and Use in Agricultural Climate Vulnerability*

The soil, topography and hydrology of a landscape are regarded as fundamental factors that regulate the influence of climate on agricultural production systems (FAO 2013). As such, this combination of climatological and physiographic characteristics of an area greatly influence the amount, quality and location of land allocated to agriculture and are key determinants of the farming sector's overall productivity and relevance for an area like the Region of Peel. Ultimately, the interaction of the climate and physiographic characteristics of a landscape greatly determine the types of opportunities and limitations of the agricultural land base and bound the productivity of different crops and livestock (Fischer et al. 2002). This concept is expressed practically through the classification and mapping of agricultural land using techniques of agro-ecological zoning and land suitability rating (Fischer et al. 2002).

In Canada, the Canada Land Inventory (CLI) for agriculture is the interpretative system used for classifying the quality of land for agriculture, and it defines a given parcel of land on a scale from prime to marginal by assessing the climatic and soil characteristics on the limitations of land for growing common field crops. Within the CLI, lands are classed into seven groups according to their potentials and limitation for cultivation of a range of crop types. Land descends in quality from Class 1, which is highest, to Class 7 soils which have no agricultural capability for the common field crops (ARDA 1965). According to the CLI, only 5% of Canada's total land base is classified as prime agricultural land (Class 1 to 3) (Oliver 1999), with just over half (51%) located in Ontario (Green Ontario 2002). Figure 4 presents a map of the land classification for Peel and demonstrates that 62% of the agricultural land is considered prime (Class 1-3). The majority of this land is located below the Niagara Escarpment in the southern portion of the Town of Caledon (Figure 5). Areas above the Niagara Escarpment further north in Caledon, are more diverse, ranging from Classes 2 through 6, with small pockets of Class 1 to the north-east. Marginal lands (Classes 6 and 7) represent 25% of Peel's agricultural land base. The implication of this variability in agricultural land classes within Peel from a climate change standpoint is that lands vary in the extent and nature of climate effect can be anticipated to be quite diverse, and thus adaptation strategies will need to differ across the Region.

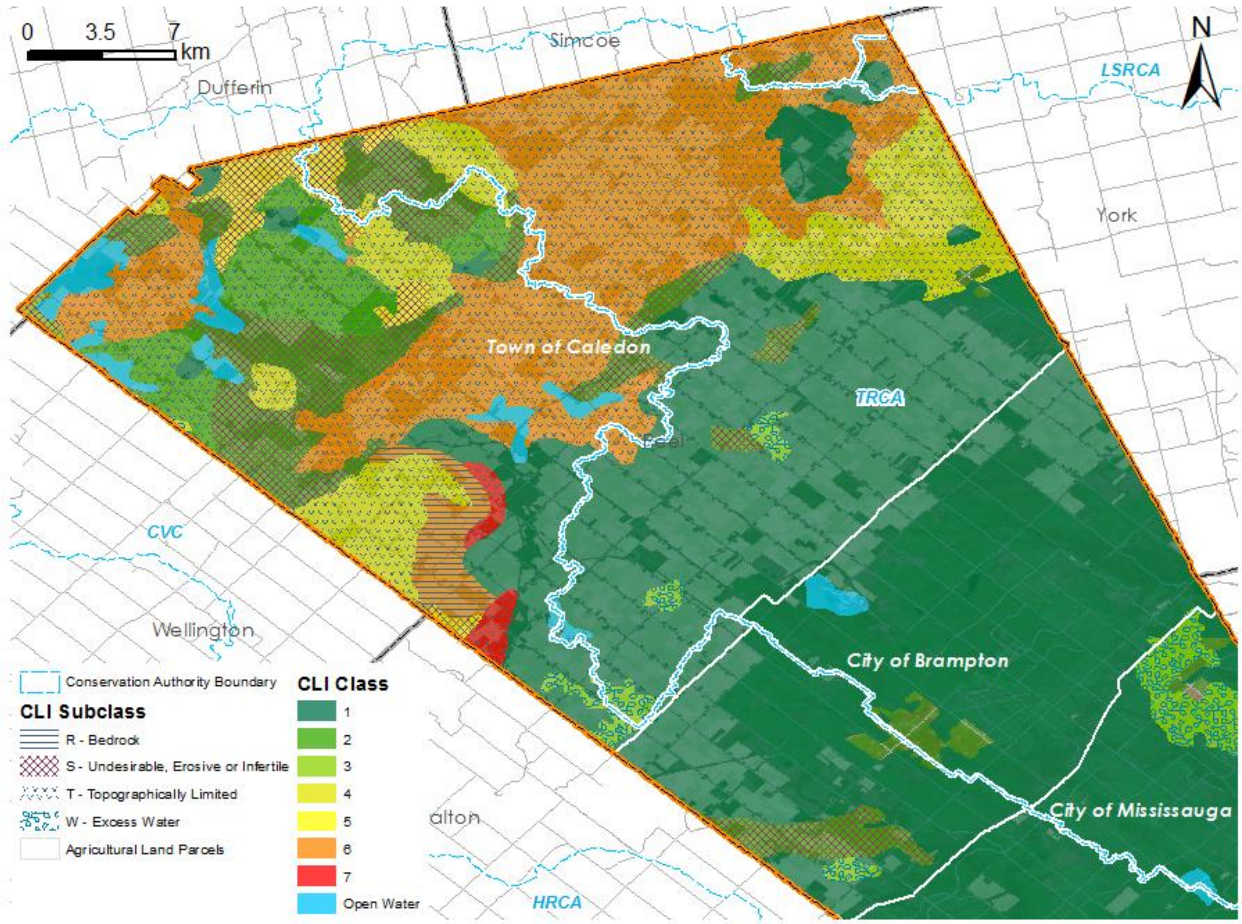

Figure 4: Map of agricultural land classification in Peel, along with an extent of agricultural lands and predominant sub-classes identifying limiting physiographic features.

The Agro-climatic Resource Index (ACRI) is the component of the CLI used for the climatic component associated with potential land productivity. The ACRI evaluates the impact of three climatic restrictions on agricultural potential, including length of the frost-free period, degree-day information (indication of summer heat for crop growth) and the degree of moisture limitation. The index combines all three climatic factors, resulting in index values ranging from 1.0 in the northern parts of Canada, to greater than 3.0 in southern Ontario (Essex County). Farmlands with ACRI values of 2.0 or greater are considered critical lands for agriculture. Based on this index, less than 15 percent of Canada's total farmland is located in areas where ACRI values equal or exceed 2.0 and only Ontario has ACRI values of 3.0 or greater, with 95% of Canada's total farmland with ACRI values of 2.5-2.9 being located within Ontario, making it a prime location for agricultural production in Canada (Environment Canada 1982). Based on the ACRI, Peel's agricultural lands have a rating of 3.0 in the southern portion and 2.5 further north.

Together, based purely on the climatic and soil conditions present in the Region of Peel, the Region's agricultural lands can be regarded as some of the most potentially productive in the country. Figure 5 presents a map of the land use in Peel and demonstrates that approximately

45% of the landscape within the overall Region is considered agricultural land. Peel's agricultural land base is predominantly located primarily in the Town of Caledon.

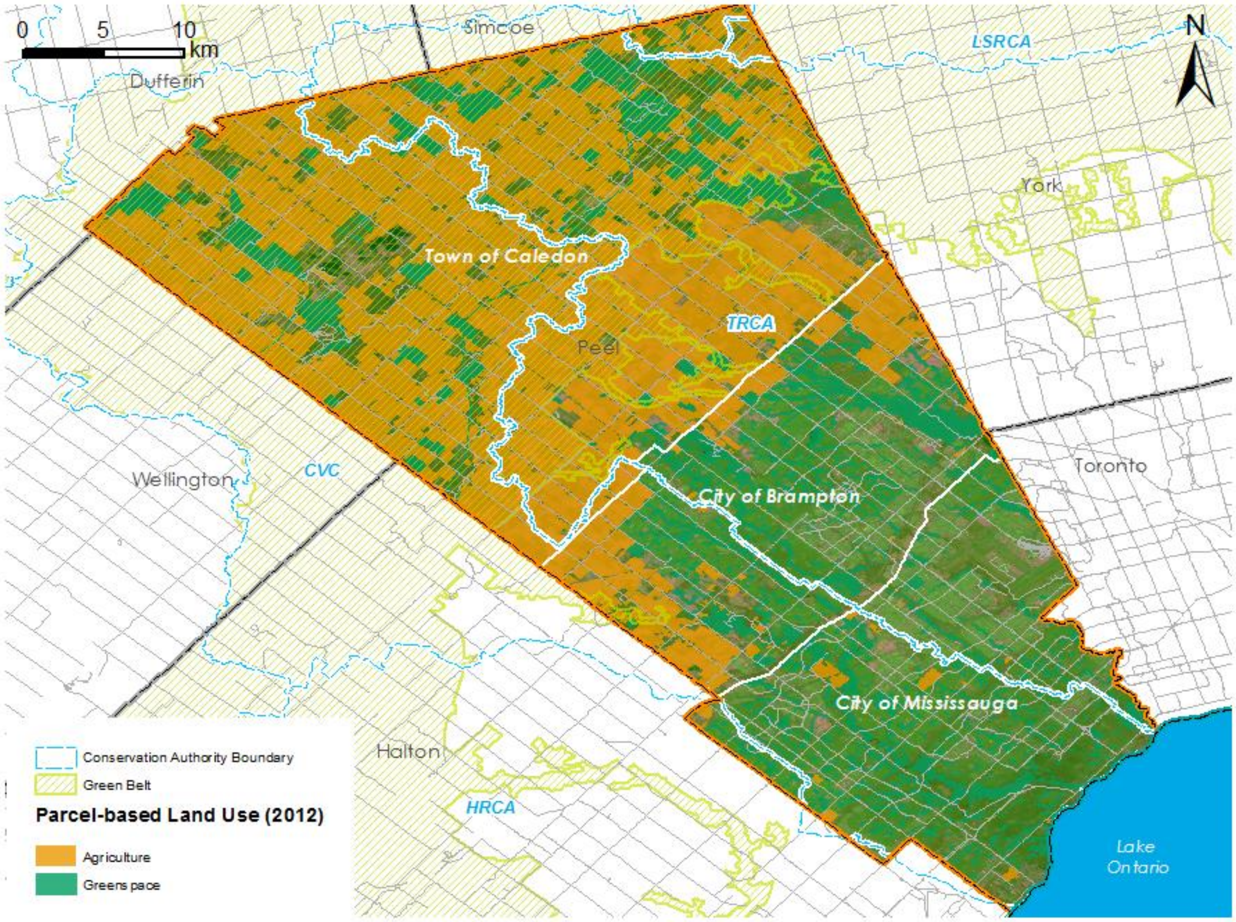

Figure 5: Map of land use in the region of Peel, based on 2012 MPAC assessment data at a land parcel basis.

2.1.3. *The Role of Water Resources and Hydrology in Agricultural Climate Vulnerability*

Climate change is altering the hydrologic cycle as a result of changes in temperature, precipitation and the occurrence extreme weather events (IPCC 2014). Agricultural production is influenced by such changes in two direct ways: (1) changes in the profile of extreme weather events, such as flooding and drought due to alterations in the climate conditions that influence hydrology; and (2) shifts in the availability, quality and demand for water as an input to agricultural production.

From a hydrologic hazard perspective, climate change is projected to increase the intensity and frequency of extreme precipitation events, resulting in increased flooding events and the associated impacts in Ontario and Peel specifically (Auld et al. 2015). Effective drainage of fields during and following a precipitation event is crucial for farmers to prevent impacts such as water-logging, soil erosion, pest infestation and leaching of nutrients (OMAFRA 2014). With proper drainage, well-drained soils can increase the opportunity to produce sustained high yields with a variety of crops under a range of moisture conditions, including extreme rainfall. In some soil types, the natural drainage processes are sufficient in self-regulating water content, while for many other soils, artificial drainage is needed for efficient agricultural production. Drain tiles can be installed to aid in draining excess water from the field. Drainage can have both positive and negative effects on water quality. Generally, less surface runoff, erosion, and phosphorus is lost from land that has good subsurface drainage in comparison to land that relies only on surface drainage. However, nitrate loss can be high from drained land due to the fact that nitrate is very soluble and therefore flows easily through the soil and into tile lines, which is a big water quality concern (USEPA 2012). Currently in Peel, approximately 5% of the agricultural land in the more poorly drained soils of the Peel plain is tile-drained (based on OMAFRA's inventory of tile drainage projects).

At the opposite end of the hydrologic hazard spectrum, instances of drought in southern Ontario are also likely to become more probable and severe under scenarios of climate change (EBNFLO and AquaResource 2011). Driven by significantly elevated evapotranspiration and a lack of precipitation, drought puts plants and livestock at risk of stress from water depletion and soil at risk of drying, cracking and eroding. Water management, particularly in the context of moisture-deprived areas, such as arid and semi-arid environments is a well advanced science; however, it requires significant investments in irrigation and field management technologies not currently widely deployed in Peel. Effective regulation of water supply and demand are also needed to ensure water sources for irrigation are managed sustainably. Currently in Ontario, surface water is the most common source for irrigation and irrigated agriculture is geographically concentrated in the southwestern part of Ontario, including the Niagara escarpment, with fruit tree and horticultural production being the dominant uses (Statistics Canada 2006). In Peel specifically, very little irrigation is implemented, with 6% of farms using irrigation, predominantly for fruit and vegetable cultivation (Statistics Canada 2011).

From an agricultural water supply standpoint, climate change is projected to increase variability in both precipitation and evapotranspiration projected under scenarios, and as such increased application of water through irrigation may be required to regulate moisture needed for traditionally rainfed crops and livestock needs (Turral et al. 2008). The projection towards longer growing seasons (Auld et al., 2015) may further increase the need for irrigation, alternative water supply and storage in order to support agricultural water needs (Betts 2005). Farms vary in amount and timing of water requirements depending on the type of production and the nature of water supplies. Crop water requirements represent the amount of water required to compensate the evapotranspiration loss, representing a key influence of climate on agriculture (Allen et al. 1998).

2.1.4. *The Role of Natural Heritage in Agricultural Climate Vulnerability*

Natural ecosystems provide a host of services to agriculture, and agricultural systems themselves can be considered both as a producer and consumer of ecosystem services (Heal and Small 2002). Ecosystem services are broadly defined as the benefits which people obtain from ecosystems, and are typically classified as regulating, provisioning, cultural and socio-economic and supporting services (MEA 2005; Smuckler et al. 2012). Specific to agriculture, these ecosystem services include, but are not limited to provisioning of healthy soil, habitat for pollinators, regulation of water quality and quantity, regulation of soil erosion and moderation of extreme winds, supporting primary production processes, and the provision of food (Zhang et al. 2007; TEEB 2011).

Considering the aquatic natural heritage system in the Region of Peel, agriculture as part of the landscape plays an important role in providing and consuming ecosystem services, specifically when considering nutrients and soil erosion. For instance, rivers and streams running throughout the region facilitate the transfer of nutrients, such as phosphorous and nitrogen, from agricultural lands to the aquatic system where it can ultimately end up in Lake Ontario. Thus, not only is the application of nutrients important from an aquatic ecosystem perspective, but crop production and plants grown in the Region of Peel uptake these nutrients that could otherwise cause issues of water quality and algal growth in Peel's rivers, streams and Lake Ontario. Similarly, tillage practices and agricultural land regulate soil erosion loss due to extreme wind and extreme precipitation events. Eroded and windswept soils can be transferred from land to water and increase the turbidity (reducing light penetration) in the aquatic system that can lead to negative impacts on biodiversity and fish species in the Region of Peel. Effective conservation tilling practices that maintain crop residue on the soil surface as well as certain crop production practices, such as intercropping and the use of cover crops, can reduce erosion losses from precipitation, wind and extreme weather events (Powlson et al. 2011).

From the regional terrestrial natural heritage perspective, agriculture regulates and provisions important benefits beyond food production. For example, in the case of flooding, agricultural lands attenuate the volume of water moving overland through infiltration into soils where water is either retained and used by crops or infiltrated to recharge groundwater aquifer systems. Furthermore, agriculture systems 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 (Rawls et al. 1982).

The benefits derived from ecosystem services rely on the presence of healthy and productive ecosystems surrounding agricultural lands (Tallis et al. 2008). Given that ecosystem health is also tied closely to the climatic niche of an area such as the Region of Peel, climate change has the potential, and has been demonstrated to, affect the viability of species, habitats and critical process associated with ecosystem services (Ackerly et al. 2012; Landsberg et al. 2013). Impacts relevant to the Region of Peel's ecosystems include shifts in vegetation regimes, altered hydrology, and reduced habitat integrity that could disrupt crop pollination services, change the amount and timing of water delivered to crops, and increase flooding thereby inundating agricultural lands (Tu et al. 2015).

Ecosystems are also under pressure from a variety of other local and global phenomena, such as land development, loss of biodiversity, encroachment by invasive species, and pollution (Zhang et al. 2007). There are a host of policies and programs designed to mitigate these potential impacts, many of directly pertain to agriculture, such as the Environmental Farm Plan, the Peel Rural Water Quality Program, and Significant Wildlife Habitat legislation. As the profile of impacts to ecosystems shift due to climate change, so too may the effectiveness of these management tools. Such changes will undoubtedly have important implications for agriculture. Tu et al. (2015) presents a comprehensive vulnerability assessment of climate change impacts to Peel's natural heritage system.

2.1.5. *The Role of Local Community, Services and Infrastructure in Agricultural Climate Vulnerability*

The ability of region's agricultural sector to remain productive in the face of climate change is highly dependent on the profile of services, infrastructure, their local markets, the community present, and their ability to serve and adaptively respond to the needs of farmers (Swanson et al. 2007). In an agricultural area with such close proximity to large urban centers of the Greater Toronto Area, transportation, electrical and water-related infrastructure are key assets in production supply chains for agriculture (GTAAAC 2012). Therefore, as these supporting systems are exposed to climate change, their ability to meet the needs of farmers will depend on their adaptive capacity and resilience.

2.2. **Agricultural Systems in Peel Region**

2.2.1. *National and Provincial Context*

The abundance and geographic distribution of agricultural production systems across a landscape are influenced by a variety of environmental constraints, namely the climate, soil, terrain and water resources, in addition to human factors such as built infrastructure, market forces, local economic drivers, and socio-cultural contexts (FAO 2013). Given the diversity of communities and environments across Canada, an equally wide array of agricultural production systems are represented, ranging from tender fruit, to greenhouse horticulture, to field crops, to livestock and poultry. Historically, crop production and beef farming has been the mainstay of Canada's agricultural industry, however, the latter has undergone a steady decline since 2006 due primarily to market and economic drivers (Statistics Canada 2011). The Canadian agricultural sector continues to restructure as many farms expand in scale of operation, consolidate, draw on technological innovations to enhance productivity, and diversify their production and sales (Statistics Canada 2011). Although there has been a slight decrease in the number of farms and land area devoted to agriculture in Canada, the average farm size has increased by approximately 7% to 778 acres between 2006 and 2011 (Statistics Canada 2011). Based on the 2011 national census, agriculture comprised approximately 7% of the nation's total land mass, with 54.6% of that area being used for crop production (Gagnon et al. 2014). This distribution of cropland represents a slight decline of 1.6% from the 2006 census (Gagnon et al. 2014). Agriculture and the agri-food system represents approximately 6.9% of Canada's gross domestic product, approximately 6% of total national export value, and accounts for approximately 12.1% of Canada's employment (Gagnon et al. 2014).

Ontario accounts for approximately 25% of Canada's farms, 21% of agricultural production by weight, 22% of all farm receipts and 7% of the national farm land area (Gagnon et al. 2014). Within the province, in 2013 agriculture accounted for 12% of all goods-producing GDP and farmland accounts for 5% of the province's total land base (OMAFRA 2013; Ontario 2014). Only three farm types increased in number as of 2011 from the previous census, those being other crops, oilseed and grains, as well as sheep and goat farms. Other crops include operations engaged in hay farming, maple syrup and the production of maple products, or combinations of fruit and vegetable or other crops (Statistics Canada 2011). This increase is likely representative of the increase in farm diversification strategies. Recently, the increased value for cash crops together with declining livestock numbers in the province has led to a shift from forages and crops traditionally used for feed (such as oats, barley, and mixed grains) to crops that are considered more profitable such as oilseeds (Statistics Canada 2014). Table 1 represents the top commodities in terms of market receipts for the province (in millions) in 2011.

Table 1: Top Commodities in terms of Market Receipts in Ontario, 2011 ($ million) (Statistics Canada 2011)

Agricultural Commodity	Ontario
Dairy products	1,895
Vegetables (including greenhouse)	1,272
Soybeans	1,077
Corn	1,338
Cattle and calves	1,028
Floriculture and nursery	784
Poultry	891
Hogs	902
Eggs	301
Wheat	315
Fruit	203
Potatoes	103
Dry beans	70

2.2.2. *Peel's Agricultural System Characteristics and Components*

The single largest form of agricultural production in the region is the grains/oilseed sector (see Table 2 for a list of farms classified by industry group in Peel). Based on the 2011 Census of Agriculture, roughly 45% of land was Peel region were used for agricultural purposes in 2011. Additionally, Peel Region has the benefit of closeness to a large consumer market with a population of roughly 5.6 million in the GTA (Region of Peel Draft Agricultural Discussion Paper 2008).

As of the 2011 census of agriculture, there were 440 farms in Peel, a decline from the 483 farms (8.5%) in the previous census in 2006. The number of hectares in agricultural use in region also saw a declined by 1.5% between census years, with a total of 37,977 hectares of agricultural land owned, rented, leased or crop-shared in Peel Region in 2011. There were 660 farmers in the region in 2011 with an additional 920 people employed in paid full-time, part-time and seasonal agricultural work (Census of Agriculture 2011). Table 2 represents the number of farms classified by industry group in Peel in 2006 and 2011and the percent of change (Statistics Canada 2011).

Table 2: Farms Classified by Industry Group in Peel (adapted from Statistics Canada 2011).

Farms classified by industry group in Peel	**# in 2006**	**# in 2011**	**% change**
Dairy cattle and milk production	42	25	-40.48%
Beef cattle ranching and farming	70	46	-32.29%
Hog and pig farming	0	0	0%
Poultry and egg production	8	8	0%
Sheep and goat farming	9	9	0%
Oil seed and grain farming	76	108	42.11%
Vegetable and melon farming	19	20	5.26%
Fruit and tree-nut farming	26	22	-15.38%
Greenhouse, nursery and floriculture production	59	47	-20.34%
Other types	174	155	-10.92%
Total	483	440	-9.90%
*other types include: miscellaneous animal production, tobacco farming, hay farming, fruit and vegetable combination farming, maple syrup and products production, and other miscellaneous crop farming			

Farmers in the region reduced their area devoted to cropland and summerfallow and increased the area of seeded or tame pasture (see Table 3) likely in response to declining farm incomes, low market prices for agricultural commodities and natural hazards (Statistics Canada 2011).

Table 3: Land use in Peel Region 2006 and 2011 (Statistics Canada 2011).

Land Use (acres)	2006	2011
Land in crops	73,481	74,193
Summerfallow land	355	174
Tame or seeded pasture	3,721	4,433
Natural land for pasture	5,667	3,855
Christmas trees, woodland and wetland	8,281	7,170
All other land	3,784	4,018
Total area of farms	95,289	93,843

Figure 6 provides a visual representation of the percentage change of farms classified by industry group in Peel between 2006 and 2011. All industry groups with the exception of vegetable and grain farming and oil seed and grain farming underwent a general decline in farm numbers. Sheep, poultry and hog and pig farming remained constant in farm numbers during this time. Figure 7 presents a map of the different farm types geographically in the Region of Peel based on the 2012 parcel-based land assessment.

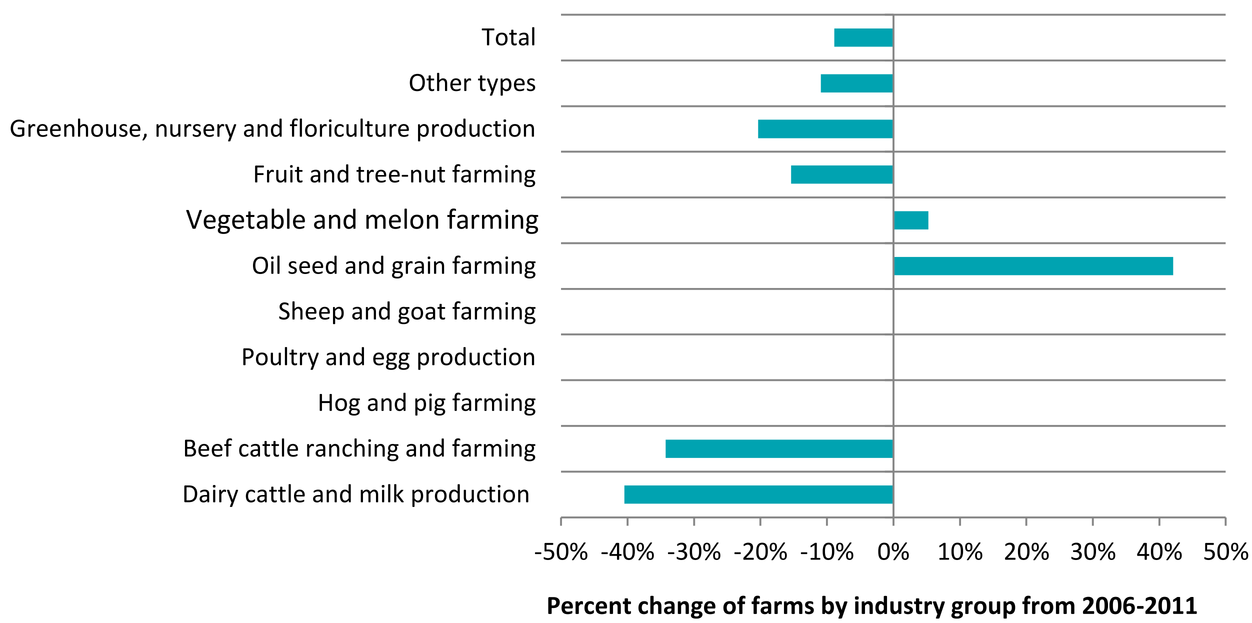

Figure 6: Percent change of farms by industry group in the Region of Peel from 2006-2011 (adapted from Statistics Canada 2011).

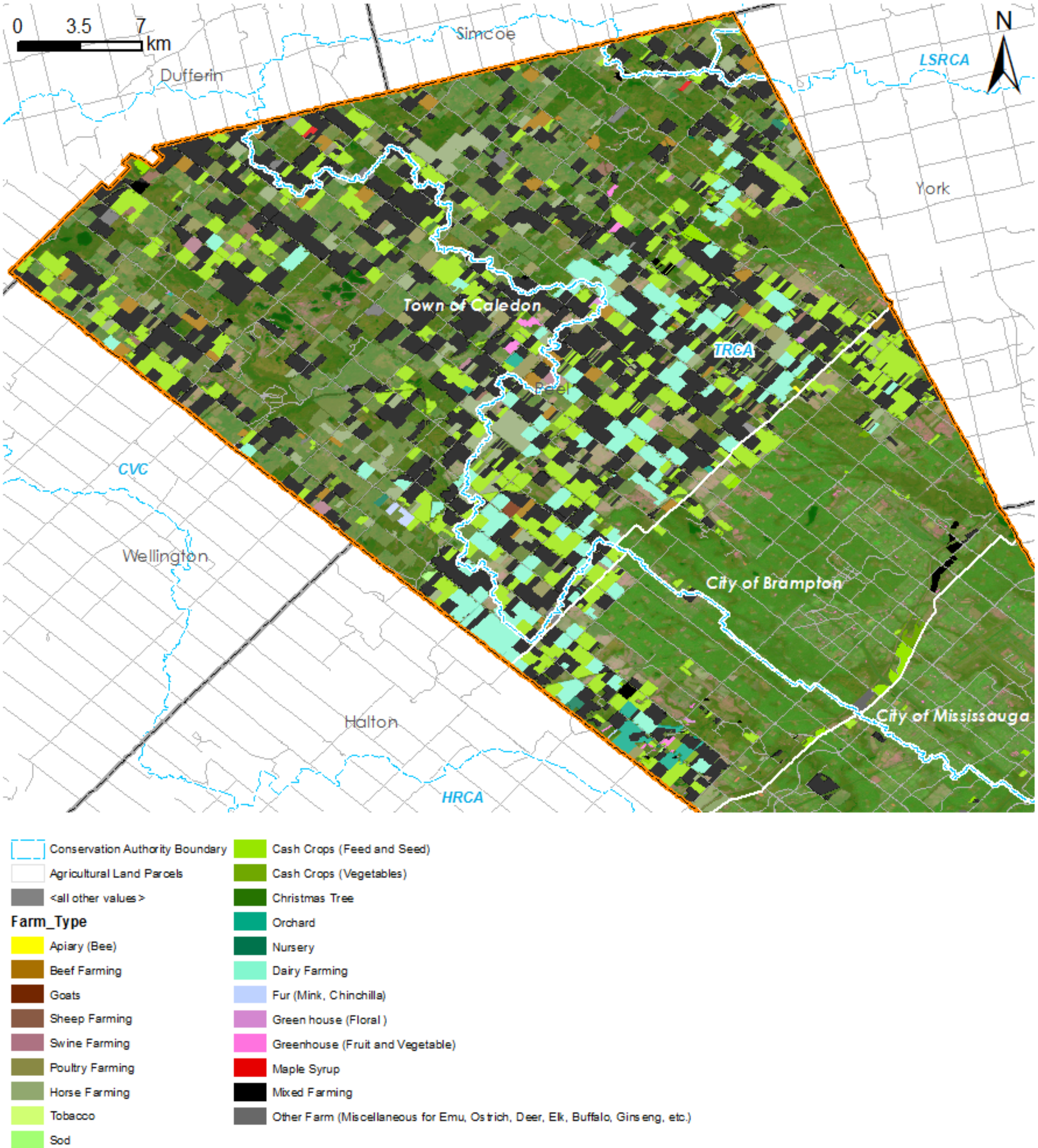

Figure 7: Spatial distribution of farms by type in the Region of Peel (from 2012 MPAC parcel-based assessment)

Agricultural production is the result of various inputs and processes used to generate added value products which are then used by society. However, the relationships among these inputs and processes are nonlinear and highly complex. Figure 8 graphically presents the key elements of the farm system and show that each of these components are inherently exposed and influenced by one another, the broader supporting systems which were identified in Figure 3 and the climate. It is significant to illustrate the interconnection between crop and livestock-based farming, given that practice mixed farming. Definitions of each box are provided in Appendix B. Figure 9 illustrates an understanding of the linkages between the agricultural production system, the whole-farm system, supporting local systems, as well as the linkage with the climate system conceptualized for this project. These components represent a mixed-farming system that produces both crops and livestock. Each of these components is present in Peel, and aside from the animal elements, most are covered throughout the analysis in this report.

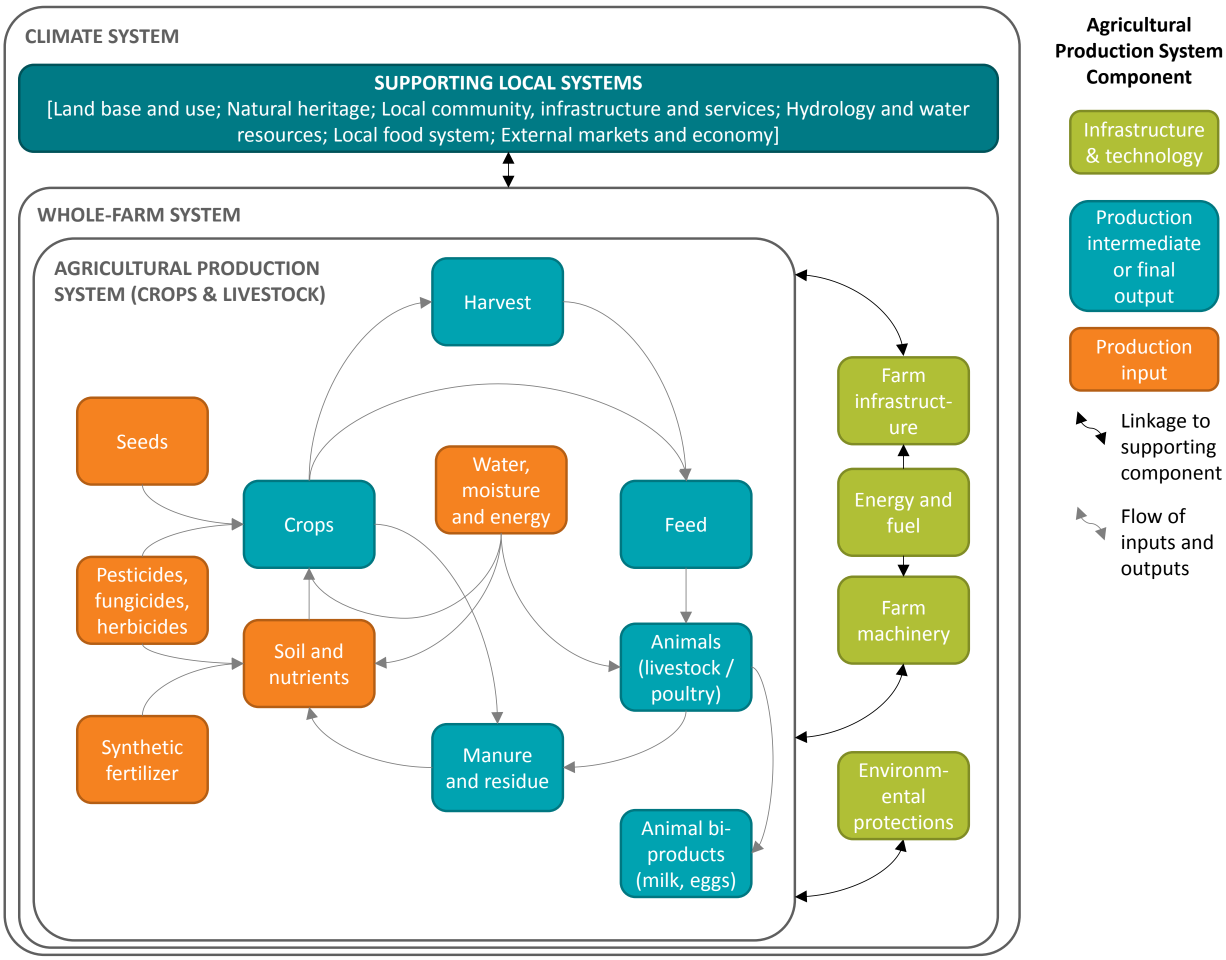

Figure 8: Conceptual model of the farm systems, identifying key inputs, intermediate and final products, infrastructure and technology, and linkages to supporting systems, all of which are embedded in and influenced by the local climate system (Adapted from Waldick et al. 2014; Rivigton et al. 2007; Rotz et al. 2004).

2.2.3. *Current Influences and Stressors on Agriculture in Peel*

While this report is focused on the interactions of agriculture with climate, effective adaptation responses need to be structured based on the broader decision-making context within which farming and sector decision are made (Bradshaw et al. 2007; Bellevue et al. 2006). Within that context, farmers face pressures related to competing land uses and increasing rental prices, market forces influencing both inputs and product sales, other crop impacts such as pests and disease, technological and financial constraints, and other socio-cultural factors (He 2012; Bradshaw et al. 2007; Bellevue et al. 2006). Across the Greater Toronto-Hamilton Area (GTHA), key pressures pertain to increasing production input and energy costs (e.g., see Figure10), and generally decreasing commodity prices, coupled with land development pressures associated with urban sprawl (GTAAAC 2012). High capital costs for new farmers or those wanting to expand operations, expensive land prices and value, attrition of farmers, and the increasing connection with global food systems resulting in a disconnect between local producers and consumers all provide additional pressures for agricultural producers (He 2012). These trends present challenges to maintaining the health of not only the agricultural sector, but to the viability of local rural economies as a whole.

Much of Canada's Class 1 farmland is located in regions with relatively high and growing population densities (Statistics Canada 2014). The Town of Caledon contains the only significant area of countryside in the Peel Region (Caledon 2004). The land closer to the edge of suburban Brampton remains one of the most productive farming areas in the Toronto Region and consists of predominantly Canada Land Inventory Class 1 land (Bunce and Maurer 2005). However, the competition for land fringing the urban development is ongoing. In 2013, the Ontario Farmland Trust (OFT) received an unprecedented number of requests from rural landowners seeking help to protect their farms from urban sprawl, aggregate pits and other non-farm development (OFT 2013).

For the most part, the dominant concern in the GTHA (which is relevant to Peel), has been over the loss of farmland to urban uses (Bunce and Maurer 2005). Other notable concerns include competition for land which can ultimately drive land prices up, debates over disjointed regulations for farmland preservation, the congestion of transportation routes which negatively affects the efficient movement of goods; complaints about normal farm practices, such as spreading manure or harvesting late at night or early in the morning; and the rising costs of energy (GTAAAC 2012). Farming in close proximity to large urban areas is known as the “urban shadow”. Not all impacts of urban shadow farming are negative, a positive element is a farmer’s close proximity to large urban markets, which offers greater opportunity to diversify though niche marketing such as farmers markets and direct sales to local buyers (OFT 2013).

Financial pressures and economic conditions also play a big role in the stability of the agricultural sector. The current costs of operating a farm associated with machinery, labour, fertilizers and other inputs along with the increasing cost of renting land are continually widening the gap between farmers’ costs and returns, especially for smaller, unincorporated farms. According to the farm input price index (FIPI), fertilizer and fuel prices have increased roughly 35%, with pesticide prices rising as much as 19% since 2000 (Statistics Canada 2006). Recent price volatility of fossil fuels (Rosset and Altieri 1997; Woodhouse 2010) and the increasing costs of mechanized farming methods that are often associated with large-scale farming operations have increased the economic pressure faced by producers (Weis 2010). Economic pressures can also be felt on smaller; more labour dependent farms (Weis 2010), as the increasing cost of hired help and minimum wage continue to rise (Statistics Canada 2006). Labour costs vary between farm types and sizes and differ depending on whether farmers are using predominantly family labour compared to capitalist farms that generally rely on hired help (Woodhouse 2010). These economic pressures, which can be exacerbated by climate change, can hinder the ability of farmers to cope with a changing climate. Figure 9 presents the annual average farm input price index for Ontario. Farm inputs have risen in all categories, with large increases in fertilizers.

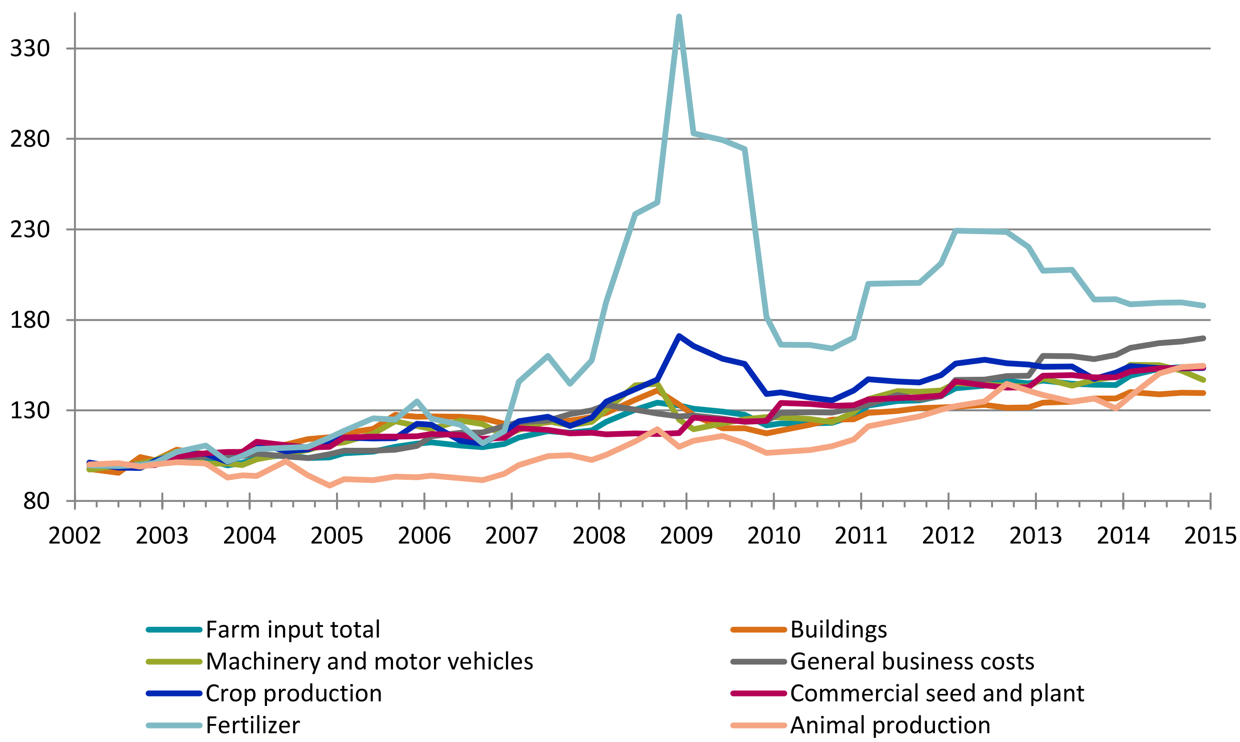

Figure 9: Farm Input Price Index for Ontario, Annual Averages (Statistics Canada 2015)

2.2.4. *Agricultural Governance, Regulations and Climate Change in Peel*

Government policies influence the market, business, and overall decision-making environment within which farms operate, as well as their ability to manage and adapt to a changing climate. The current policy regime that influences the climate resilience of agricultural systems in Peel is defined by regulations and guidelines at the local, provincial and federal levels. Examples include local regulations, such as minimum distance separation requirements, provincial nutrient-management legislation, and at the federal level through agricultural and foreign policies, such as the supply-management system in Canada.

More broadly than individual farms, there are also a suite of policies pertaining to the protection of rural lands from development in response to the growing demand of trying to balance farmland protection with urban growth. In Ontario, these plans included the Oak Ridges Moraine Conservation Plan (2002), the Greenbelt Plan (2005) and the Places to Grow, Growth Plan for the Greater Golden Horseshoe (2006). It has been suggested that these plans, aimed at addressing the protection of the agricultural land from an allocation perspective, failed to address the economic viability of the farming business (Bunce and Maurer 2005). Population within the Regional Municipality of Peel is rapidly growing (Regional Municipality of Peel 2012) with a current population of roughly 1.3 million people (Census 2011) which will likely further exacerbate the pressures of urban sprawl. The population in the Greater Toronto Area alone is expected to increase from 7.4 million people in 2000 to 10.5 million people in 2031 (an increase of 43%) (Winfield 2003).

Policies and governance frameworks that support adaptive management are critical elements of successful strategies for building climate resilience (Moench and Tyler 2012). Government support programs have the ability to increase farmers' capacity to cope with climate as well as market-related impacts through support programs such as income stabilization, crop insurance, and disaster relief (Reid et al. 2007). Proper planning and effective support programs contribute directly to the capacity of farmers to build a robust adaptive management strategy. Table 4 illustrates the relevant agricultural policies at the federal, provincial, and local level and identifies their connection with climate change.

Table 4 Agricultural policies and climate change connections relevant to Peel (relevant specific policies list adapted from Desir 2012).

Management Theme	**Climate Change Narrative**	**Relevant Specific Policies**		
		Federal	***Provincial***	***Local***
Water Resources & Conservation	Climate change will affect water supply, demand and exposure to hydrologic hazards, which have major implications for agriculture production and rural livelihoods. Key impacts pertain to water supplies for irrigation and domestic use, irrigation system operations and drainage infrastructure. As the hydrologic cycle becomes more unstable, best management practices at the farm and landscape scales will need to be adapted to new hydrologic impacts.	•Canada Water Act	• Agricultural Tile Drainage Installation Act • Conservation Authorities Act • Drainage Act • Ontario Water Resources Act •Environmental Protection Act •Safe Drinking Water Act •Nutrient Management Act	•Caledon Official Plan •Source Water Protection Act •Peel's Official Plan
Land Use & Agri-environmental Management	Land use practices have played a role in changing the global carbon cycle and the global climate as a whole. Agriculture has significant effects on climate change, primarily through the release of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. Although modern agriculture has become successful in increasing food production, certain land-use practices have resulted in impacts to the environment, which many policies are aimed at addressing. As these impacts shift and GHG mitigation becomes an imperative due to climate change, so will the way land is used, allocated and	•Growing Forward II •Canadian Environmental Protection Act	•Farming and Food Protection Act •Planning Act •Minimum Distance Separation •Greenbelt Act Lake Simcoe Protection Act •Niagara Escarpment Planning and Development Act •Oak Ridges Moraine Conservation Act	•Peel's Official Policy Plan •PARWQAC •Municipal Act •Caledon Official Plan

Management Theme	Climate Change Narrative	Relevant Specific Policies		
		Federal	***Provincial***	***Local***
	managed at multiple scales in rural Peel.			
Livestock & Poultry Issues	Livestock producers face a range of direct and indirect climate-related impacts to animal health, feed supplies, and both farm and off-farm built infrastructure. Due to the dependence of livestock systems on crop production, vulnerabilities in this management theme are highly relevant to livestock and poultry production. Key among the direct vulnerabilities are vector borne diseases, impacts to forage and pasture, and the resilience of barns, storage facilities, transportation networks and electrical supplies to extreme weather. Creating resilience in the overall production system will go a long way to adapt to the evolving climate.	• Health of Animals Act • Feeds Act •Farm Products Marketing Act •Farm Products Payment Act	•Animal Health Act •Food Safety and Quality Act •Health Protection and Promotion Act •Nutrient Management Act	
Crops Production	Crop production vulnerabilities are related to the timing of planting and harvesting operations, exposure of crops to extreme or unseasonal weather conditions during maturation (e.g. heavy rainfall, drought or alterations in growing season energy and water budgets), which are all directly influenced by climate change. Several intermediate impacts farmers are challenged with already, and which will be altered due to	•AgriInsurance •AgriStability •Seeds Act •Fertilizers Act •Pest Control Products Act •Plant Production Act •Weed Control Act •Farm Products Marketing Act •Farm Products Payment Act	•Fertilizers Act Grains Act •Plant Disease Act •Crop Insurance Act •Pesticides Act •Nutrient Management Act	

Management Theme	Climate Change Narrative	Relevant Specific Policies		
		Federal	***Provincial***	***Local***
	climate change are managing pests and disease, and nutrient supplies. Agricultural best management practices and the supporting programs and policies will need to be examined to ensure the overall system is resilient.			
Wildlife Protection & Biodiversity Conservation	Agricultural practices and land management have long been influenced by the need to protect wildlife, biodiversity and supporting habitats. Climate change is projected to result in a new profile climate drivers that affect agricultural runoff and soils, which influence quality of nearby water bodies and habitats. Concurrently, the natural ecosystem will be exposed to its own profile of climate change impacts. These ecosystem-specific impacts have the potential to require changes to the policies and practices designed to conserve biodiversity and habitat, including those governing agricultural lands and best management practices.	•Fisheries Act •Migratory Birds Convention Act •Species at Risk Act •Canada Wildlife Act	•Fish and Wildlife Conservation Act •Endangered Species Act	

3. ASSESSMENT METHODS

3.1. Overall Approach

In order to understand the meteorological, biophysical and human factors that mediate the effects of climate change and to determine impacts and opportunities in the Region of Peel on agricultural production, the overall approach to this project was carried out in a phased manner (Figure 2). A focus on engaging local stakeholders and iteratively refining analysis as new information was produced or became available at each step. The phases were focused on generating information needed to assess the various factors influencing current vulnerability. These specific phases of analysis were based on guidance for conducting climate change risk and vulnerability assessments in ICLEI (2012), UKCIP (2003), Gleeson (2011) and Engineers Canada (2011). Similar approaches have been applied specifically to agricultural vulnerability assessment in Espeseth et al. (2012) and IISD (2006). The FAO's CSA program also recommends following existing climate vulnerability assessment methodologies, but suggests that individual users are best suited to identify and use a range of qualitative and quantitative tools for characterizing both current and future vulnerability. The cities of Toronto, Chicago, London, Vancouver, Halifax, New York, Los Angeles, and regions such as the State of Wisconsin, the Okanagan Valley and parts of the western Canadian plains all provided helpful guidance in completing climate or extreme weather vulnerability assessments, as they all drew upon the aforementioned documents. Common in all these example jurisdictions and from the broader body of literature in adaptive management and climate resilience are the following key features that have been adopted in the current study:

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

Figure 10 provides a more detailed overview of the steps involved in the analysis employed in this assessment, and it is consistent with others completed in the Region of Peel on themes of natural heritage, municipal services and infrastructure, public health, and the economy. While

Figure 10 presents the project phases as a linear, it should be noted that certain steps proceeded in tandem, for example "system characterization" and "climate impact identification", as well as "climate drivers and indicators" and "vulnerability factors and indicators". Sections 3.2 through 3.7 provide more details on how each phase was completed.

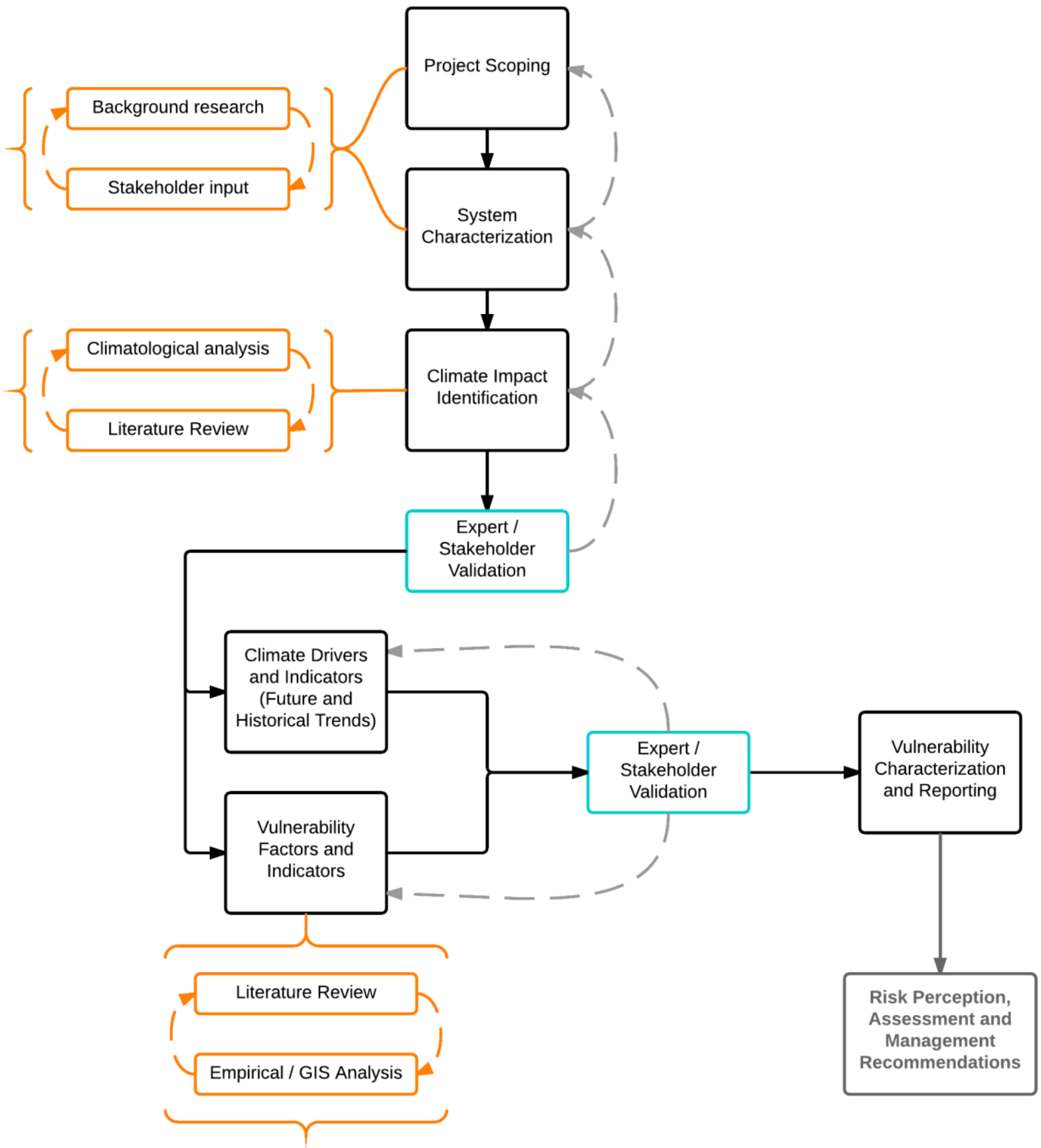

Figure 10: Flow chart illustrating overall flow and individual phases

The analysis steps were completed in order to develop the pieces of information needed to assess current and future vulnerability, although it was beyond the scope of this study to fully assess the latter. The first set of step is identifying the scope of vulnerability analysis, which is followed by defining the systems and their components to be assessed. These steps were informed by background research on how others have defined agricultural systems and scoped their studies, in addition to seeking feedback from stakeholders. The second set of steps involved elucidating, and where possible quantifying, historical or potential future climate impacts to the system defined previously. This impact information was cross-validated using a combination of local stakeholder perspectives, literature information and empirical data. Following the identification of impacts, a systematic literature review was conducted to identify key vulnerability "factors" (e.g. extreme heat events, drought events, unseasonal frost) and associated metrics, or "indicators" (e.g. Crop Heat Units, 1-day maximum precipitation accumulation) used to characterize vulnerability for the most critical impacts locally in Peel. The outputs of these steps were then synthesized into a series of "storylines" describing the most important vulnerabilities. This information identifies potential adaptation alternatives that could be pursued to address root sources of vulnerability.

3.2. Stakeholder Input

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

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

Workshop participants were also asked to provide feedback on preliminary lists of system vulnerability indicators developed through a literature review. During the exercise, participants were first asked to individually rank the perceived importance of the different vulnerability factors, and were then guided through a discussion to arrive at a group consensus and explain the rationale for their ranking. A summary of the key stakeholder engagement processes conducted subsequent to the initial project scoping within each case study is presented below (Table 5).

Table 5. Timeline of Agricultural Sector Stakeholder Engagement, Caledon.

Nov, 2012	**Peel Agricultural Action Working Group Meeting**	The project team made a brief presentation to the Peel Agricultural Action Working Group, which included agricultural sector representatives, municipal staff, local councilors and local area residents.
Jan, 2013	**Peel Federation of Agriculture AGM**	The project team set-up an information booth and also made a presentation at the Peel AGM to both highlight the project and advertise the upcoming workshop. Conversations with attendees proved useful in disseminating information on the workshop as well as the overall project.
Mar, 2013	**Producer and Stakeholder Workshop**	The workshop represented the most significant interaction with the agricultural sector to date. The focus was on communicating the intended outcomes of the project and the importance of stakeholder involvement, while at the same time providing workshop participants (predominantly farmers) with information and resources that would be of use to them, i.e., information on changing weather trends, effective new farming techniques, etc. During this session the participants were able to identify and prioritize climate events, impacts and opportunities that were of significance to their operations.
May, 2013	**Peel Farm Tour**	The project team has endeavored to maintain connections with the agricultural community and better understand the challenges it faces. Participating in such activities has provided valuable insights to the project team and positively informed the projects development. Additionally, initial results of the climate impact identification were presented to stakeholders for feedback.
Jun to Sep, 2013	**Interviews with local farmers for documentaries**	Discussions focused on understanding the role of farms in the overall watershed health and the impact of climate change; how climate has affected production; and the importance of the local food with respect to community resilience, health and well-being.
Nov, 2014	**Meetings to present preliminary assessment findings and adaptation alternatives to PAAWG and GTAAAC**	Presentations summarizing the vulnerability pathways and indictors were shown to stakeholders, who then had opportunities to provide comments through round-table discussion. Focus was placed on refining the adaptation alternatives (from literature review and stakeholder consultation) and understanding important parameters for advancing adaptive capacity.

3.3. Project Scoping

The first phase of this assessment was solidifying the scope of the vulnerability analysis to be undertaken. The scope would define the geographies of interest, target systems and scales of focus within the overall agro-ecological system, timeframes for future vulnerability assessment, and key decision-making processes for consideration within adaptation alterative research. Table 6 presents a summary of the key aspects of the study scope.

Table 6: Summary of study scope parameters decided following initial background research and stakeholder discussions

Geography	All of Peel's agricultural lands
Timeframe	Priority 1: Current vulnerability, to climate conditions to understand current profile of climate impacts and how they could be managed with adaptation Priority 2: 30-50 years for future-oriented vulnerability pertaining to strategic decision (crop systems, infrastructure, investments, etc.)
System	Cash crop production, assuming some transferability to other cropping systems
Scale	Priority 1: Cash crop production systems at the farm scale Priority 2: Scaling-up of farm-scale vulnerably to landscape
Potential decision-making & policies implicated	Regional and Conservation Authority programming and policies designed to support individual farmers and the sector with agri-environmental management

The study was scoped firstly by consulting with a committee of representatives from relevant agricultural groups in Peel and the GTA (primarily the PFA, PAAWG, GGHFFA), representatives from both Conservation Authorities and Peel's agricultural planning group within integrated planning. Based on the results of meeting with each of these groups and informal discussions with representatives, it was concluded that there was a need to focus on a high-impact commodity group. By looking at the agricultural census and through discussions with stakeholders, grains/oilseeds were perceived as being the most in need of detailed information. Other sectors that were considered for detailed analysis included: tender fruit, horticulture, livestock and equine, however it was determined that these systems could be addressed in future work within an adaptive management framework. Nonetheless, it is likely that many of the findings from this study will be applicable to those commodity groups. It was also determined that the scale of analysis should begin with the "farm" and then be scaled-up in subsequent analysis or studies to the landscape scale. All of Peel's agricultural lands were selected as the geography of interest. Understanding current vulnerability, was identified as a priority for the timeframe of analysis, given the short-term decision making cycle for grains and oilseed production. That being said, a time horizon of 30 to 50 years was identified as important for more strategic decision, such as crop system suitability and infrastructure type decision. As such the 2050s (2041-2070) was selected as the period of analysis for the assessment of future climatic exposure.

3.4. A Framework for Characterizing Adaptive Capacity in Agricultural Systems

Agriculture is inherently sensitive to climate and weather, and therefore is frequently noted as a sector that is potentially vulnerable to climate change (IPCC 2014). However, the degree to which an agricultural system, or at the local scale, an individual farm, is ultimately vulnerable to changes in temperature, precipitation, or extreme weather events, depends on its ability to cope and remain productive under a range of different and highly variable conditions (Belliveau et al.

2006). This ability is often referred to as resilience, which closely related to a system's ability to absorb stresses from climate change and also it capacity to adapt to changing conditions over time, known as adaptive capacity (Gallopin 2006).

The most recent version of the IPCC's definition of adaptive capacity is: "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2014, p. 1758). This is a useful concept in describing the presence of and ability to mobilize resources for effectively responding to multiple and evolving climate drivers in both the immediate and long-terms (BC Agriculture and Food 2012). Adaptive capacity is recognized as counteracting vulnerability (Figure 2) (IPCC 2014). Resources associated with adaptive capacity may exist at the farm scale, sector level, or broader social, biophysical, economic, or institutional contexts (BC Agriculture and Food 2012; Swanson et al. 2007). Agricultural systems with high adaptive capacity are effectively able to mobilize their resources to respond to a range of conditions, while simultaneously maintaining an ability to continuously learn from those experiences (Stokes and Howden 2010). Adaptation requires both changes in practices or behavior, as well the resources and context that enable change. Figure 11 represents a conceptual framework of the categories of resources that have been demonstrated in previous studies to increase adaptive capacity.

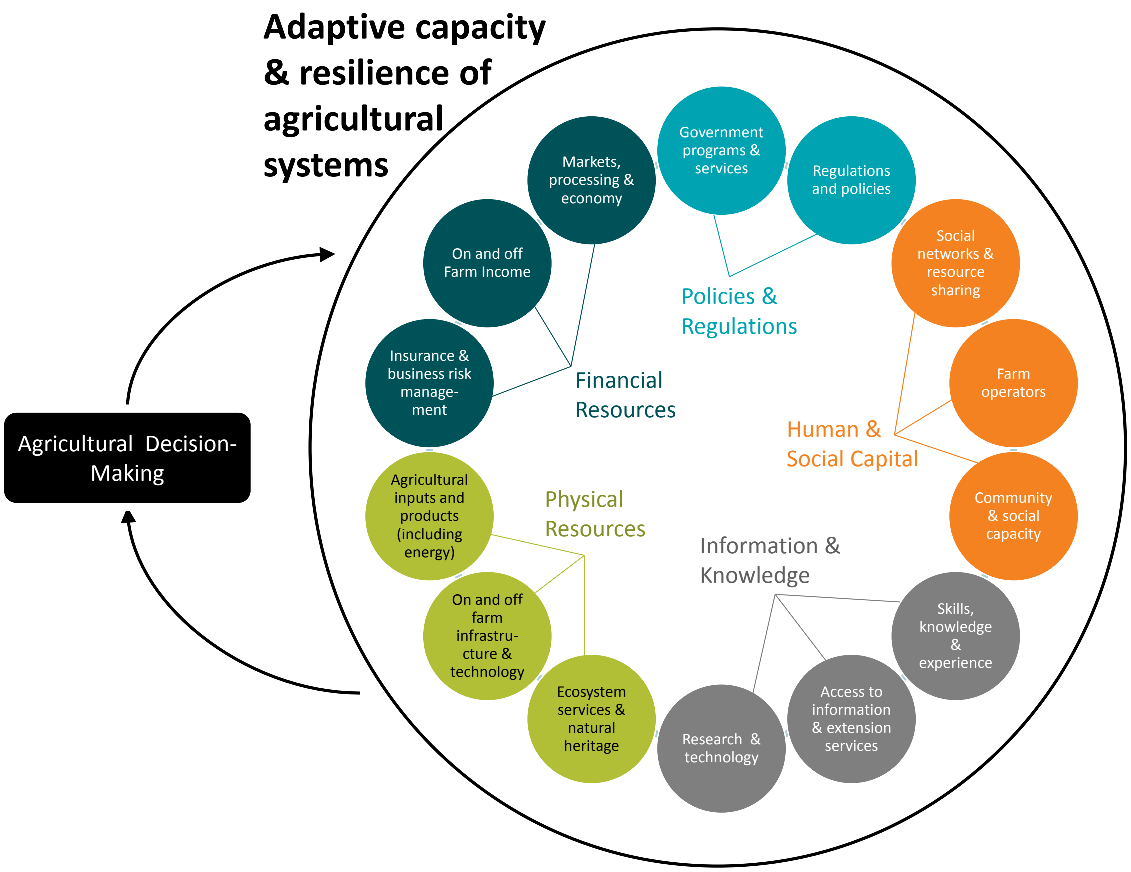

Figure 11: Conceptual diagram that illustrates the relationship between different levels of management and elements that factor into the agriculture sector's resilience. These elements are expressed as interrelated types of resources: financial, policies and regulations, human and social capital, information and knowledge and physical resources (Reference: adapted from Waldick et al. 2014; BC Agriculture & Food 2012; Reid et al. 2007; Swanson et al., 2007).

Based on the assumption that climate change and extreme weather events will continue to increase in magnitude and frequency and will likely have implications for the agricultural system, enhanced adaptive capacity and climate resilience are becoming increasingly recognized as key objectives of agricultural and rural decision making. Adaptive capacity and resiliency-based decision making aim to reduce climate risk by understanding and responding to the underlying factors that contribute to a system's vulnerability, such as the biophysical processes, community assets, socio-economic status, health of ecosystems (Cabell and Oelofse 2012; Rival 2009). Such approaches also rely on developing strategies that simultaneously target multiple sources of vulnerability and which have co-benefits to other management objectives.

Within the context of agricultural and rural decision making, recognition of the linkages between the human and natural systems is a critical aspect of building climate resilience and adaptive capacity (Cabell and Oelofse 2012). This theory recognizes that healthy socio-economic, built and natural systems are all required to ensure optimal agricultural production and rural prosperity (Cabell and Oelofse 2012). Because agro-ecosystems operate simultaneously at multiple scales and within varying contexts from the field to the global scales, there are many determinants that can be targeted to increase overall resilience. Sustaining the necessary supply of ecosystem services that shape and sustain the agricultural system, such as water and soil resources, is a critical element (Chapin et al. 2009).

3.5. Climate Impact Identification

A key step in the vulnerability assessment process is understanding the range of potential impacts to the system under consideration (IPCC 2014). Several different pieces of information and approaches were used to identify key climate impacts of relevance to agricultural production in Peel, representing a combination of "top-down" and "bottom-up" methods following best-practices identified in Fellmann (2012). It should be noted that initially, climate impacts were identified as conditions that could significantly affect agricultural production either positively or negatively. The first aspect of this phase was completing background research to identify a range of potential climate impacts and opportunities on agricultural systems in general. These impacts and opportunities are summarized in Appendix C.

Following this broad identification of potential impacts, it was then necessary to identify which of these represent scenarios of particular relevance to the project scope and stakeholders in Peel. This was accomplished through a combination of stakeholder consultation and forensic analysis of historical climate impacts to agriculture in Peel, specifically in the last 20-30 years (since 1980). The forensic analysis was completed by reviewing periodical reports, such as OMAFRA's annual crop reports, other scientific literature pertaining to climate impacts in Ontario (OCCIAR 2011; Qian and Gameda 2010; Reid et al. 2007; Morsch et al. 2000), and analyzing time series of climate stations in the Greater Toronto Area to identify significant years for agriculture.

The list of climate impacts and opportunities relevant to Peel was presented to stakeholders at a focus group workshop to elicit their perspectives (see Appendix F) and prioritize the list items associated with specific climate drivers that would require more detailed vulnerability factor and indicator analysis. Participants were asked to rank their top 3 choices of importance of the biggest opportunities and impacts (1 being the most important, 3 being less important) based on importance as agricultural production impacts (see Table 7). The ranking was done first individually and then a group consensus using the Institute for Cultural Affairs' "consensus workshop" method described in Stanfield (2002). The stakeholders were also provided with information on historical and future climate projections in a variety of formats and asked to provide feedback to the following questions pertaining to local impacts and vulnerabilities:

- What are climate-related impacts of priority concern?
- What are the key system response thresholds?
- How are climate impacts currently managed?
- What additional information would you require to adapt to the projected changes in climate?

Although the sample size is too small to be representative of all producers, it represents common trends of many representatives from decision maker groups and shows that consensus was formed around the top climate drivers – those being drought, hail, extreme rainfall, wind, late spring/spring frost, wet spring and early fall frost. When thinking about the potential climate derived opportunities, participants were prompted to think about how or why the list of predetermined climate/weather conditions benefit production for their crop type and under what conditions are they most likely to have positive impacts (e.g., soil type, equipment, etc.)?

These identified impacts were then compared with historical crop yield data obtained for a range of cash crops to qualitatively validate their impact on agricultural production. Together, the combination of crop yield analysis and stakeholder input was used to identify the most critical climate conditions or weather events for agricultural production, which would then undergo more detailed vulnerability factor and indicator analysis. This is consistent with a "bottom-up" approach to climate vulnerability analysis (Brown et al. 2012).

Table 7: Summary of historical climate events used for prioritization with stakeholders. Asterisks (*) denote years showing in Figure 10

Climate Driver	Example Year	Description
Growing Conditions		
Cold and wet season*	1992	Strongest cold anomaly for Orangeville Station during period of record; notably low yields for corn and soybean though average to slightly above average year for winter wheat; precipitation slightly above average. Attributed to Mt. Pinatubo eruption.
Drought*	1988; 2007	Significant drop in corn and soybean yields, less severe reductions in wheat yields; largest growing season (May-Aug) dry anomaly at Orangeville on record (1961-2012)
Early fall frost	2003, 2011	First frost in 2011 mid-September (15^{th}); -1.0C; First frost of year killing frost at -2.5C on Oct 3, 2003
Spring frost	2012	Frost in May resulted in impacts to many horticultural and fruit crops

Climate Driver	Example Year	Description
Ideal/Good (Goldilocks) Growing Conditions (temp, precip., length)*	2010, 2006, 2005	Combination of above average temperatures, regular occurrence of rain (7-10 days), lack of severe weather. E.g., 2010 led to large corn, soybean yields.
Warm season*	1998, 1999	Good yields for corn, wheat and soybean; temperatures significantly above average for entire growing season, hottest growing season on record (Orangeville), precipitation only slightly below average. Hot growing season in 998 classified as an El Nino Year.
Wet spring*	2000	largest total March-May accumulations on record (Orangeville)
Early spring*	2012	Warmest March on record, followed by slightly cool April
"Million Dollar" rain	No Recorded Year	Crop saving rain during an otherwise below average or drought year.
Off-Season Conditions		
Dry winter	No Record Year	Concerns regarding soil moisture at start of season, increased sensitivity of soil to wind erosion before plant growth
Mild winter	2009, 2010	Record warm winters
Extreme Weather Events		
Wind (summer)	Jul 23, 2012; Sep 22, 2010	Trees and large branches down, power outages, 123 year old barn blown over and scattered up to 1200 ft (McClure farm), cell tracked from Caledon to north Brampton 7:30-8:30 PM; 12 hydro poles down Mayfield Rd, between Peel Rd. 50 and Coleraine, knocking out power to
Extreme Rainfall	May 12, 2012 - flash flood (Credit River)	Flash flood Credit River; 76.8 mm at Orangeville, est. >$1 million in damage (Dufferin Co. Emergency Management Co-ord), train tracks near Orangeville (Dawson Rd.) washed out; large hail reported as well; minor damage to power grid from falling trees
Winds (winter)	Jan 30, 2008 - power outages	School buses cancelled Dufferin and Caledon, power outages incl. traffic lights Regional Rd. 50; gusts to 93 km/hr at Pearson
Lightning	July 25, 2012	Two structural fires started by lightning, Caledon East and Palgrave shed fire $15k and house fire (garage) $20K
Hail	Summer 2008 -	Damage to crops- bad year for Ontario farmers in several locations, damage to peach and apple crops at numerous locations, though locations in Niagara Penn, Grey/Bruce and London areas most severely affected

Climate Driver	Example Year	Description
Tornado	Various (e.g. May 31, 1980 Georgetown-Bramalea tornado) - high impact events	1980 tornado destroyed farm buildings, trees, est. $2 million in damages ($CDN 1980); Several recent examples to north and east of Caledon (e.g. Goderich Aug 21, 2011, Durham, Aug 20, 2009); long return period, high impact event

3.6. Climate Indicators

Climate indicators were selected (Auld et al. 2015) based on the most critical climate conditions or weather events for agricultural production. Climatological indicators are used to inform vulnerability, and characterize potential risks (IPCC 2014). In the context of agriculture, climatological indicators are also used to determine the suitability of different crop types and can express potential opportunities for production. Historical analysis of climate data along with future projections relevant to agriculture in the Region of Peel are presented in Section 5.2 of this report and further detail on trends and projections is presented in Auld et al. (2015). Table 8 summarizes the indicators selected to represent the main climate impacts and opportunities employed during the stakeholder consultations. For each climate indicator, historical baseline and future trends and statistics were analyzed to inform current and future vulnerability.

Table 8: Summary of climate indicators used to represent various climate conditions prioritized by stakeholders

Climatic Condition	Climate Indicator
Growing Season Conditions	Growing Season Average Temperature [°C]
	Growing Season Total Precipitation [mm]
	Crop Heat Units [CHU]
	Growing Season Length (frost-free period) [days]
	Growing Season Start Date [date of year]
	Growing Season End Date [date of year]
Frost	Growing Season days per month with daily minimum temperature $\leq X$, $X = \{3, 0, -2\}$ [days]
Drought / Moisture Deficit	Growing season days per month with no precipitation [days]
	Growing season moisture index (precipitation – evapotranspiration) [mm]
Extreme precipitation Intensity	1-day maximum precipitation accumulation [mm]
	5-day maximum precipitation accumulation [mm]
Extreme precipitation frequency	95^{th} Percentile Daily Precipitation [mm]

Indicators based directly on temperature and precipitation datasets from McKenney et al (2011) produced by the Canadian Forest Service were used as the baseline. In brief, this dataset interpolates Environment Canada climate station data and produces a spatially continuous climate surface at daily intervals. This dataset is often used as a baseline for climatological studies, as its residuals are quite low. Interpolated values showed average annual residual value of 0.36°C, 0.66°C and 4.7mm compared to the observed maximum temperature, minimum temperature and total annual precipitation normal for 1981-2010 period for the Pearson

International Airport Station. A key benefit of using gridded data was that it provided information on the spatial trends in the Region of Peel. A key limitation with the McKenney et al (2011) dataset is that it tends to mute the signal of climate extremes (Razavi et al. 2015). For humidity and wind velocity variables, it was not possible to obtain historical gridded data. As such, station-based records from the Pearson International Airport Station were used, as they represent the closest station with information pertaining to these variables, in addition to having the longest period of record. Auld et al. (2015) contains additional information on historical trends.

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

Many of the impacts discussed in this assessment make assumptions about generic crop development cycles and management practices, however in reality; there is significant variability within these at the local scale. Where possible, the report assesses impacts in a way that recognized this variability; however data gaps and analytical resource constraints prevented this. In particular, there was missing information on the specific crops and varieties cultivated in Peel, and no crop yield modeling was conducted.

With its most recent report, the IPCC has become much more confident in the findings about climate change at the global scale, confidence at the local scale is much more limited. This is due to critical scale and parameterization limitations in global climate models, gaps in historical climate data, and fundamental limitations in understanding within climatology and climate impact assessment. The greatest confidence is 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 vulnerability indicators used to contextualize more generic processes and factors to Peel have not been ground-truthed. Although they have all been used in previous studies, highly precise interpretations of these indictors in Peel are not recommended. Additionally, while there is generally confidence with regards to the broad classes of agricultural impacts expected under scenarios of climate change, the scenarios themselves are uncertain (Moss et al. 2010). The corollary is that the impacts discussed in this report should not be managed with approaches that require an assumption of precision or accuracy (Tyler and Moench 2012).

3.7. Vulnerability Factors and Indicators

Given that soil, environmental conditions, and agricultural production systems vary across the Region of Peel, so too will the vulnerability of individual farms. Additionally, at the scale of an individual farm, different climate conditions will have varying impacts. Therefore, an individual farm will have varying vulnerability based on the biophysical and management factors defining a given operation (see Figure 2). For instance, different crop types will experience varying levels of stress under the same drought conditions that affect the entire Region of Peel, and as such, farms will vary in their vulnerability to drought based on numerous factors. The identification of these factors and the relevant processes they influence are critical pieces of information for understanding current and future vulnerability, and are also essential to effective ongoing adaptation monitoring and evaluation (FAO 2013).

In this study, we use the concept of “Vulnerability Factors” to represent a quality or characteristic of an agricultural system that causes it to be more or less vulnerable to a given climatic condition or event. Such factors can represent either biophysical features or human management aspects of agricultural production. Given that many of the impacts of interest, for example declines in yield, result from a series of intermediate processes, an important part of the understanding vulnerability is the elucidation of these, which are termed “Intermediate Impacts”, for this study. Vulnerability Factors and Intermediate Impacts were elucidated through a systematic literature review of existing studies on the interactions between climate and agricultural production. A standardized series of Microsoft Excel ® templates, known as the Peel Climate Risk Analysis Framework and Templates (P-CRAFT), were used to extract information from individual studies and reports, and interpret commonalities in the information to determine and codify the most salient Vulnerability Factors, Intermediate Impacts, and their relationships. Fully completed templates are provided in Appendix D. See Appendix E for keywords, datasets and grey literature from relevant organizations reviewed.

Following the identification of vulnerability factors, metrics were selected for representing these factors locally in Peel, termed “Vulnerability Indicators” (see Appendix E). These indicators were developed using a set of criteria described in Appendix E. Datasets were then collected and analyzed using a combination of spatial and statistical methods. The analysis of the storylines included: mapping of Topographic depressions using the Topographic Wetness Index based on a 1-m digital elevation model (Beven et al 1979), and implementing of routines for calculating the soil erosivity factor (K) and slope length and steepness factors (L and S) for the Region of Peel as a way of expressing a physical soil erosion vulnerability index associated with soil conditions across the landscape. The Universal Soil Loss Equation (USLE) and the Revised USLE (RUSLE) are both well-defined models used for calculating the potential erosion associated with a given field (see Appendix G) for equations. Lu et al. (2004) present a method for calculating the RUSLE spatially across a landscape using geographic information systems (GIS) and spatial datasets. The results of the analysis are presented in the relevant “storyline” throughout Section 4.

3.8. Characterization of Major Agricultural System Climate Vulnerabilities in Peel

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

The narratives for each “Storyline” are drawn from the results of the systematic review of literature completed using the P-CRAFT templates (Appendix D) and when possible, supported by further analysis. Each impact scenario is derived from a conceptual diagram of the relationships between the climate driver and the ultimate impact of interest by way of a series of intermediate impacts. The analysis is based firstly on characterizing the biophysical processes through which climate conditions translate into altered crop yield outcomes. The farming, or management, interventions used to manage those conditions are then superimposed by adding other “processes” and relevant vulnerability factors. It is important to note that the scale of analysis for each storyline is a single “field”. The idea behind this detailed characterization is to identify key factors and processes that influence the extent of impacts a given climate driver will have on the ultimate outcome of crop productivity.

The production system, as defined in this study includes the field operations and components that go into producing a crop, such as the soil, the plants and the field management practices. It should be noted that this concept does not capture variables such as the farmer’s health and wellbeing, machinery and how it is exposed, or market implications.

4. RESULTS

4.1. Climate Impacts and Opportunities

Within a geographic region and for a particular system, climate and weather can have a wide range of differing and interactive impacts. Individual components of Peel's agricultural system will have a unique profile of impacts based on their exposure to climate, their physical properties, relationships to other systems/components, and how they are managed. As such, the analysis of climate impacts is not necessarily straightforward, and requires understanding the chain of events that begins with a climatic condition or weather events, and ends with the ultimate consequence of interest for stakeholders (Eggen and Waldmueller 2012; Fellmann 2012; Fussel and Klein 2006). These component-to-component relationships are captured in Figure 8 for generic mixed-farming systems.

The concept of "climate impact chains", akin to Bayesian network analysis used in risk modeling, are increasingly used in vulnerability assessments to understand how climate results in impacts for a variety of systems, including agriculture (Smith et al. 2014; Pramova et al. 2013; Eggen and Waldmueller 2012). Given the array of potential impacts to different system components, summarized in Appendix C, the stakeholder focus group workshop results were used to refine which of these was of greatest relevance in Peel. Figure 12 presents the results of the ranking by individuals of opportunities as perceived by the producers. Both, the individual and the group ranking results consistently indicated late fall frost, early spring, and the overall increase of rainfall and temperature as the top sources of opportunities.

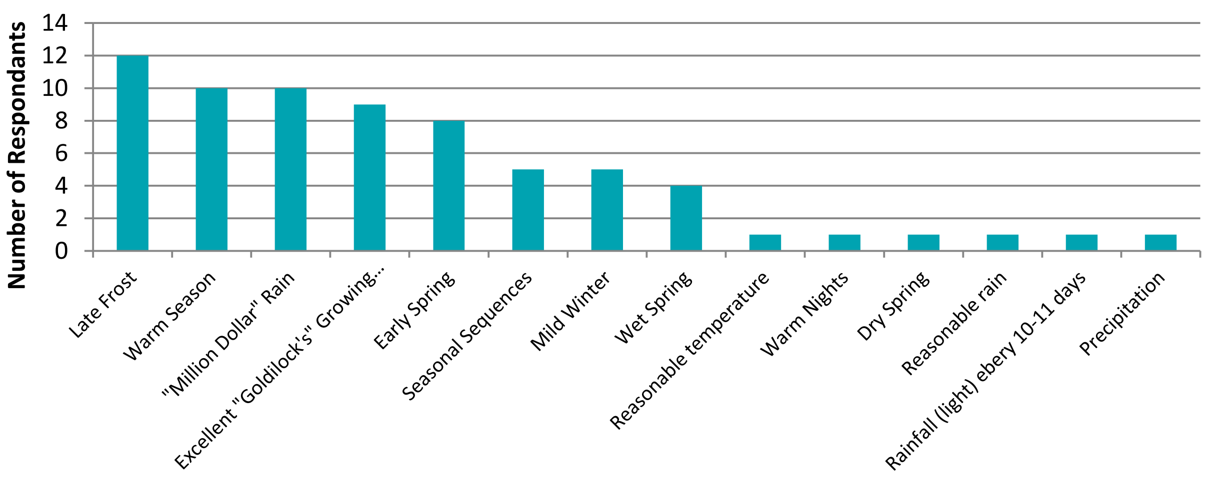

Figure 12: Results of producer perspectives on climate events that present opportunities in the Region of Peel based on individual worksheets.

Figure 13 below represents participants' perceptions on climate drivers that may impact Peel and Appendix F elaborates on their thoughts on what types of impacts the climate drivers could cause (e.g., rain driven erosion resulting in reduced yields from topsoil loss and nutrient leaching). In addition, producers were also asked to reflect on under what conditions these climate drivers are important (e.g., soil type, equipment, etc.) (see Appendix F). Concerns were predominantly centered on the impacts to the crops and plants themselves. Based on these results, it is evident the majority of impacts identified were related to either soil or crops/plants, with impacts to yield being identified as the main “consequence” of interest to stakeholders. The other identified impacts can be regarded as representing intermediate processes that ultimately impact yield.

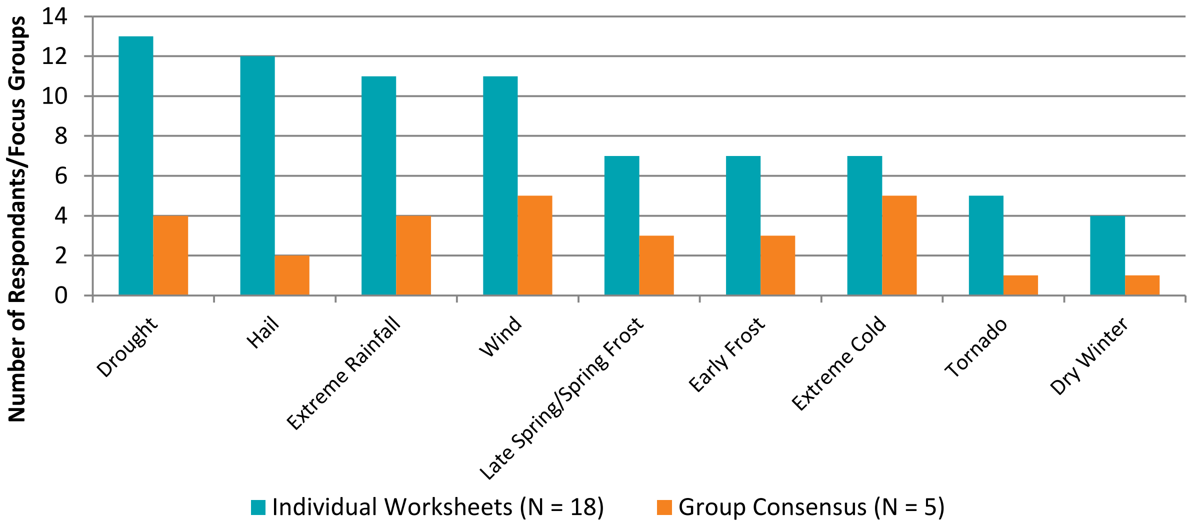

Figure 13: Top-ranked climate events that result in impacts, based on the number of individual participant worksheets and group consensus process that identified the each climate event as important to crop production or agricultural operations.

When a farmer experiences a bad crop year, either as a result of a low crop yield or crop failure, the implications can result in overall reduced farm income and loss of investment for the season, along with a host of broader consequences to the agricultural sector and rural communities (FAO 2013). Many rural communities are less diverse in their economic activities in comparison to urban areas, and changes to one traditional economic sector, such as agriculture, can have disproportionate stresses on the community’s stability (Hales et al. 2014). The economic implications extend beyond the farm to the community, as fewer agricultural commodities are being sold within the local economy and therefor the community experiences reduced revenue generation. Further impacts include loss of local good supply to the markets, which can shift changes in social behaviors such as consumption habits of the community members if food demands cannot be met locally. Further impacts to the community include loss of local food supply to the markets, and as a result, loss of business and revenue for the local food economy (Ziervogel and Calder 2003). Ultimately, these changes to the broader agricultural system impact subsequent food processing and manufacturing, food storage facilities, transportation, and broader agricultural goods and services (Ziervogel and Calder 2003). These changes and fluctuations in the agricultural system can lead to reduced food security. The degree to which a farm, farmer and community will experience or be affect by these potential impacts will be dependent upon many factors, including the adaptive capacity, experience with similar events and level of preparedness (Fraser et al. 2005). Similarly, various social, institutional and agro-ecological factors play a role in determining how vulnerable a community is to food insecurity as a result of poor crop productivity and reduced yields (Fraser 2007).

On its own, the list of historical climate impacts presented in Table 7 is not sufficient for understanding the relative importance and impact of these climatic conditions on agricultural production. As such, each event-year was compared to crop yield to qualitatively identify potential impact. Figure 14 presents a summary of several of these events that have been attributed to having a strong influence on annual crop yields. It should be noted that this is a qualitative analysis and it is impossible to determine exact cause-and-effect relationships from this information alone. That being said, such information is useful in combination with the initial identification and stakeholder perspectives for identifying priority climate impact.

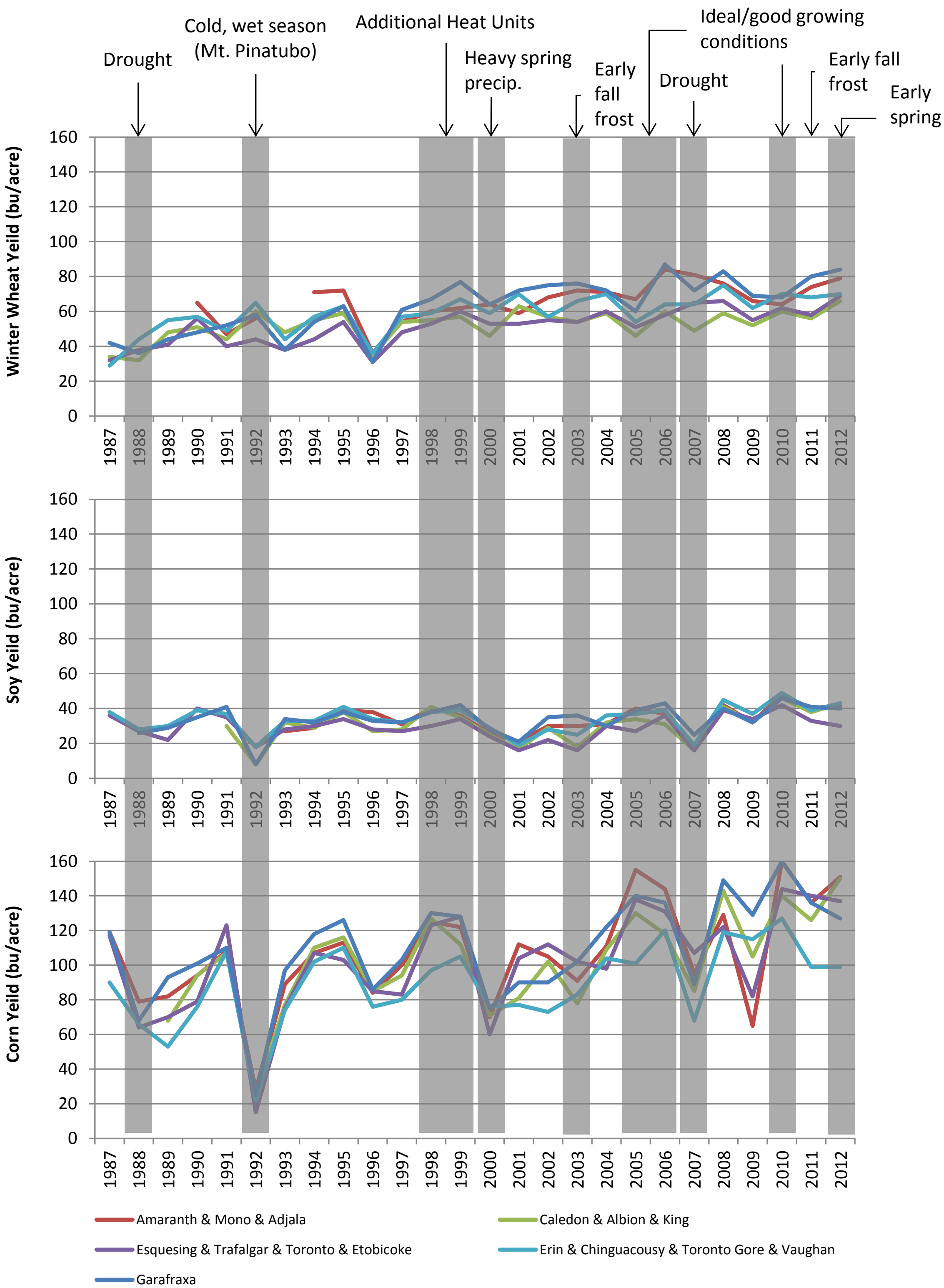

Figure 14: Graphical representation of historical trends in crop yield for corn, soy and winter wheat for several townships in the Region of Peel, highlighting key climate impacts years.

Based on the sum of evidence from the forensic analysis, crop yield comparison, and stakeholder consultation, the following types of climate events or conditions were identified as representing the most critical drivers and possible opportunities for agricultural production and more directly to crop yield:

- **Climate Events:** Drought, hail, extreme rainfall, wind, late spring/spring frost, wet spring and early fall frost.
- **Opportunities:** Above-normal precipitation and temperature (not-extreme), warmer overall growing season (i.e., more heat units), and normal timing of seasonal changes.

Opportunities were perceived by stakeholders to be stronger when multiple individual conditions occur within a given year. This is further partly supported through the analysis of crop yield information in Figure 14, which shows increased yields for corn, soy and wheat in 1998 and 1999 when growing seasons were slightly longer than average and temperatures were well above average. The 2006 and 2010 growing seasons were also particular good for all three cash crops, attributed to longer growing seasons, and above average temperature and precipitation. Quantitative analysis of these impacts to determine the threshold temperatures and precipitation was beyond the scope of this assessment.

The majority of climate drivers identified pertain to extreme weather events. Attribution of extreme weather events to crop yield impacts was not possible in this assessment, given the amount of data and effort required to conduct statistical analysis and/or modeling of such relationships. However, stakeholders did identify extreme weather events as being critical to operations, such as planting and harvesting, and also plant development. Interestingly, hail was identified by individual respondents as a top event, but its importance was reduced during subsequent group consensus discussions. Aside from extreme weather events, drought was identified as a critical impact, and its effect on crop yield is also evident in Figure 14, with 2007 and 1988 being widely recognized during the workshop and the literature as severe drought years. From Figure 14 and based on the stakeholder consultation, it is also evident that the colder and wetter conditions associated with the Mount Pinatubo eruption in 1992 resulted in significant yield loss. Concordant with this effect in crop yield, stakeholders also identified early late frost and early fall frost as key climate drivers.

4.2. Climate Trends in the Region of Peel

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

The general scientific consensus is that climate change is very likely to result in increased temperature globally (IPCC 2013); however, the specific manner in which that trend will affect the local climate in the Region of Peel is complex. For certain variables, specifically monthly precipitation, winds, humidity, and indices dependent on daily sequences, the specific changes are predicted within large ranges of uncertainty (Schindler et al. 2015; Deser et al. 2012). That being said, certain trends can be elucidated with higher confidence. In particular, the region will likely see increased temperatures over all seasons, and seasonal changes in precipitation distribution, along with greater probability of extreme temperature and precipitation events. More precipitation is likely 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 (Schindler et al. 2015), unseasonal frost is still an important climate driver (Holland and Smit 2014). Corn heat units (CHUs) are also projected to increase by between 19 and 38 percent, however if accompanied by a lack of precipitation, this trend may not be beneficial to producers. Additionally, the increased occurrence of extreme heat events during the growing season can compound issues of lacking moisture. The aforementioned trends are summarized in Table 10, and it is evident from the estimates that the uncertainty associated with climate change will make predicting seasonal weather conditions more difficult.

Many of the changes described previously and highlighted in Table 8 are evident in the recent climatic history. Figure 15 provides an overview of changes in the agro-climatic variables of growing season length and corn heat units and demonstrates trend increases over the three most recent normal periods. With respect to moisture, Figure 16 provides an overview of growing season moisture index based on Environment Canada’s homogenized monthly climate data, and demonstrates a trend toward drier growing seasons. Applying the Mann-Kendall trend test reveals that this trend toward drier growing seasons is indeed significant.

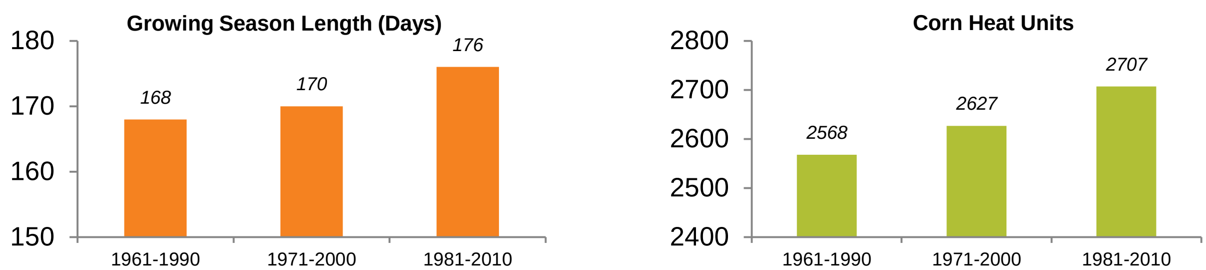

Figure 15: Historical trends in agricultural variables of growing season length, corn heat units and frost-free period for the Orangeville climate station. Results show increases in the each variable over time.

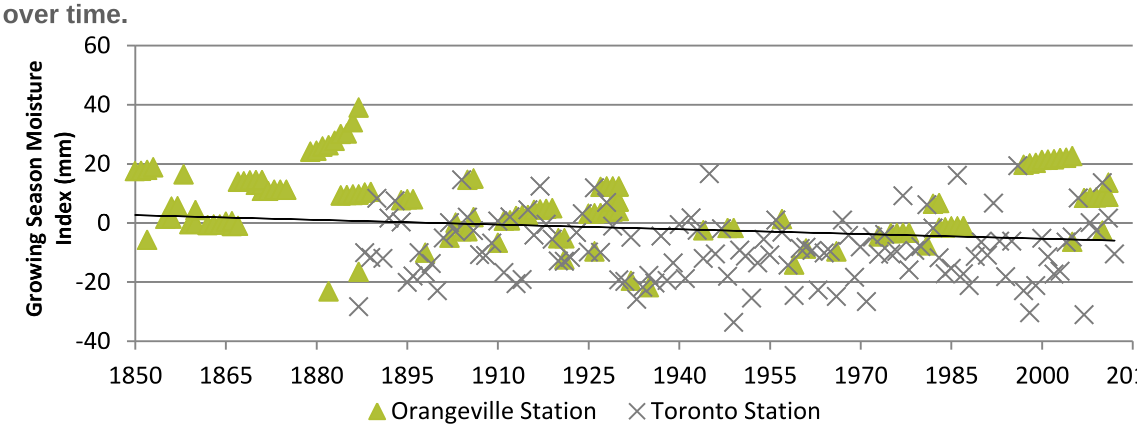

Figure 16: Growing season moisture index record for the Toronto and Orangeville stations since 1850. Application of the Mann-Kendall trend test reveals a statistically significant trend toward a drier climate (tau = -0.135, 2-sided p-value =0.0105 at 0.95 confidence level).

Table 8: Baseline (1981-2010) and future (2041-2070) projected values for agricultural climate indicators, along with interpretation of trends for the future

Climate Condition / Event	Indicator	Baseline Value	Lower Estimate	Upper Estimate	Lower Estimate Change	Upper Estimate Change	Interpretation
Growing Season Condition	Crop Heat Units [CHU]	3087.2	3674.3	4246.9	19%	38%	Very likely more
	Growing Season Length (frost-free period) [days]	164.5	178.0	197.5	13.48	32.95	Likely longer[b]
	Growing Season Start Date [day of year]	124.3	109.6	118.6	-14.67	-5.68	Likely earlier[b]
	Growing Season End Date [day of year]	287.8	298.9	313.9	11.13	26.12	Likely later[b]
	Growing Season Average Temperature [°C]	15.1	16.8	18.9	1.70	3.80	Very likely warmer
	Growing Season Total Precipitation [mm]	464.5	414.4	573.7	-11%	24%	Likely overall drier season, with more precip. in shoulder months
Frost	Growing Season days per month with daily minimum temperature ≤ 0°C [days]	2.9	0.8	1.9	-2.06	-0.96	Uncertain - assume more frequent
	Growing Season days per month with daily minimum temperature ≤ 2°C [days]	1.5	0.3	0.9	-1.19	-0.61	Uncertain - assume more frequent
	Growing Season days per month with daily minimum temperature ≤ 3°C [days]	5.5	2.4	4.1	-3.09	-1.38	Uncertain - assume more frequent
Extreme Heat Events	Total growing season days with daily maximum temperature > 30°C	10.3	3.1	23.4	-70%	127%	Likely more frequent

Table continued on next page…

Climate Condition / Event	Indicator	Baseline Value	Lower Estimate	Upper Estimate	Lower Estimate Change	Upper Estimate Change	Interpretation
Extreme Precipitation Frequency	Total annual precipitation in the 95th percentile mm]	228.9	223.6	337.5	-2%	47%	Likely more frequent extreme precip.
Extreme Precipitation Intensity	1-day maximum precipitation accumulation [mm]	37.0	35.0	47.0	-5%	27%	Likely more intense extreme precip.
	5-day maximum precipitation accumulation [mm]	59.2	55.9	75.1	-6%	27%	Likely more intense extreme precip.
Drought / Moisture Deficit	Growing season moisture index (precipitation – evapotranspiration) [mm]	9.3	-52.1	13.2	-661%	42%	Likely overall drier season[c]
	Growing season days per month with no precipitation [days]	119.3	116.0	121.6	-3	2	Uncertain – assume overall more dry days with more days of heavy precipitation. [c]

Notes:

a. Interpretation is based on ensemble changes, in combination with expert opinions on the reliability of climate models in simulating the variable in question

b. Overall growing season length is projected to increase, however this does not consider the fact that inter-annual variability may result in more instances of unseasonal frost

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

4.3. Storylines of Major Agricultural System Climate Vulnerabilities in Peel

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

- **Extreme precipitation** leading to impacts on farm operations and crop productivity
- **Drought** leading to impacts on farm operations and crop productivity
- **Changes in timing of growing conditions** leading to impact on farm operations and crop productivity (agronomic variables of growing season start, end and duration; crop heat units; optimal temperature and moisture conditions; unseasonal frost)
- **Extreme heat, or hot-spells,** leading to impacts on farm operations and crop productivity

A summary of the vulnerability factors identified in the literature as playing an important role in translating one or more of the identified climate conditions or weather event into impacts on crop yield is presented in Appendix H. For each factor, a rationale and definition of the factors are provided. These vulnerability factors represent an attribute of the system which makes it more or less vulnerable to the climate, either biophysical in nature or human/management oriented.

4.3.1. *Storyline 1: Extreme Precipitation Impacts on Crop Productivity*

Extreme precipitation is defined in this study as a rainfall event that exceeds a normal or average rainfall and is a higher intensity storm taking place in a short duration. Under scenarios of climate change, precipitation is generally projected for the Great Lakes Basin to be concentrated into more extreme, heavy episodic rainfall events with high runoff (Christensen and Christensen 2004; Pal et al. 2004; Meehl et al. 2005). Extreme precipitation impacts crop productivity through effects on plant development and growth cycles, which has ultimately been characterized in this study as being influenced by four main biophysical processes, as follows:

- water logging and flooding of soil;
- soil nutrient availability alteration (loss and transformation of nutrients);
- pest and disease infestation;
- physical plant damage and changes in plant development.

Figure 17 provides a conceptual diagram of the relationship between these aforementioned processes, in addition to highlighting the role of delayed field operations, and identifying key environmental and farming factors that influence the extent of the impact of extreme precipitation on crop productivity.

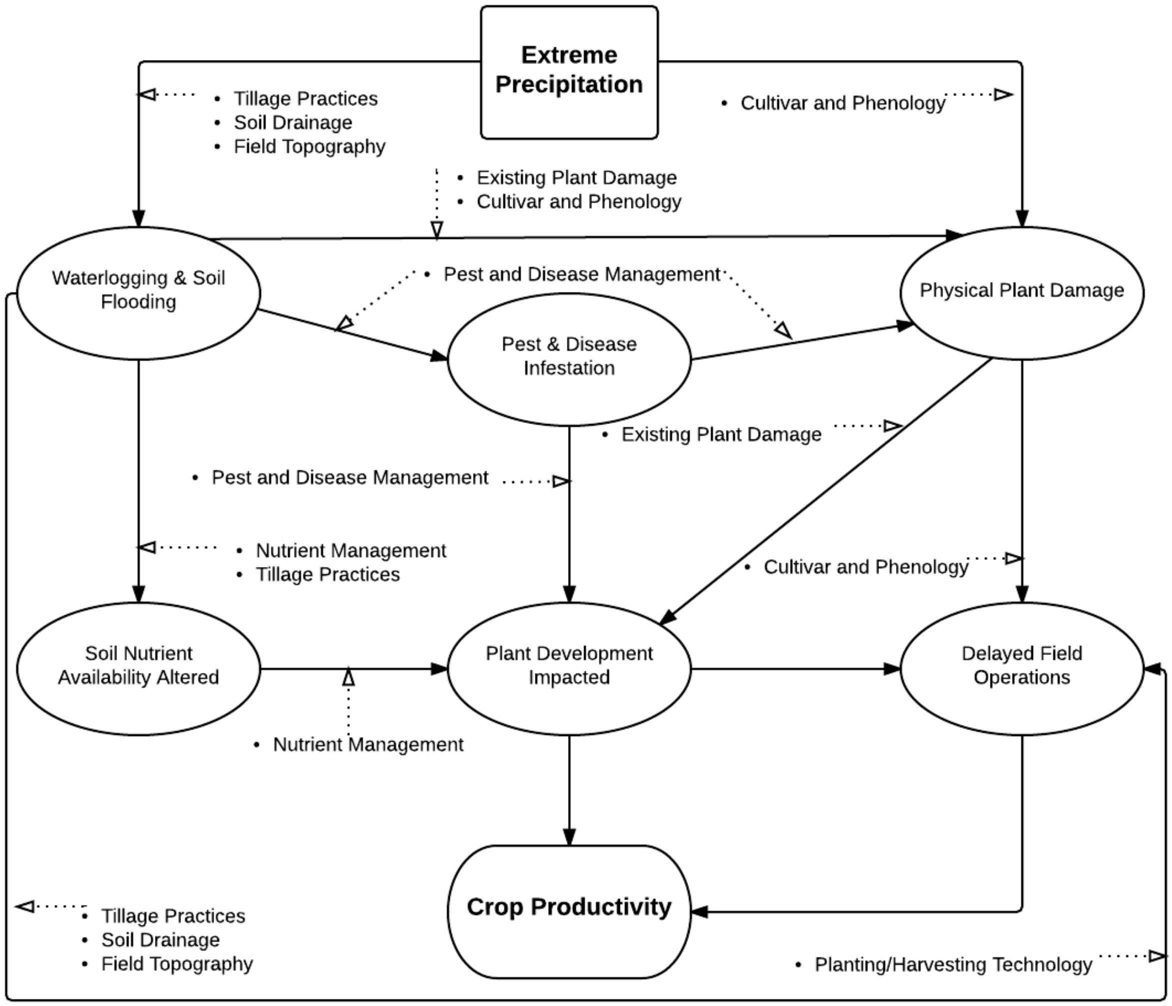

Figure 17: Impact pathway diagram highlighting the processes and key vulnerability factors influencing the extent of impacts of extreme precipitation on crop productivity.

Water Logging and Soil Flooding

Water logging in agricultural fields, as a consequence of intense and concentrated rainfall, may cause inadequate oxygen supply to root respiration, directly impacting and damaging plants (Grable 1966; Russell 1977). The location, extent and duration of flooding associated with a given rainfall event is attributed to the drainage and hydraulic characteristics of that field, which is influenced by the soil's hydraulic properties and the flow gradient influenced by field topography. Fundamental principles of hydrology suggest that flooding occurs when the infiltration capacity of a given area is exceeded by the intensity of rainfall, or the accumulation of water. Key factors influencing the vulnerability of fields to flooding, are field topography and soil hydraulic properties, which can be expressed using drainage ratings from soil surveys.

Topographic depressions are the most susceptible landforms to water-logging, and the extent of this impact is increased in areas with slower-draining soils. Figures 18 and 19 present maps showing the distribution of soil drainage capacity and topographic depressions in the Region of Peel, respectively. Based on analysis of these Figures, only a very small portion (2.5%) of Peel's agricultural land has either poor or very poor drainage, with these lands being located throughout the study area. These areas are associated with clay and clay-loam soil types soil types. The majority of agricultural land is classified as either good or imperfectly drained, with the more vulnerable "imperfect" soils located below the Niagara Escarpment (see Figure 18). Topographic depressions are located predominantly in the northwest and just south of the escarpment, and comprise approximately one third of Peel's agricultural land. Together, these maps and analysis demonstrate that areas of higher vulnerability to flooding and soil waterlogging are generally located below the Niagara Escarpment. To prescriptively determine vulnerability a distributed hydrologic modeling could be used to identify with more confidence specific areas vulnerable to flooding, however, this was beyond the scope, time and resources of this assessment.

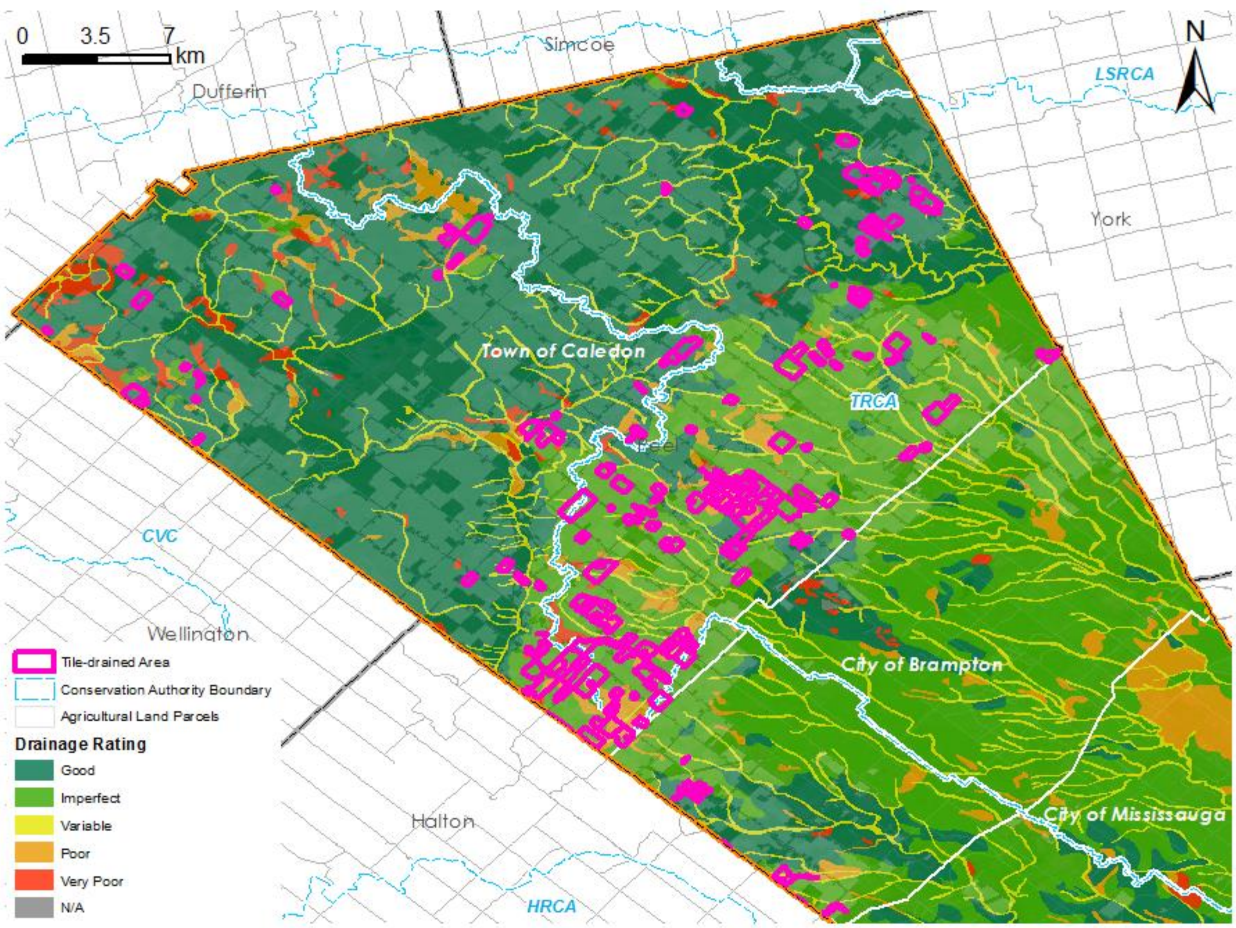

Figure 18: Drainage rating in Peel Region including identification of tile-drained areas.

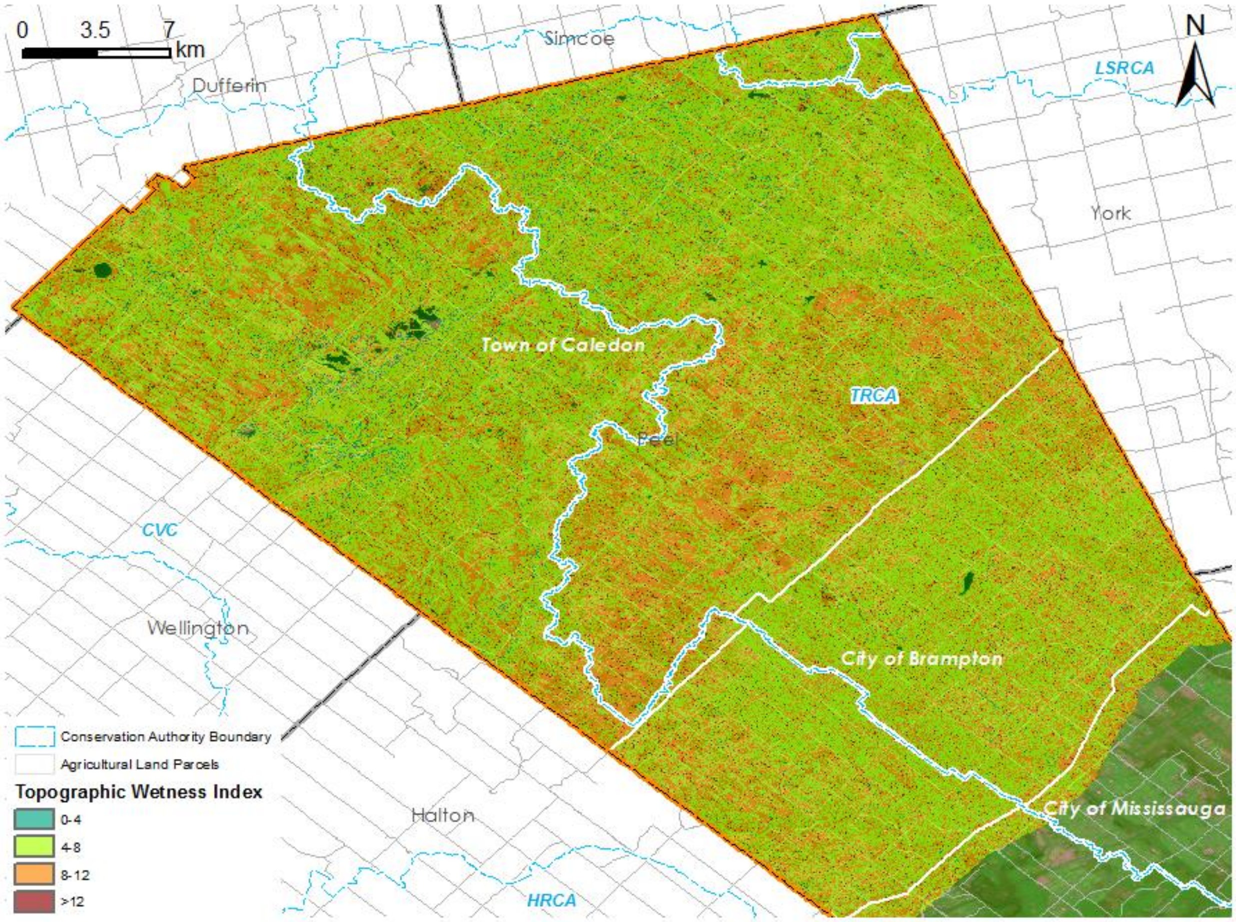

Figure 19: Map of Topographic Wetness Index identifying areas with topographic depressions that are susceptible to water accumulation.

When waterlogging occurs, plants often experience yellowing leaves, inhibited root development, reduced branch number and nodulation (in soybean), defoliation, and even plant death (Linkemer et al. 1998; Minchin and Pate 1975; Oosterhuis et al. 1990; Purcell et al. 1997; Stanley et al. 1980). Studies conducted in the Mississippi delta region indicate that a short period flood, lasting 2 to 4 days in duration, showed yield increases in cultivars, though all cultivars began to experience a decline in yield at longer flood durations (Rhine et al. 2010). Impacts and extent of damage varies depending on crop type and growth stage. During reproductive stages, soybeans can tolerate floods for two days without significant yield reduction (Griffin et al. 1988). Aside from the physical damage, waterlogged conditions may delay farming operations such as planting and harvest. During the planting season, the later farmers wait to plant their crops, the higher the probability of the crops not maturing on time (Reid et al. 2007; Almaraz et al. 2008). In harvest season, waterlogging can result in ripening grain lodging in standing crops (Pantaleoni et al. 2007; Motha 2011), rust in grain (Kettlewell et al. 1999; Reid et al. 2007), sprouting of the grain in the ear, and fungal disease infections of the grain (Kettlewell et al. 1999). These pest-related impacts can be managed through effective pest-management measures, which are explored further in this storyline.

Tile drainage represents an important management measure that can reduce the vulnerability to soil flooding and water-logging. Currently in Peel, 5.8% of the agricultural land is tile-drained. Drainage is most predominant in the imperfectly-drained soils south of the Niagara Escarpment (Figure 18). Most of these tile drains are installed in cash crop or mixed farming lands.

Soil Erosion and Nutrient Availability Altered

Extreme precipitation often results in flooding and waterlogging which can cause soil erosion, anoxic nutrient cycling, and leaching of nutrients from soil. Multiple modelled studies conducted by Hammad et al. (2006) and work done in the Mediterranean region (Pimentel 2000; Brodowski 2013) have identified that soil erosion is predominantly related to the total amount of rainfall during an event. Hammad et al. (2006) classified the total amount of rainfall in an event in relation to soil erosion into four categories: 0-10mm, no impact on soil erosion; 10-20mm, low impact; 20-50mm, moderate impact; and 50-70mm, severe impact. Under extreme rainfall conditions, a 1% increase in total rainfall increases soil erosion by 1.7%, whereas with regular rainfall, a 1% increase in total rainfall increases soil erosion by 0.85% (Pruski and Nearing 2002). Soil erosion is subject to slope gradients in that the steeper the slope, the more prone it is to soil erosion (Fox and Bryan 1999). In an experiment conducted by Brodowski (2013), soil erosion was examined on three slope gradients: 4%, 12%, and 25%. Results showed that, under various rainfall conditions, sediment loss on a 12% slope is about twice that on a 4% slope, while sediment loss on a 25% slope is about 3.7 times.

Like flooding and water-logging, the extent of soil erosion on a given field is driven by the characteristics of the soil and its environmental setting. In Caledon, the main soil type is Luvisolic, whose texture slightly varies from loamy-dominant to clay-dominant across the study area. Loamy soils have better infiltration capacity (Toy et al. 2002; Gumiere et al. 2009), while clay soils have good resistance to detachment by flow. Modeled studies by Gumiere et al (2009) did not show a consistent difference in the erodibility of these two types of soils. Additionally, soil characteristics affect the amount of water and nitrate that leach through the soil profile (Miller et al. 1993), which ultimately impacts crop productivity and yield. However, under very well drained soils, extreme precipitation may provide the benefit of increasing soil moisture which in turn increases some level of retention and microorganism activities, resulting in soil nutrient availability (Bérard et al. 2011).

Results from the RUSLE analysis (Lu et al. 2004) are provided in Appendix G and Figure 20 for the LS, K and vulnerability index aggregated by agricultural field (LSxK), respectively. This analysis reveals that there are very few farms that have moderate or high physical soil erosion vulnerability and the majorities with higher vulnerability are in the north-east, atop the Niagara Escarpment. This area is also identified as being topographically limited within the CLI classification, indicating that topography is likely the greater control for high vulnerability areas compared to soil type.

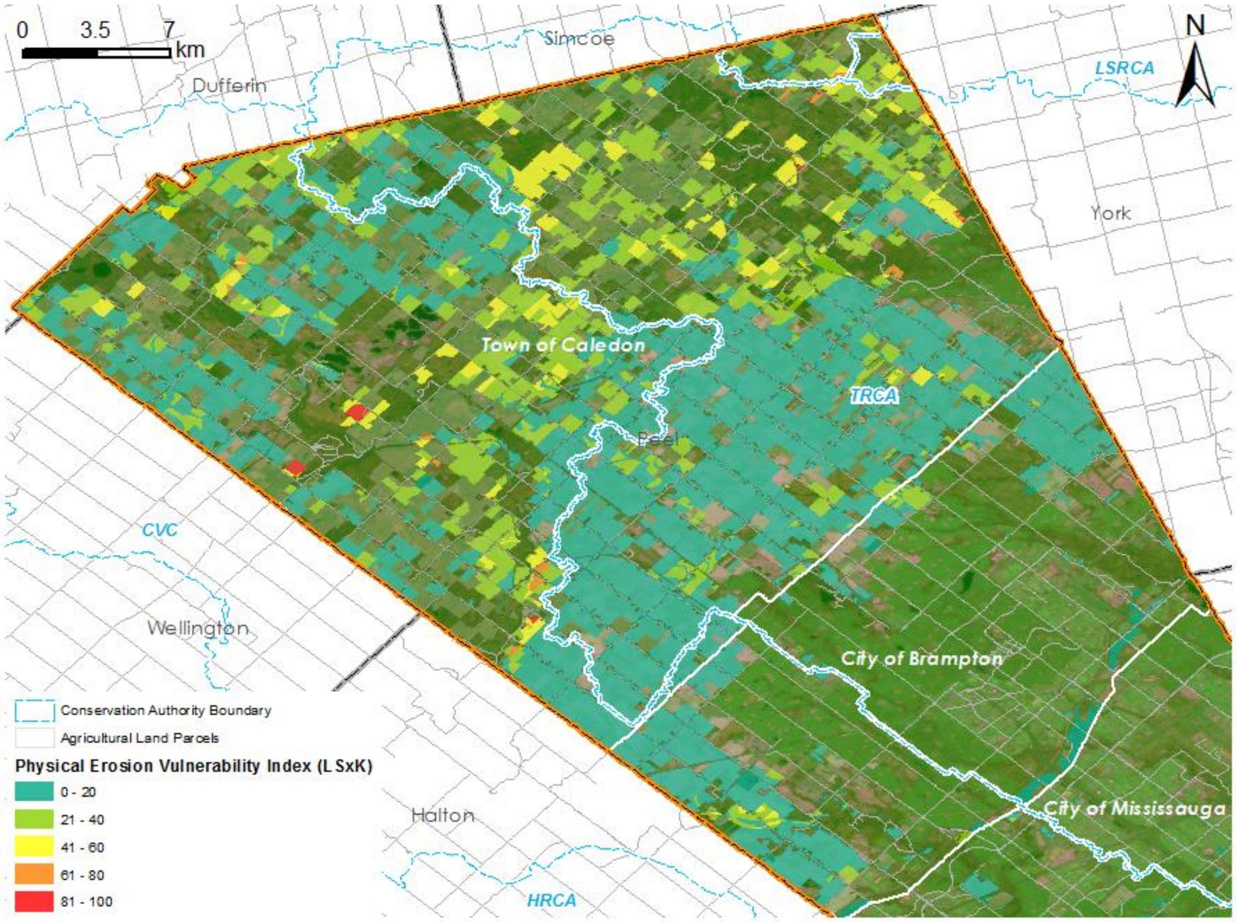

Figure 20: Soil erosion physical vulnerability index map. Index is calculated from the LSxK factors within the RUSLE.

Despite this physical vulnerability, field management practices play a critical role in determining overall vulnerability of field to erosion and nutrient loss. Tillage practices can range from conventional and traditional plowing techniques options to more conservation type practices such as no-till, or reduced till. Certain tillage practices can promote the conservation of organic matter, slow soil deterioration, improve drainage, increase water and nutrient holding capacity, and allow necessary soil organisms to thrive. Less physical disturbance of the land by tillage can reduce environmental degradation and increase water-holding capacity (Swanson 2007). In addition, conservation tillage is a proven practice for supporting the maintenance of soil moisture while mitigating soil erosion from wind and water, which is anticipated to become a more frequent challenge as result of climate change (BCA & FCAI 2012). Figure 21 shows the percentage of farms in Ontario and Peel Region employing tillage practices that maintain most crop residue on the surface and tillage practices that incorporate most crop residue into the soil. Conservation tillage practices are those that aim to maintain crop residues on the soil surface in order to protect the soil from erosion. Interpretation of this breakdown demonstrates that approximately 30% of Peel's farms employ conservation tillage practices, which is consistent with rates at the provincial scale. It is still the case that the vast majority of farmers still practice more traditional forms of tillage. The RUSLE specifies more quantitatively the contribution of crop choices and field management practices (tillage and row orientation) to soil erosion. A Monte Carlo sensitivity analysis was conducted using the values for each factor provided by OMAFRA to understand which of these factors and combinations yield the most benefit to reducing soil erosion vulnerability. Further RUSLE results are presented in Figure 22, and they demonstrate that hay and pasture provide the most substantial reduction of soil erosion vulnerability, followed closely by not-till, ridge tillage and zone tillage. The greatest erosion vulnerability reduction was evident under scenarios of zone tillage or no tillage on fields with hay or pasture oriented cross slope.

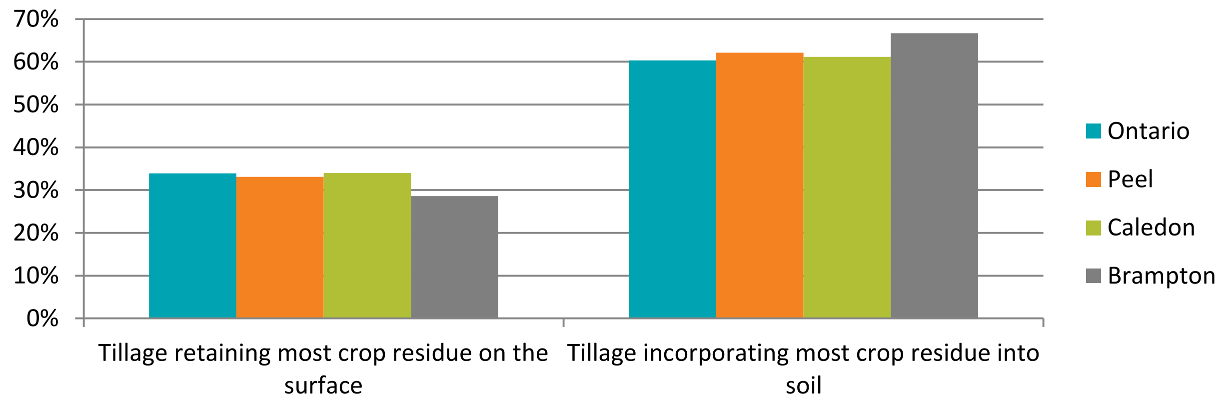

Figure 21: Percentage of farms in Ontario and Peel Region using tillage practices that retain most crop residue on the surface and practices that incorporate most crop residue into the soil (in comparison to the total number of farms prepped for seeding, i.e. active) (Census of Agriculture 2011, CANSIM Table 004-0205).

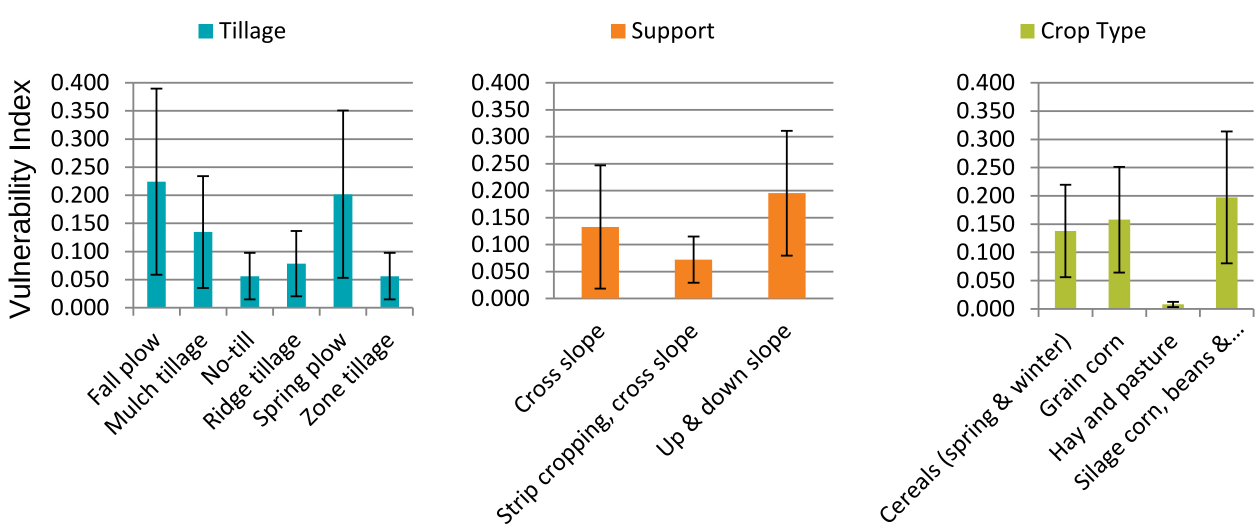

Figure 22: Results of sensitivity analysis of field management and crop type factors on the soil erosion vulnerability. The vulnerability index was calculated by multiplying OMAFRA values for each factor by one another in accordance with the formula in the RUSLE. Higher values denote variables that contribute the greatest to soil erosion. Error bars denote the vulnerability index value’s standard deviation when that specific factor was isolated.

The Census of Agriculture defines nutrient management planning as a detailed plan for applying nutrients to a land base with the intention of optimizing their uptake by crops while minimizing environmental impacts and operating costs. Nutrient management practices can help maintain and reduce nutrient loss prior to and following extreme precipitation and erosion events (Beegle et al. 2000). Nutrients applied to a field can be in the form of manure and commercial fertilizers. Nutrient management planning is a best management practice (BMP) that can be tailored based on field and crop properties to optimize crop yield and quality. Key parts of nutrient management in determining the amount of inputs to add by estimating what nutrients, and in what quantity, are required for a target yield. It is well known that the majority of farmers plan, in some form or another, their nutrient application strategies.

Impacts of Extreme Precipitation on Pests and Disease Infestation

The response of pests and fungi to excessive moisture conditions associated with extreme precipitation, soil waterlogging, and flooding is species-dependent, based on key factors of current plant health or level of pre-existing damage and pest and disease management practices currently employed. It is anticipated that with climate change and an extended growing season, the reproduction and survival rates of certain pests, diseases and insects will increase, presenting an enhanced probability of infection and related damage. Additionally, with changing climatic conditions, there is the potential for the establishment of new and invasive crop pest species (BCA and FCAI 2012). Of the three major species, *Fusarium spp* is associated with corn ear rot in Ontario; *F. graminearum* is often associated with wet years, while *F. moniliforme* and *F. verticillioides* are associated with dry years (Miller et al. 1995, Sutton 1982; Vigier et al. 1997). Another pest species favoured in wet years is western corn rootworm (*Diabrotica virgifera virgifera*) (Wright et al. 1996), which is known as one of the most devastating corn rootworm species in North American, decreasing yields of maize by 10–13% (Apple et al. 1977). Overall, an increased frequency of extreme precipitation events may result in increased dispersal of airborne plant pathogens such as rusts, splash-borne pathogens such as bacteria, and windborne insects and vectors such as aphids and psyllids (Luck et al. 2011). Abundant moisture can also accelerate weed growth, therefore intensifying a crops' competition for nutrients and light. This effect is particularly significant when it occurs before crops are fully developed (Almaraz et al. 2008). Accordingly, modeling on 30 years of simulated crop and pest competition has revealed that early season precipitation was correlated with maize yield loss (McDonald and Riha 1999).

Farmers employ a host of Integrated Pest Management Strategies (IPMs) to deal with pests and diseases, such as choosing and applying the appropriate fungicides, herbicides, pesticides and insecticides at appropriate times and in the right quantities (see Figure 23). As the climate and weather become more variable, farmers will need to adapt management practices to deal with an increase or new pest and diseases. Longer growing seasons may increase the lifecycles of existing pests, while increasing temperatures may introduce new and invasive species not previously considered a concern in the region. Tools exist for optimizing pest management in the context of various weather and climate conditions (e.g., Weather Innovations LP:

http://www.weatherinnovations.com/models.cfm); however, information on the extent to which such tools are currently being used to optimize farming in Peel was not available for this assessment.

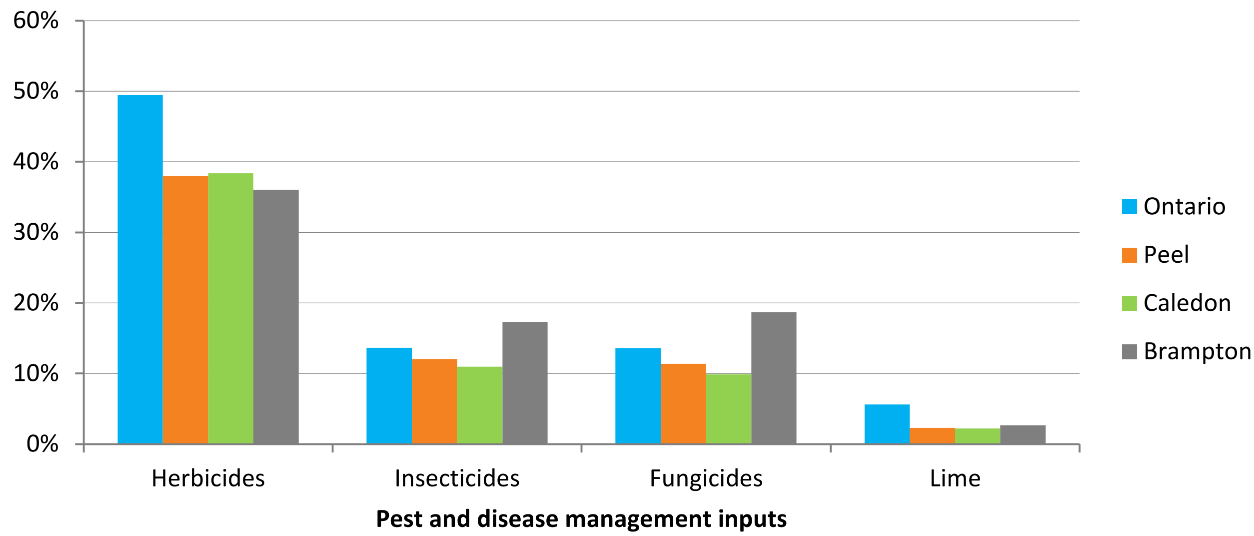

Figure 23: Percentage of farms in Ontario and Peel Region using various pest and disease inputs (in comparison to the total number of farms in each area) (Census of Agriculture 2011, CANSIM Table 004-0206).

Impacts of Extreme Precipitation on Plant Development

Different crops and, and within that cultivars, reach various growth stages and maturation at different times throughout their development. Length to and duration of various growth stages is also dependent on the microclimate, planting dates, and planting patterns of the crop. Crops are more vulnerable to climate events and extreme weather at certain imperative stages of growth, and have different requirements for optimal growth during these stages. Corn, soybeans, and wheat share in common that they are most vulnerable to adverse environmental conditions during their early growth, flowering and grain filling stages (Griffin and Saxton 1988; Linkemer et al. 1998). A study on soybean shows that waterlogging stress at the R1 growth stage reduced assimilatory capacity to reduce branch number, which results in a significant yield loss (Linkemer et al. 1998). Significant yield loss was also reported to occur when rain fell in excess during the period of maturity and harvest (Penalba et al. 2007).

Another case study on soybeans by Linkemer et al. (1998) indicates that if 30 to 50mm of rain falling over 1 to 2 days during sensitive growing periods could result in significant yield reductions. Similarly, 100mm of rain in a single week during a sensitive growing period falling on poorly drained soils would likely result in waterlogging stress to crops. For instance, if prolonged flooding occurs at floral initiation or the beginning of the seed filling stage, yield may be reduced by more than 40% (Steduto et al. 2012). As for corn, field observations shows that after an excess rainfall about 200% of normal precipitation for late growth stage (July 2003), about 17% of corn was physically damaged, though a large proportion of these plants recovered in about one week (Pantaleoni et al. 2007). Within the same crop species, different cultivars largely vary in their flooding tolerance. Yields of all soybean cultivars tested were reduced by flood at the R1 stage, with the most flood-tolerant cultivars reduced to 39% and the most flood-sensitive cultivars reduced to 77% (Shannon et al. 2005). Currently, no information was available on the dominant cultivars used in Peel to determine their relative vulnerability to extreme precipitation, however it is anticipated that such information exists with agricultural input suppliers and manufacturers.

4.3.2. *Storyline 2: Drought Impact on Crop Yield*

Drought, as defined in this study, is a period of abnormally dry weather long enough to cause a serious hydrological imbalance. Agricultural drought refers to a shortage of precipitation during the growing season which in turn affects crop production (IPCC 2012). Drought impacts crop productivity primarily by limiting the availability of moisture for satisfying crop water requirements. Additional stress can be caused by exposure of plants to extreme heat, which often accompanies drought. The following four main processes were characterized in this study as influencing drought vulnerability of agricultural production:

- soil moisture depletion;
- altered soil properties and nutrient availability;
- pest and disease infestation; and
- impacted plant development.

The Figure 24 provides a conceptual diagram of the relationship between these aforementioned processes and identifies key environmental and farming factors that influence the extent of the impact of drought on crop productivity.

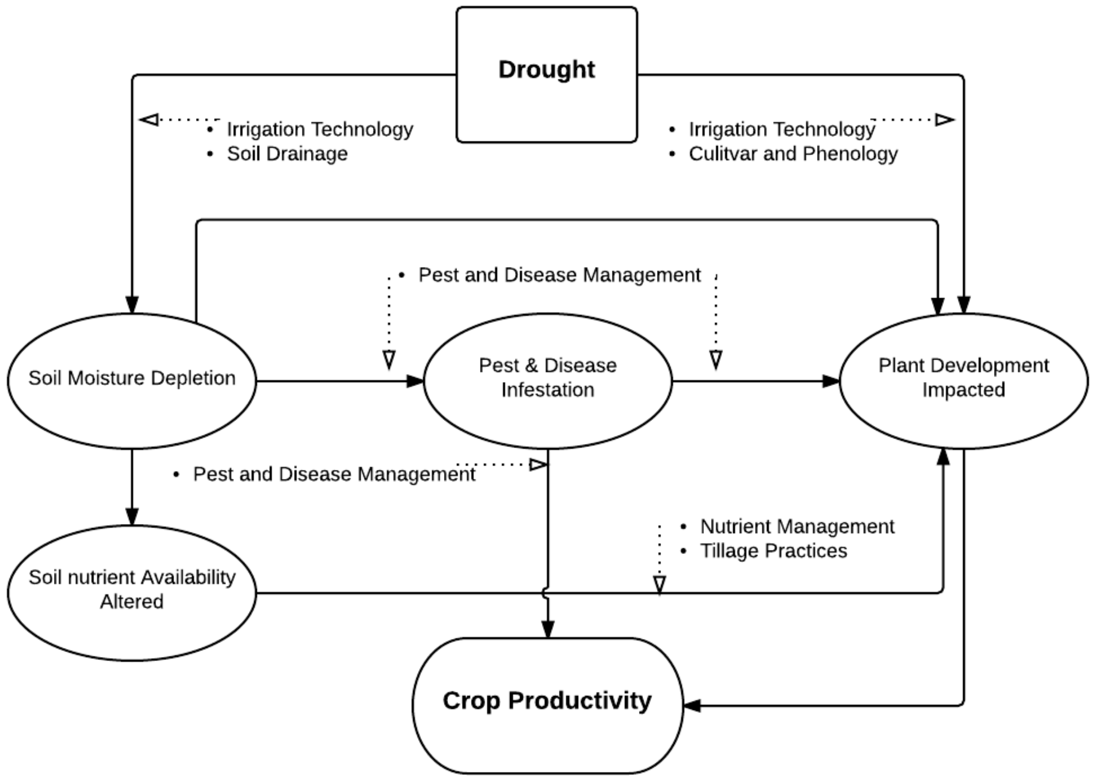

Figure 24: Impact pathway diagram highlighting the processes and key vulnerability factors influencing the extent of impacts of drought on crop productivity.

Through the numerous processes described in Figure 24, drought can significantly reduce crop yield. Results from modeling show that soybean yield is directly proportional to precipitation rates (Mera et al. 2006). A 37.5% reduction in soybean yield was observed in a field experiment in North Carolina conducted by Grinnan et al. (2013). Azeez et al. (2005) indicated that drought stress reduced the corn stover weight and grain yield by 6% and 34% respectively. Further studies show that germination under osmotic stress conditions can lead to maize seedling death by 14% to 24% (Grzesiak et al. 2013). Drought in the early vegetative stage may suppress leaf and root development (Kausar et al. 2012), and plants grow a much smaller canopy (Steduto et al. 2012). Severe drought may lead to root shrinkage and as a result, soil-root contact. For instance, North and Nobel (1997) reported that corn can endure a moderate soil drought (10% w/w water content) for a period of up to ten days. When soil water content further decreased to 5%, plants N-uptake ability was reduced to about 20% in comparison to the well-watered controlled plants. Furthermore, when water stress is sufficiently server, older leaf senescence is accelerated and the period of seed-filling is shortened (Brevedan and Egli 2003), which may led to a substantial yield reduction in addition to poor grain quality (Azeez et al. 2005; Hernandez-Garcia et al. 2010; Ferreira and Rao 2011), though drought had little effect on mid-season (mid-July) growth rate (Grinnan et al. 2013).

When soil moisture is decreased, soil nutrients that are transported by mass flow and diffusion also decrease in availability for plant uptake (Mackay and Barber 1985a, b; Seiffert et al. 1995). As a result, farmers need to tailor their nutrient management strategies in order to ensure sufficient nutrient availability for crops, but without over-applying. As was previously discussed in Storyline 1, nutrient management that is adaptive to climatic conditions is a critical aspect of responding to drought conditions.

Aside from the climate itself, soil moisture is dependent primarily on the soil type, specifically the bulk soil moisture capacity, which is in-turn the result of numerous properties. Moreover, dry soil conditions inhibit microbial activities (Bloem et al. 1992; Walworth 1992). When drought conditions become severe, microbial communities may undergone a drastic biomass killing (Bérard et al. 2011), resulting in reduced soil nutrient cycling and supply to plants. It is anticipated that climate change may increase the frequency and duration of drought events (IPCC 2013), ultimately reducing crop productivity and yield if crop water requirements and essential nutrients are not met.

Although drought may have many negative impacts on crop yield, slighter soil moisture deficits have been shown to produce some benefits to crop productivity. For instance, low soil moisture may force more rapid downward growth of roots (OMAFRA 2013). Also, dry spells lasting less than 2 days were observed to slightly accelerate flowering and pod maturity date (Grinnan et al. 2013). In addition, drought pretreatment may induce chilling tolerance in certain sensitive corn genotypes (Aroca et al. 2003).

The impacts of drought on crop productivity will be dependent upon farming and environmental factors and practices, namely such as the presence or absence of irrigation technology. The benefits of irrigation include; controlling water quantity for crops during rainfall shortages to ensure crop water requirements are met at critical growth stages, increasing the opportunity for double cropping in a season and improving the overall quality and quantity of crops (USEPA 2012a). While the choice of cultivar and phenological stage of the crop, tillage practices, pest and nutrient management all play a role in drought vulnerability, the lack of moisture is a fundamentally limiting factor. Table 9 below shows the number of farms using irrigation technology on various crop types in Ontario and Peel Region, and demonstrates that approximately 6 percent are equipped with irrigation technology, with only two farms reporting use for field crops. Despite the potential benefits that irrigation offers for drought resilience, there are potential drawbacks and negative consequences that need to be considered, such as the high capital cost for farmers, and cumulative impacts on water supplies, hydrology and ecosystems. Figure 25 provides a map of current water-taking permits in the Region of Peel and demonstrates that there is currently only a small number of agricultural water taking permits active in the Region of Peel; however in the area north of the Niagara Escarpment, there are a significant number of permits for other uses. This implies that there may be potential trade-offs in water use that need to be considered if irrigation is to become more prominent.

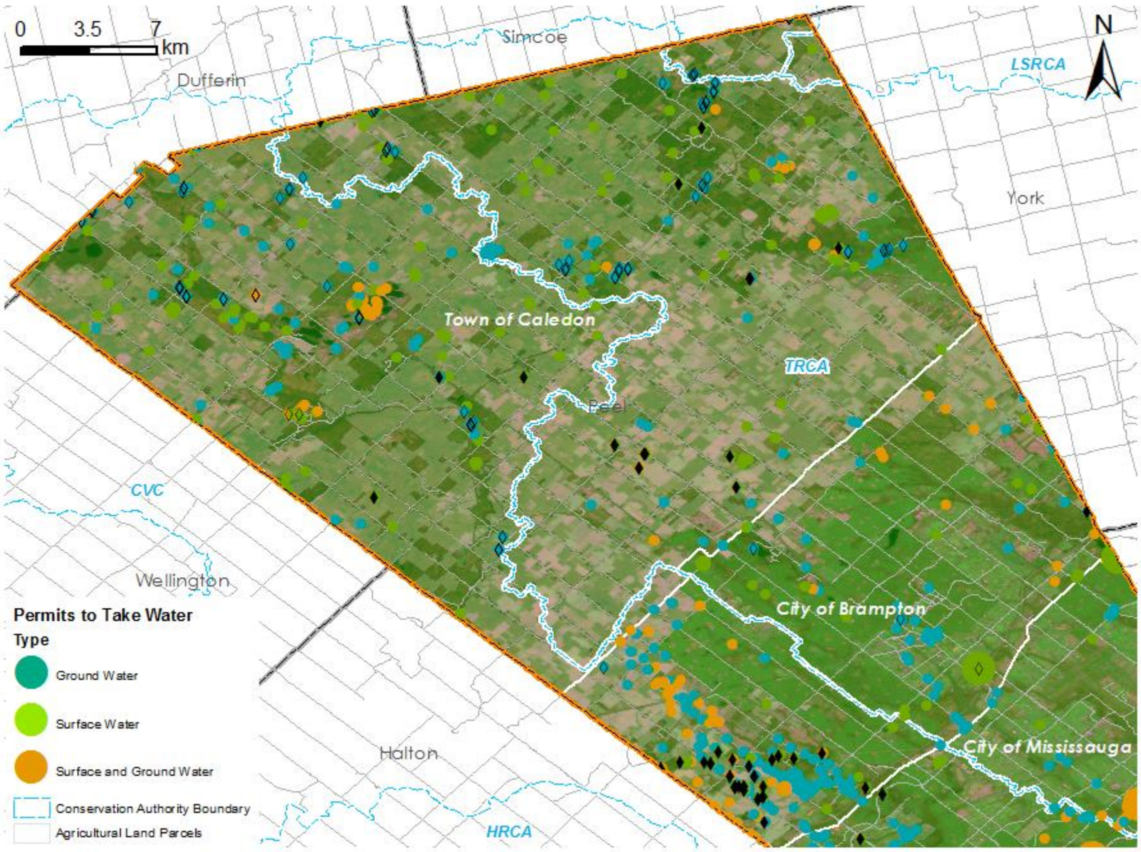

Figure 25: Map of water taking permits in the Region of Peel, diamonds denotes permits for agriculture.

Allen et al. (1998) provides guidelines for the determination of crop water requirements, which are used to assess irrigation needs, based on crop type, soils and climate conditions. Initial work has been done in Kundurpi (2013) to assess crop-water requirements for wheat and soy (Table 10), and identify key phonological thresholds. Similar information on other crop types would be helpful in assessing more fully the need and feasibility for irrigation and other drought resiliency adaptation options, such as alternative drought-tolerant cropping systems.

Table 9: Number of farms in Ontario and Peel Region reporting irrigation use by crop type (Census of Agriculture 2011, CANSIM Table 004-0210).

	Ontario	Peel	Caledon	Brampton
All irrigation use	1987	28	18	10
Irrigated alfalfa, hay and pasture	74	1	1	0
Irrigated field crops	424	2	0	2
Irrigated vegetables	923	11	5	6

Table 10: Drought thresholds for wheat and soybean at varying growth stages (Kundurpi 2013).

	Wheat	Soybean
Climate event	**Threshold**	
Drought	Initial stage: ≤ 8.9mm (30days)	Initial stage: ≤ 7.8mm (10 days)
	Development stage: ≤ 34.5mm (30 days)	Development stage: ≤ 35.1mm (20 days)
	Middle stage: ≤ 118.9 (40 days)	Middle stage: ≤ 131.4 (40 days)
	Late stage: ≤ 85.1mm (40 days)	Late stage: ≤ 33.4mm (20 days)
	≥ 8 consecutive days without rain	≥ 8 consecutive days without rain

There are also important effects of drought on crop pest and disease infestation. And like the other impacts, these effects are complex and depend on the infesting species, timing, and various plant attributes, such as current level of plant health or pre-existing plant damage (Koricheva et al. 1998; Huberty and Denno 2004). In Southern Ontario, mainly five *Fusarium* species infest corn, some of which are favoured in wet years while others are favoured in dry years (Miller et al. 1995; Sutton 1982; Vigier et al. 1997; Motha 2011). For example, the *fumonisin* contamination, produced by several *Fusarium* species such as *F. verticillioides*, mainly occurring in corn, wheat and other cereals, is spreading during below average rainfall following pollination (Miller et al. 1995; Parsons and Munkvold 2012). In contrast to the *Fusarium* species, which favor consistent moisture conditions, the western corn rootworm, (*Diabrotica virgifera virgifera* LeConte Coleoptera: Chrysomelidae), varies its soil moistures requirement along its life span (Apple et al. 1977; Parsons and Munkvold 2012). As for leaf chewing insects, such as the aphid, they appear in serious form on the water-stressed crops and particularly during drought years (Azeez et al. 2005). Meanwhile, under dry conditions, weeds may intensify the competition for water and nutrient resources. Weed treatment by Azeez et al. (2005) has found a 10% reduction in corn grain yield, whereas Tollenaar et al. (1997) observed a yield loss of 23% when weed growth was present in corn plots. If drought conditions increase in duration and frequency as a result of climate change, farmers will likely need to adapt their pest and disease management strategies and practices in order to maintain productive crops (see Figure 23 for current percentage of farmers in Ontario and Peel Region using various pest and disease management inputs).

4.3.3. *Storyline 3: Changes in Timing of Growing Conditions*

Changes in timing of growing conditions impacts crop productivity through effects on plant development and growth via changes in planting and harvesting date. The Figure 26 provides a conceptual diagram of the relationship between these processes and identifies key environmental and farming factors that influence the extent of the impact of these changes on crop productivity. Changes in growing conditions resulting from climate change are a complex set of effects, which can be positive or negative, depending on the specific changes.

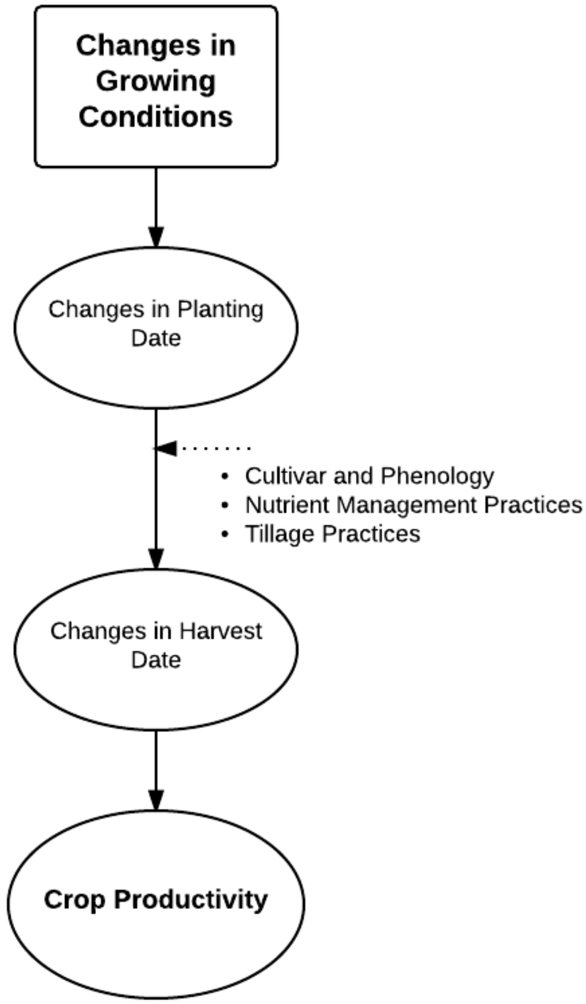

Figure 26: Impact pathway diagram highlighting the processes and key vulnerability factors influencing the extent of impacts on changes in growing conditions on crop productivity.

Changes in temperature and precipitation patterns will influence the growing conditions and growing season length in Ontario. The consistent warming in air temperature increases Crop Heat Units (CHU) and extends growth season, therefore providing the potential to plant and harvest crops earlier than traditional dates. The potential benefits of increasing temperatures and a longer growing season will only be beneficial to farmers if supporting climatic variables such as precipitation and frost free days during critical growing stages are met. See Tables 11 and 12 (crop water requirements and thresholds at various growth stages and climate event and thresholds at various growth stages) for critical climate thresholds and crop requirements at critical growth stages for select crops. Additionally, tillage practices and principles may need to change in order to take advantage of or react to changes in growing conditions. For example, farmers may choose to leave more crop residue on fields in order to reduce soil erosion and nutrient altering during extreme precipitation events.

Table 11: Ideal crop water requirements and excessive rain thresholds for wheat and soybean at various growth stages (Kundurpi 2013).

	Wheat	Soybean
Climate event	**Threshold**	
Ideal Rainfall	317.1mm/growing season	259.5 mm/growing season
	Initial stage = 11.4mm	Initial stage = 9.7mm
	Development stage = 44.2mm	development stage = 43.9mm
	Middle stage = 152.4mm	middle stage = 164.2mm
	Late stage = 109.1mm	Late stage = 41.7mm

Table 12: Climate event thresholds for wheat and soybean (Kundurpi 2013; Tollenaar 2013)

Climate Thresholds	Wheat	Soybeans	Corn
Days required for Growth	120-150	135-150	69-88
Ideal Temperature °C	26-30	25	33-35
Min Temp °C	5	8	0-10
Max Temp °C	35	40	45

For most of Ontario, soybeans are typically sown in mid-May. A field study experiment in Southern Ontario spanning three years (2010-2012) was conducted to examine soybean yields between early planting (April 15-May 5), for longer maturing cultivars and the normal planting (May 5-20), and late planting (May 21-June 5) with adapted cultivars (Crop Advances Field Crop Report 2013). Based on climate variable studies in Southwestern Ontario, in general, precipitation in January and April are negatively related to corn and soybean yields and positively related to wheat yield. Alternatively, precipitation in July has a positive effect on the yield of corn and winter wheat (Cabas et al. 2010).

Furthermore, increased precipitation together with increased air temperature may impose an interactive effect on crop yields (Kucharik and Serbin 2008). If modest increases in total summer precipitation (i.e. 50mm) were to occur, counteracting a portion of the negative effects associated with increased temperature, yields increase of 5–10% could be expected. Similarly, Travasso et al. (2009) have found that during the last decades, increases in precipitation and minimum temperature coupled with decreases in maximum temperature led to about 40% increase in soybean yields in Argentina. In general, studies in Southern USA show that soybean seed yield may be boosted by 7.20 kg for each mm of total water received (rainfall and irrigation) (Hernandez-Garcia et al. 2010). As discussed in Storyline 1, extreme precipitation events can alter soil nutrient availability. Due to the high certainty that extreme precipitation events and subsequent runoff will increase in frequency and intensity in the future (IPCC 2013), farmers will need to revise or plan their nutrient management strategies and practices accordingly in order to maintain healthy and functioning soils.

In exceptional growing condition years, such as 2010, the early plating date had an advantage of approximately 3 bu/ac (4.5%) over the traditional planting date, and 10 bu/ac (16.8%) over a later planting date (Bohner et al. 2012). This strategy proves a significant improvement in yield considering it costs the farmers nothing to sow their crops earlier (OSCIA 2011). However, in the following two years (2011 and 2012) with less favourable weather conditions, there was no significant difference between early planting and normal planting, though with an early planting date, some cultivars resulted in greater yield than others (OSCIA 2013). Nevertheless, planting late has shown to produce significantly lower yields, with losses averagely 5 bushels per acre (-7.6%). Figure 27 provides a conceptual diagram of the changes in growth length starting and end dates and the subsequent yield outcomes (bu/ac) based on growing length and Crop Heat Unit (CHU) changes.

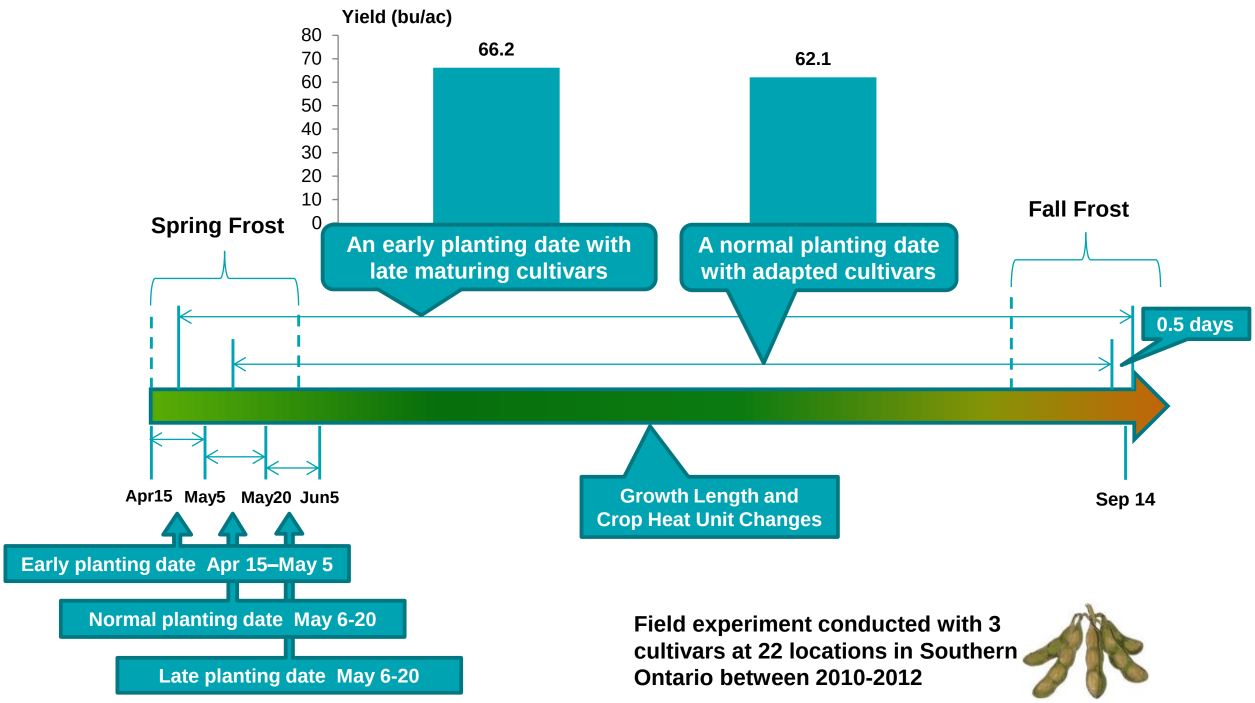

Figure 27: Conceptual diagram illustrating potential yield benefits associated with earlier planting.

Similar to soybeans, studies show that corn yield increases from late-maturing cultivars with longer growth periods (Steduto et al. 2012). Cabas et al. (2010) conclude that the greatest impacts of climate change on corn yield will likely arise from the changes in the length of the growing season: a 10% increase in the number of growing degree days is predicted to increase corn yield by 12.2%, whereas a 20% increase in the coefficient of variation in temperature or in precipitation decreases corn yield by 2.6% and 0.6% respectively. Thus, the positive impacts of climate change on corn in Ontario associated with a longer growing season may outweigh the effects of greater variability in warming and rainfall (Cabas et al. 2010).

Longer maturing cultivars planted in earlier date have greater yield potential than the adapted cultivars (OSCIA 2013). There was a concern that planting later maturing soybean varieties would complicate wheat planting as a result of a later than normal soybean harvest. Results show that comparing a longer maturity soybean variety planted in an early window and an adapted variety planted in a normal window, the delays to maturity was only half a day. This would have little impact on winter wheat planting timing (OSCIA 2013).

The role of frost in damaging crops is a significant threat when considering early planning or late harvests. According to the literature focusing on corn and frost, initial signs of damage can occur when ambient air temperature dips to around 1.67°C (Coulter 2010). This will often involve relatively mild damage localized to the upper leaves, and most agree that the plant will generally recover almost entirely so long as the corn growing point, located below the soil until later development stages and therefore more resilient to low ambient temperature, has not been damaged (Nielsen 2008). As a result, such temperatures usually only have a small if any effect on corn growth and ultimate yield (Wiebe n.d.). However, when temperatures below -2°C persist for more than a few hours, the corn growing point can be injured or killed even when it is below the soil surface, leading to permanent damage and more substantial harvest yield losses (Wiebe n.d.). Therefore, the assessment considered exposure probabilities of these two related but distinct climate event thresholds associated with markedly different impacts and related probabilities: a "soft frost" occurring at 1.67°C leading to superficial damage and small yield losses, and a "hard frost" occurring at -2°C which jeopardizes growing point integrity and threatens greater yield losses (Ontario Ministry of Agriculture and Food 2013).

4.3.4. *Storyline 4: Plant and Soil Stress Due To Extreme Heat*

Extreme heat is defined as a heat event that exceeds a normal or average temperature. It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes will occur in the 21st century at the global scale, as well the duration of extreme heat events (IPCC 2012). Extreme heat impacts crop productivity through effects on plant development and growth cycles, which has ultimately been characterized in this study as being influenced by physical plant damage. It should be noted that heat stress is different from drought stress, as drought stress is often a combination of temperature and moisture whereas heat stress is solely related to extreme temperatures (Rizhsky et al. 2004; OMAFRA 2009).

Figure 28 provides a conceptual diagram of the relationship between these aforementioned processes, in addition to highlighting the role of delayed field operations, and identifying key environmental and farming factors that influence the extent of influence of that impact.

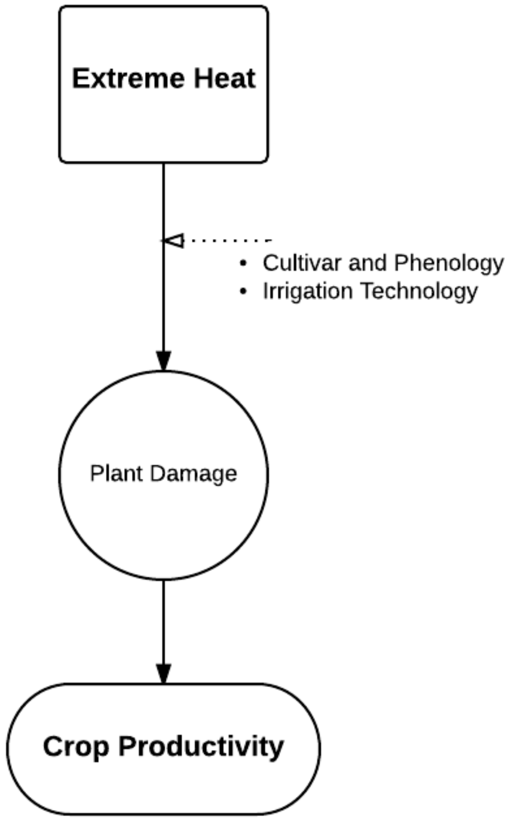

Figure 28: Impact pathway diagram highlighting the processes and key vulnerability factors influencing the extent of impact of extreme heat on crop productivity

Extreme heat has a wide range of effects on crops in terms of physiology, biochemistry and gene regulation pathways (Bita and Gerats 2013) and can affect crops in different ways depending on the cultivar and phenological stage of the crop (see Table 12 above: Climate event thresholds for wheat and soybean for ideal temperature and maximum temperature values). The effects of extreme temperature stress for most crops are more prominent on reproductive development than on vegetative growth (Young et al. 2004; Hedhly et al. 2009; Thakur et al. 2010; Zinn et al. 2010). Crops are impacted through biophysical and physiological processes such as decreased photosynthesis, leaf senescence, scorching of leaves and stems, decreased pollen production and pollen viability and seed abortion, ultimately lowering grain number and grain weight, and as a result, crop productivity and yield (Vollenweider and Günthardt-Goerg 2005; Asseng et al. 2011). The decline in crop yield in relation to extreme temperatures is generally associated with pollen infertility (Young et al. 2004; Zinn et al. 2010). Critical temperature thresholds vary between crops and cultivars, as some are more adapt or bred to withstand higher temperatures (Sanchez et al. 2014). The presence or absence of irrigation technology will have a big influence on the potential impact of extreme heat on crops (refer to Table 9 for the number of farms in Ontario and Peel Region using irrigation systems), as irrigation can help cool plants and reduce heat stress (USEPA 2012a).

Heat stress and plant damage is particularly severe when extreme temperatures occur concurrently with critical crop development stages, particularly the reproductive period (Wheeler et al. 2000; IPCC 2007b). Peaks of high temperature, even when occurring for just a few hours, can drastically reduce crop productivity and yield (Porter and Semenov 2005). Shah and Paulsen (2003) found in a controlled modeled study that extreme heat during reproductive development in wheat crops accelerated the decline in photosynthesis and leaf area, reduced the overall shoot and grain mass as well as weight and sugar content of kernels. Cereal crops in many temperature regions respond negatively to extreme heat, as the decline in grain number is directly proportional to increasing temperatures during the flowering and grain filling stage (Porter and Semenov 2005; Mahmood et al. 2010). Cereals also show a high sensitivity to extreme heat during their flowering stage (Frank et al. 2009; Saha et al. 2010).

5. EXISTING ADAPTIVE CAPACITY IN PEEL

The assessment framework employed in this report identifies adaptive capacity as an attribute of agricultural systems that has can reduce vulnerability to existing and potential future climate impacts. Figure 11 identified five main categories of resources that can be regarded as determinants of an agricultural system's adaptive capacity and Table 13 provides an overview of specific examples that contribute to each of these categories in Peel specifically. Swanson et al. (2007) provides a framework for in-depth adaptive capacity assessment using indicators from the Canadian Census of Agriculture. While it was beyond the scope of the current assessment to conduct such an in-depth analysis, adaptation strategies could benefit from this information.

Table 13 demonstrates that there are a large number of adaptive capacity resources present across a range of categories. At a recent November, 2014 meeting of the Peel Agricultural Action Working Group, members perceived the sector to be well able to take advantage of these resources and continue on a long history of continual adaptation to new challenges and opportunities in farming.

Table 13: Synthesis of resources for adaptive capacity in Peel's agricultural sector

Resource Category		Resources in Peel
Policies and Regulations	Government programs and services	• Conservation Authority, municipality, OMAFRA and AAFC agricultural extension programs • Peel Rural Water Quality Program • Environmental Farm Plan program
	Policies and regulations	• Ontario Farmland Trust • Growing the Greenbelt • Growing Forward 2 • Peel Region Land Evaluation and Area Review and Contiguous Area Analysis to refine prime agricultural land boundaries
Human and Social Capital	Social networks, resource sharing, community and social capacity	• PAAWG • OFA • Commodity groups (e.g., Grain Farmers of Ontario) • GTA AAC • GHG&F Alliance • PFA • 4-H • OSCIA • Caledon Countryside Alliance
	Farm operators	• Farms with long histories of operation and knowledge of impacts, issues and adaptive strategies
Information and Knowledge	Research, technology and access to information	• The Ontario Business Research Institute Tax Credit • Ontario Universities specializing in agricultural adaptation research (Guelph, Trent, Waterloo, Carleton) • Federal and provincial government grants supporting adaptation • Agricultural Adaptation Council programs
	Skills, knowledge and experience	• Workforce Development Programs: • Apprenticeship Training Tax Credit Ontario • Career Bridge Program • Sector Initiatives Fund • The Jobs and Prosperity Fund

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Resource Category		Resources in Peel
Physical Resources	Ecosystem services and natural heritage	Provisioning Services: • Food Production • Maintenance of Genetic Diversity • Water Quality Regulation Supporting Services: • Biomass Production • Soil Production • Nutrient Cycling • Water Cycling • Habitat Provisioning Regulating Services: • Buffer Zones • Flood Attenuation • Moderating Effect on the Urban Heat Island Cultural Services • Farm Tourism • Aesthetic Values
	On and off farm infrastructure and technology	• Dense and well maintained road, electricity, telecommunications and water infrastructure • High Performance New Construction Program • Ontario Community Infrastructure Program • Municipal Infrastructure Strategy • The Rural Connections Broadband Program
	Agricultural inputs and products (including energy)	• Presence of active and knowledgeable farm input suppliers
Financial Resources	Insurance and business risk management	• AgriCorp (crop insurance) • Farm Credit Canada • Local banks and credit unions • Grain Financial Protection Board and Program • Livestock Financial Protection Board • Normal Farm Practices Protection Board • Growing Forward 2 • Advance Payments Program • The Canadian Agricultural Loans Act

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Resource Category		Resources in Peel
	On and off farm income	• Proximity to large urban centres offers substantial access to alternative income-generation opportunities
	Markets, processing and economy	• Rural Economic Development Program • GF2 Funding Assistance for Capacity Building • Agri-Food Trade Service • Export Development Canada • Proximity to major trade routes (rail, shipping, air, freeway)

5.1. The Role of Best Management Practices in Adaptive Capacity

Many field-scale strategies and best management practices (BMPs) do not require policy action but can be implemented on-farm, and offer benefits of both reducing potential negative effects of farming on the environment and reducing vulnerability to climate impacts (Hatfield et al. 2011). BMPs offer a practical, affordable approach to conserving a farm's soil and water resources, which ca be regarded as a “no regrets” strategy for responding to climate vulnerabilities. Adoption of BMPs can be viewed as a strategic decision on the part of farmers to bolster the health of soil, the natural environment, while reducing reliance on artificial farm inputs, thereby reducing potential exposure to the climate conditions that translate into crop production impacts (Reid et al. 2007).

For instance, practices such as incorporating cover crops, the addition of shelterbelts and strip-cropping are techniques that not only help reduce erosion but also help protect the water quality on and around farms (AAFC 2000). Reid et al. (2007) found that, despite the long-term and gradual process of installing tile drains, farmers found that artificial drainage improved crop yields in both wet and dry years and was thus worth the investment. Controlled tile drainage technology and greywater reuse also offer promising technologies for coping with drought and managing runoff (BC Agriculture and Food 2013).

Table 14: Select best management practices and potential benefits for reducing vulnerability

On-Farm Practice	Climate Resiliency Benefits
Conservation tillage / no till	Minimize soil erosion; increase moisture availability; retains nutrients
Cover crops and intercropping	Soil stability and moisture; frost protection; nutrients retention; regulates soil and plant temperature
New rotations and varieties	Take advantage of new climate regimes and hedge risk on a short-term basis: e.g., buckwheat, quinoa, amaranth, rye, edible varieties, fruit trees, switchgrass, resilient hybrids
Wind breaks	Erosion prevention; soil moisture retention
Irrigation & water reuse	Drought mitigation; frost prevention
Drainage	Extreme precipitation impact reduction
Ongoing monitoring	Better understand all impacts and opportunities; Optimize field practices (timing, techniques)

Employing BMP's can also help producers operate in a more sustainable fashion which allows them to preserve the necessary ecosystem services needed to produce viable yields while at the same time reducing greenhouse gas (GHG) emissions. Agricultural producers can reduce gases such as carbon dioxide (CO_2) through BMPs for example by replacing fossil fuels with renewable energy (biomass, geothermal, wind and solar energy). Additionally, farmers can increase the amount of carbon they store, or sequester, by adopting certain practices such as increasing shelterbelts and woodlots on their farms. Nitrous oxide (N_2O) emissions can be reduced by employing techniques that improve soil aeration, and by keeping barns clean and well aerated to avoid anaerobic conditions. Furthermore, farmers can use BMPs to reduce methane (CH_4) emissions by using techniques such as improve manure storage systems by covering manure tanks, removing manure frequently and storing at lower temperatures (OMAFRA 2014).

Figure 29 provides a breakdown of the usage of various field-scale best management practices comparing Peel with the rest of Ontario. This analysis reveals that for almost every single practice, Peel as a whole has a higher frequency of farms compared to the Ontario average. That being said, most BMPs still have rates of below 30%, highlighting an opportunity for increased action to promote these practices.

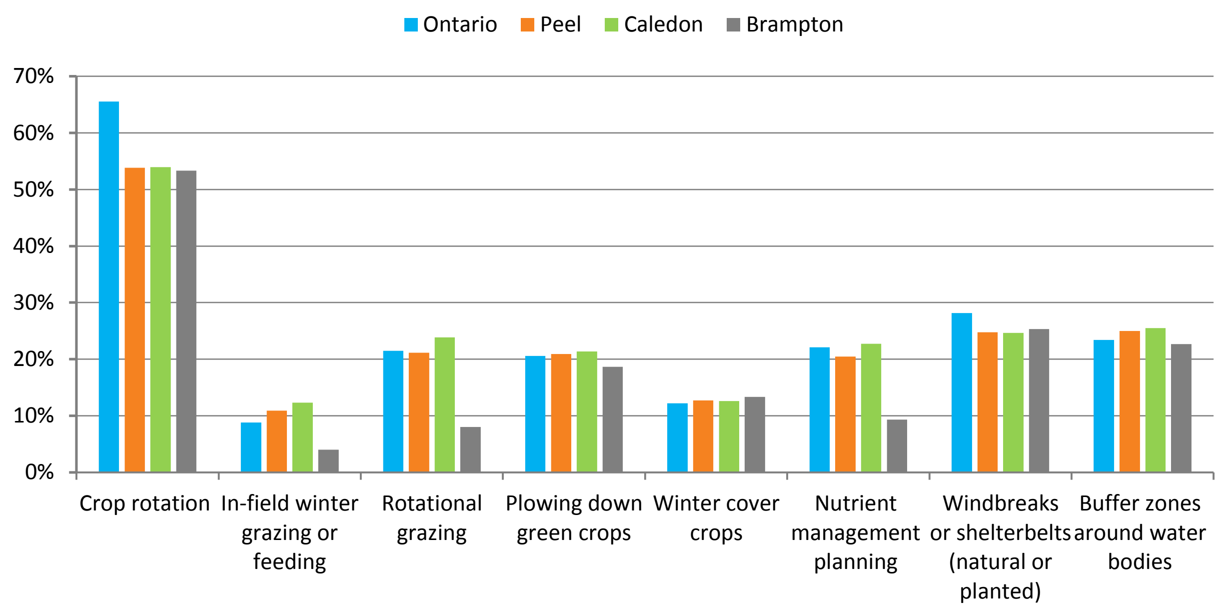

Figure 29: Percentage of farms within Peel Region and Ontario that implement field-scale best management practices.

Given the potential for climate change to increase the frequency and intensity of heavy rainfall events, the identification of strategies for reducing runoff impacts is an imperative for effective on-farm environmental protection. Table 15 provides a summary of BMPs for protecting water resources that also offer climate resiliency benefits, as water resources are a critical input for agricultural production.

Table 15: Best Management Practices to protect Water Resources (Jones and Shortt 2010).

Water Source	Best Management Practices
Streams	• Use an off stream settling pond – allows large particles that may contain pathogens to settle out of the water and reduce the potential contaminant load. • Work with neighbours to reduce livestock access to water sources. • Establish vegetative buffer zones to filter water and slow down run-off.
Ponds	• Fence pond to prevent animals, both wildlife and domestic, from defecating in or near water. • Re-direct runoff so that it flows around the pond and avoids contaminants entering pond through runoff (e.g. form a bank around pond or channel ditches away from pond). • Establish grassed waterways or vegetative buffer strips to filter water before it enters the pond. • Install steep sides or rocky berms to discourage geese from nesting.
Stream-fed Ponds	• Avoid harvesting water during the peak flows after a rainfall – this water carries the majority of the sediment (and possibly pathogens) washed by the rainfall. • Establish vegetative buffer zones to filter water and slow down run-off.
Wells	• Mound up the ground around the outside of the well or well pit with clean earth to provide drainage for surface water so that runoff flows away from the well. • Maintain well casing above grade. • Ensure that well casing is intact and there are no cracks or openings • Don’t allow any space between the well casing and the surrounding soil (this could act as a pathway for surface water to contaminate the well).

6. CONCLUSIONS AND IDENTIFICATION OF ADAPTATION ALTERNATIVES

The impacts and opportunities perceived by farmers in the Region of Peel, along with the climate data show some prominent trends in the agricultural sector. The regional average temperature is projected to increase over all seasons, with the greatest increases projected for the winter months. As the overall temperature increases locally, it is expected with confidence that the frequency and intensity of extreme high temperature events will also increase, while extreme cold events will decrease. With increasing temperatures come a longer growing season and the potential for an increase in Corn Heat Units (CHU). This may provide farmers with an opportunity to plant earlier and harvest later. However, this increase in temperature is punctuated by greater uncertainty regarding the timing of irregular frost and extreme weather events. Additionally, increasing temperatures will likely only provide an opportunity for farmers if other crop requirements are met, such as adequate precipitation.

Precipitation trends are much more variable than temperature. Looking ahead, the total mean annual precipitation for Peel is projected to increase from the current baseline average. Seasonally, winter and spring precipitation amounts are projected to increase, while summer and autumn precipitation are projected to either remain steady or slightly decrease. The frequency of extreme rainfall events is also projected to increase, resulting in shortened return periods associated with current storm intensities. In other words, heavy precipitation events will not only be more intense, but will occur more frequently. This may pose many challenges for farmers, such as soil erosion and nutrient alteration, physical plant damage, pest and disease infestation, and the delaying of farm practices such as planting and harvesting if the fields are too waterlogged.

Reduced precipitation also poses a threat for farmers if there is not enough water to meet crop growth requirements. Drought conditions can also lead to decreased soil nutrients, plant withering and mortality, and pest and disease infestation. As noted above, precipitation patterns will either remain the same or slight decrease during the summer and autumn months, which may pose a threat for farmers, as this coincides with the growing season.

As the climate changes, current vulnerabilities to climate and the probability of extreme weather events taking place can be exacerbated if they are not addressed through strategies that target root causes and promote flexible, adaptive decision-making. If current and potential climate vulnerabilities are addressed strategically, it is likely that farm operators will be able to take advantage of the new climate regime, which does present certain benefits for crop productivity. This assessment characterized current, and identified potential future, climate vulnerabilities in crop production in Peel's agricultural sector, in addition to possible benefits. These are synthesized in Table 19. Some vulnerabilities and benefits were explored in significant detail throughout the storylines in Section 4.3, while others were elucidated from stakeholder input and a more general literature review of agricultural impacts (Appendix C).

Table 16: Summary of potential benefits, current and future vulnerabilities of climate change on agricultural production, as identified throughout this report.

Climate Variable	Potential Benefits	Current Vulnerabilities	Future Vulnerabilities
Longer growing seasons	• Double-cropping • Greater yields • New crop systems and varieties	• Farm storage limitations • Timing for sales to markets • Availability of required farm inputs (e.g., seeds)	
Additional heat units and positive temperature anomalies	• Greater yield • New crop systems and varieties	• Availability of required farm inputs (e.g., seeds)	• Precise timing may not align with timing of crop development and farm operations
Additional spring precipitation	• Water storage opportunities (including aquifer recharge)	• Ability of soils and farm water storage systems to absorb excess rainfall	• Precise timing may not align with timing of crop development and farm operations
Extreme precipitation	• Flushing of excess nutrients	• Nutrient losses • Pest and disease • Disrupted field operations • Crop yield losses • Harvest spoilage	• Greater frequency and intensity of heavy rainfall events
Inter-annual variability	• Maintains soil health and diversity of pollinators and microbes	• Difficult for planning of crop types, farming operations and investments	• Greater unpredictability in all agro-climatic variables, further increasing planning difficulties
Extreme heat		• Plant damage • Disrupted field operations (farmer exposure to extreme heat)	• Greater frequency of extreme heat events

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Climate Variable	Potential Benefits	Current Vulnerabilities	Future Vulnerabilities
Drought and dry spells		• Nutrient losses • Pest and disease • Additional crop and livestock water requirements needed • Water supply restrictions during low water conditions • Disrupted field operations • Crop yield losses	• Greater frequency of dry spells and overall drier growing seasons • Potential conflicts over scarcer water supplies

Despite the abundance of information on climate trends and potential impacts, there is substantial uncertainty regarding the precise extent and nature of the effects climate change will have on agriculture. It is recognized that current understandings about both climate and its interactions with agriculture need to be constantly improved. As such, ongoing monitoring of the climate and the effectiveness of any measures aimed at reducing vulnerability is a cornerstone of the adaptive management cycle. Efforts should be made to improve the amount and quality of information related to climate and weather observations, along with tracking of agricultural impacts, including the relationship between the specific opportunities and vulnerabilities identified in Table 19. Because, the ways in which farmers take advantage of potential opportunities and deal with the vulnerabilities to a changing climate will depend on the adaptive capacity and resilience of farm-scale operations, but also the broader supporting systems, it is essential that monitoring and evaluation consider these multiple scales. A crucial element of effective adaptation monitoring and evaluation will be augmenting the quality and coverage of the climatological and hydrometric networks in Peel.

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

- **Policies and regulatory frameworks** shape the agriculture sector, with numerous levels of government influencing the programs, services and policies. These policies and frameworks must be flexible enough to deal with the great level of uncertainty that comes along with managing and adapting to climate change.
- **Human and social capital resources** are the primary asset for enhancing the resilience of agriculture, as it is farmers themselves who need to be in a position to adapt. Traditional farmer knowledge and experience is the keystone of agricultural production, however the changing climate presents a new set of conditions that may

preclude strategies that were effective historically. Adaptive measures need to be targeted to support the farm operators and by extension the community in order to build on-farm capacity as well as social community capacity by means of social networks and sharing resources as new conditions emerge.

- **Knowledge and information** is at the root of adaptive decision making, as a farmers' experience and skills are an integral part of learning. Providing farmers with new information and extension services to assist in decision making, especially under a changing climate that brings with it a great level of uncertainty is key to adaptive management and planning.
- **The physical on-farm and off-farm supporting resources** play an important role in how producers can adapt. The natural supporting services and ecosystem services, (such as flood attenuation, maintenance of habitat diversity, primary production, etc.) are equally as important as the built infrastructure and technology and agricultural inputs. Extreme weather and a changing climate will challenge both the natural and built resources needed by farmers for agricultural production. Adaptive strategies and infrastructure will need to be able to cope with a certain degree of uncertainty and extreme weather, and ensuring supporting systems are as equally capable of adaptation as farming itself goes a long way to supporting agricultural adaptation.
- **Financial resource** strongly constrains how agriculture will be able to adapt to changing conditions. Sufficient and stable financial resources can ensure there is a capability in the agricultural sector of investing in innovation, testing new strategies and implement new technologies. As such, the accessibility and structure of financial resources must be adapted to this new reality, which can includes flexible and predictable insurance programs, access to credit and opportunities for added-value and off-farm income.

Adaptation needs to be integrated across multiple scales, including on and off-farm, with the right policies and economic market environments. The resource categories described in Figure 6 are interconnected, with many impacting and affecting the others. Given that there is an array of potential strategies for building adaptive capacity, it is necessary to have a process for assessing these alternatives and prioritizing them. Employing participatory scenario development and testing, present promising approaches to help develop and test alternative adaptations before selecting optimal ones. Work is ongoing through Agriculture and Agri-Food Canada's (AAFC) Science and Technology branch using an integrated decision support tool, called Envision, to conduct such scenario testing. Engaging in this process presents a unique opportunity to advance momentum in agricultural adaptation planning in Peel. This process has been used successfully around the work, including in the Canadian Plaines (see Espeseth et al. 2012), and is recommended in FAO (2013).

Currently, this report does not rank the relative significance or importance of different climate change effects in Table 19 and throughout the report. This is because such a prioritization requires further stakeholder input, and in the context of Peel's broader adaptation planning process, needs to incorporate findings from the other assessment themes and supporting systems, assess trade-offs among impacts, and consider cumulative effects. As such is risk assessment is the next logical step for identifying and development adaptation priorities.

This report demonstrated that Peel has a high rate of adoption of best management practices (BMPs) in area of soil conservation and environmental protection. These BMPs are a critical way of addressing many of the vulnerability factors and process identified throughout Section 5 of this report. Given that these BMPs were initially designed to provide benefits to both farm productivity and environmental protection in the long-term, furthering their adoption in Peel should remain a priority. That being said, there are an array of BMPs not currently being used widely in Peel, such as cover crops, advancing these and other innovative approaches to farming will situate Peel at the leading edge of agricultural adaptation. Additionally, the use of scenario testing, as is currently being implemented in AAFC's Envision project, will enable decision makers to understand the benefits of BMPs at the landscape scale described above. The following represent a combination well-established BMPs, farming practices/technologies, and broader sector strategies that could be considered in an agricultural adaptation plan:

- **Conservation tillage practices:** No till processes can be used to decrease the disturbance to the soil, and allows for the accumulation of organic matter, water and the growth of soil microbes. As climate change is expected to change precipitation patterns, investing in no-till and conservation practices could help reduce impacts to crops associated with drought and periods of low precipitation (Lobb 1994; Duiker and Myers 2005).
- **Testing alternate seeding/planting schedules:** Double cropping can be used to try to take advantage of warmer temperatures and a lengthening growing season. Staggering seeding and harvesting dates through choosing a variety of crops that require a range of growing conditions so that crops are at different stages may increase adaptive capacity, as vulnerability to various climate drivers and weather events will impact crops differently based on cultivar and phenology (Wall and Smit 2005). Additionally, investing in field trials for new and diversified and resilient crop rotations such as buckwheat, quinoa, amaranth, rye, fruit trees, switchgrass and resilient hybrids is necessary. Funding support and guidelines for in-field adaptation tests and monitoring projects is needed to test climate-resilient best management practices and help disseminate information on effective adaptations.
- **Increasing the number and types of conservation land features such as windbreaks and shelterbelt:** These features can reduce negative impacts from drought by maintaining water tables, increasing biomass in soil, and ensuring surface moisture is kept on the land. Additionally, shelterbelts provide protection from heat and wind for livestock, and can increase the heat units in adjacent fields (OSCIA 2013).
- **Installing tile drainage and collecting surface runoff in closed loop systems:** Runoff is stored in a reservoir during periods of water excess and can then be returned to the field as irrigation during water deficits. This process is useful during high and low water/ rain periods. An additional benefit is that this process allows for

the recycling of chemicals, which in turn decreases the use of pesticides (Tan and Reynolds 2003; Tan et al. 2007).

- **Evaluating irrigation technology:** Certain irrigation systems could be well suited to help reduce the negative impacts of climate change, such as drip irrigation systems which helps decrease the amount of water lost to evaporation when compared to over-head sprays (Tan and Reynolds 2003). Additionally, irrigation can help reduce heat stress for crops during extreme heat events, as the water provides a cooling effect. It is important to caveat a discussion of irrigation technology with the need to ensure there are effective watershed-based strategies for source water protection, and that technologies that minimize demand through efficient water application and timing are used.
- **Increasing diversification:** This includes agricultural, structural and income diversification (Meert et al. 2005), such as cooperative added-value processing for local markets. These strategies include: milling, malting, seeking investment from local grocery stores and retailers, restructuring existing farm resources into new non-agricultural products or services such as farm tourism, farm gates and you-pick strategies.

While the aforementioned farming practices and strategies represent potential and demonstrated strategies for enhancing resilience to climate change in agriculture, there are important considerations that have been identified through consultation to ensure adaptive capacity can be enhanced. These are:

- **Avoiding Over-Regulation:** Ensuring government, farmers, community interest groups and the agricultural supply chain work together to identify priority adaptation strategies, and avoid top-down regulatory approaches. Approaches that balance incentives, information on costs/benefits, and are supported with tools for adaptive decision making were identified by stakeholders as being the most promising approaches for adopting climate-smart agricultural practices and strategies.
- **Engaging with the Downstream Market and Consumers:** Market forces, including the preferences of consumers and downstream players such as wholesalers, exporters and retailers play a significant role in determining cropping choices. Farmers need to respond to these forces when making decision about crops, investments in technology and long-term farm planning. The potential opportunities of growing new crop types and investing in the necessary technology and inputs to make that switch will only be viable if there is market demand for the products produced. As such, dialogue and negotiation are needed with the downstream market to convey the realities of a changing climate on farming, and what new opportunities and constraints if places on product selection, availability and price. It was suggested that "we need to start consulting with consumers on what they are willing to pay for food… as the costs of production are impacted by higher levels of climate variability". Given the role of consumers in driving market demand, engaging with this group, including youth, has also been identified as critical.

- **Engaging with Upstream Market and Suppliers:** If new climate realities require farmers to adopt new and adjust existing technologies and practices, including crop choices, they will require the necessary inputs to do so. Currently, most farmers purchase seed, fertilizer, machinery, and pest management products from a select number of agricultural supply companies locally. For both strategic and annual decision making farmers rely on advice from extension services offered by these companies. Therefore, unless these companies have the knowledge, experience, and supplies required for farmers to implement new crop types and technologies, uptake will be fundamentally constrained. Agricultural input and agronomic advisory companies have always played a key role in making research and science accessible to farmers. Given this, it is essential that they are actively engaged in strategies to enhance the update of CSA in Peel.

6.1. Additional Analysis and Research

Through this report and the research process undertaken, a number of key questions remain to be addressed. Addressing the following research questions would enable continued progress on building adaptive capacity in Peel's agricultural by enhancing the Information and Knowledge and providing opportunities to continually engage with stakeholders:

- Development and/or application of a tool/model to predict yield impacts as well as GHG emission reductions of specific farming practices and strategies would be very useful for extension staff when working with farmers to analyze and select options. Such a tool would greatly benefit from crop yield response modeling.
- Irrigation was identified as an important strategy for increasing resiliency to drought, dry spells and also unseasonal frost. Likewise, drainage technology was identified as a key strategy for addressing excess moisture. That being said, a more detailed feasibility assessment is needed to assess the costs/benefits and potential implications of expanded irrigation and drainage in the Region of Peel.
- Research is necessary to determine the feasibility of different high-value, climate resilient crop types. For example, initial work has begun locally in growing drought-tolerant crops such as amaranth, quinoa, switchgrass, however there are other potential plants and varieties that should be assessed. Again, this would benefit from crop yield response modeling. This analysis would also benefit from quantitative analysis of climate effects to determine critical climatic thresholds.
- Information and a greater understanding of the sensitivity of nutrient and pest management practices to climate is necessary, with a potential emphasis on the soils and pests present in Peel specifically. There are numerous tools available for Ontario to assist farmers in adjusting their management practices to climate, such as those offered by Weather Innovations Inc. There is however a need to understand its current rate of usage and potential avenues for improvement to improve the use of such information in farming. Information on the specific pest and nutrient management practices used in Peel would also help better identify appropriate and specific strategies for enhancing climate resilience in these areas.

- Currently, there is no clear estimate of the contribution of various farming activities to GHG emissions. An assessment of the potential for farms to provide GHG reduction benefits should be assessed to fill this information gap to ensure that adaptation strategies can also have mitigation benefits. It is recommended that if this work is undertaken, it should be done using an industry-standard model such as Holos produced by AAFC: http://www.agr.gc.ca/eng/science-and-innovation/science-publications-and-resources/holos/?id=1349181297838
- There are many other cropping systems that are either practiced by a small number of farmers or which may be potentially viable to strengthen the agricultural sector in Peel. An assessment of other cropping systems, including suitability of different crop types under scenarios of climate change would be beneficial to gaining a deeper understanding of climate change effects. Such information may be useful in prioritizing adaptation alternatives.
- Many of the effects described in this report have additive or cumulative effects. For new pests may become present due climate change, but also infestations are likely to become more probable and severe due to many of the climate effects described in this report. As such, it is important to gain a better understanding of these potential interactions so strategies can be holistic.
- From a climatic standpoint, there are two important questions pertinent to extremes that remain underexplored to date and they are: (1) understanding how to characterize weather and crop specific impacts at finer time steps and spatial scales using climate projections, as well as how to define and test adaptation and management responses in light of different spatial and temporal extremes and drivers of change that may impact a region.

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

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

APPENDIX B: WHOLE FARM SYSTEM COMPONENT DEFINITIONS

Component Type	Component	Definition
Production Input	Seeds	Purchased or saved seeds, representing annual inputs for cash crop production
	Pesticides, herbicides, fungicides	Purchased products applied to fields and plants for pest control
	Synthetic fertilizer	Purchased synthetic fertilizer applied to fields
	Soil and nutrients	The naturally occurring organic and inorganic materials contained in a soil matrix
	Water, moisture and energy	Naturally occurring or anthropogenically applied sources of moisture and energy required in photosynthesis and plant development
Production Final or Intermediate Output	Crops	Plants at any stage of development within the field that will ultimately mature to produce a harvest
	Harvest	The fully developed plant that is harvested from the field and either sold, stored or used on the farm
	Feed	Purchased or harvested grain, or planted pasture, consumed by livestock
	Animals / Livestock	The livestock produced and used on a farm
	Manure and residue*	Natural fertilizers produced by livestock or through decomposition of crop residue
	Animal by-products	Any products produced as a result of livestock rearing, including eggs, milk, meat, etc.
Infrastructure and Technology	Farm infrastructure	All of the built and engineered structures and systems used for farming, including storage, water supply and treatments, etc.
	Energy and fuel	Energy sources required to power farm infrastructure and machinery
	Farm machinery	All equipment used in farm operations, such as planting, harvesting and processing
	Environmental protections	Natural or built systems designed to minimize the impact of farming on the natural environment, such as buffer strips, runoff treatment ponds, etc.

Notes:

* May be considered an input

APPENDIX C: SUMMARY OF GENERAL CLIMATE IMPACTS ON AGRICULTURE AND RURAL SYSTEMS

NOTES ON INTERPETING IMPACT TABLE

Primary Scale at Which Impact Occurs (Colour Legend): Farm Scale Impact
Farm and Landscape/Market Scale Impact
Landscape/Market Scale Impact

Underlined impact denotes a potential opportunity

*** Impacts are based on climate events defined in terms of an intensity that is threshold-based. For example an extreme storm would be defined as the local 100-year storm intensity/duration or a drought event defined by the number of days of drought conditions. It is assumed that if the frequency of these events increases due to climate change the longevity, or long-term viability, of the system component would be affected due to repeated exposure to climate events that exceed current levels of accepted risk. The other assumption here is that these thresholds assume current conditions, which in many cases may not account for adaptation (i.e., the current system would need to be adapted already to account for adaptation). Additionally, the impacts listed are ones that we are confident about because there is consensus in the literature.**

**** Pertains to changes in the precipitation and energy balances**

AGRO-ECOSYSTEM AND RURAL LANDSCAPE SYSTEM		**CLIMATE DRIVER***						
Management Theme	***System Component***	***Extreme Precipitation***	***Extreme Heat***	***Extreme Cold***	***Extreme Wind***	***Drought***	***Ice Storms and Freezing Rain***	***Agro-climatic Variability*****
Crop Production	Cash & Field Crops	-water logging[1] -crop damage[2] -root rot -delayed planting and harvest[3] -reduced yield	-heat damage (drying of plants, plant mortality)[4] -reduced yield	-freeze / frost damage[5] -reduced yield	-damage to crops (i.e. broken cornstalks)[6] -reduced yield	-crop root shrinkage (able to take up less available water)[7] -need for additional crop-water requirements -reduced yield if crop water requirements are not met[8]	-damage to crops -reduced yield	-shift in timing of planting/ blossoming[10] -shift in timing of harvesting[11] -shift in timing of nutrient requirements -changes in pest and disease exposure[12] -reduced

AGRO-ECOSYSTEM AND RURAL LANDSCAPE SYSTEM		CLIMATE DRIVER*						
Management Theme	***System Component***	***Extreme Precipitation***	***Extreme Heat***	***Extreme Cold***	***Extreme Wind***	***Drought***	***Ice Storms and Freezing Rain***	***Agro-climatic Variability****
						-reduced yield due to plant stress[9]		yield
	Fruit, Vegetable & Nut Crops	-water logging[13] -crop damage[14] -root rot[15] -delayed planting and harvest[16] -reduced yield	-heat damage (drying of plants, plant mortality) -reduced yield	-freeze / frost damage[17] -reduced yield	-structural damage to tree limbs[18] -reduced yield	-crop root shrinkage (able to take up less available water)[19] -crop root shrinkage[20] -reduced yield[21]	-damage to fruit trees and tender veg. crops -reduced yield[22]	-shift in timing of planting/ blossoming -shift in timing of harvesting -shift in timing of nutrient requirements -changes in pest and disease exposure -reduced yield
Livestock and Poultry Production	Equine	-flooding of pastures (more time indoors)[23]	-heat related morbidity and mortality	-cold related morbidity and mortality		-damage to forage crops and feed	- animal injury	-disease -shift in availability of feed stocks
	Livestock	-flooding of pastures (more time indoors)[24]	-heat related morbidity and mortality[25] -reduced rates of animal growth[26]	-cold related morbidity and mortality		-damage to forage crops and feed	- animal injury	-changes in pest and disease exposure -shift in availability of feed stocks
	Dairy	-flooding of pastures (more time indoors)[27]	-heated related morbidity and mortality	-cold related morbidity and mortality		-damage to forage crops and feed		-changes in pest and disease exposure

AGRO-ECOSYSTEM AND RURAL LANDSCAPE SYSTEM		CLIMATE DRIVER*						
Management Theme	***System Component***	***Extreme Precipitation***	***Extreme Heat***	***Extreme Cold***	***Extreme Wind***	***Drought***	***Ice Storms and Freezing Rain***	***Agro-climatic Variability****
			-reduced rates of milk production[28]					-shift in availability of feed stocks
Water Resources	Irrigation Infrastructure (Water Demand)	-irrigation storage capacity exceeded[29] -damage to irrigation equipment[30] -reduction in water-taking	-increased demand for irrigation to cool crops and livestock		- damage to irrigation equipment	-increased demand for irrigation[31]	- damage to irrigation equipment	-shift in timing of irrigation needs[32] -additional irrigation requirements of equipment to address unseasonal frost -changes in the timing of water storage
	Groundwater and Surface Water Sources (Water Supply Quality and Quantity)	-increase in available water for farm use through recharged watersheds -potential water quality impacts from agricultural runoff	-declines in water quantity and quality for farm and domestic uses[33]			-declines in water quantity and quality for farm and domestic uses		-changes in water quality and quantity
	Drainage Infrastructure	-drainage system capacity exceeded[34]			-damage to conveyance channels	-hardening and cracking of conveyance channels	-damage to conveyance channels and storage ponds	-changes in the timing of drainage operations

AGRO-ECOSYSTEM AND RURAL LANDSCAPE SYSTEM		CLIMATE DRIVER*						
Management Theme	***System Component***	***Extreme Precipitation***	***Extreme Heat***	***Extreme Cold***	***Extreme Wind***	***Drought***	***Ice Storms and Freezing Rain***	***Agro-climatic Variability*****
		-damage and blockage of conveyance channels -drainage water quality declines[35]				and storage pond lining -less water required to be drained		
Environmental Management and Biodiversity Protection	Soil	-water logging[36] -soil nutrient leaching and loss[37] -soil erosion[38]	-surface heating -soil hardening and cracking		-soil erosion and dust creation[39]	-soil hardening and cracking -reduced soil moisture content[40]	-soil erosion[41]	-changes in the availability of soil moisture and nutrient content
	Biodiversity and Habitat	-changes to the aquatic system and species dynamics[42]	-heat stress for flora and fauna	-cold stress for flora and fauna	-damage to trees[43]	-lack of water resources for the provision of ecosystem services[44]		-shift in species diversity and abundance -shift in flora phenology[45] -shift in freeze and thaw dynamics[46]
Rural and Built Infrastructure	Rural roads	-flooded and washed out roads[47]	-pavement damage (i.e. buckling, asphalt sliding, softening)[48]	-road damage (i.e. cracking, heaving)[49]	-erosion of dirt roads			-shift in freeze and thaw dynamics (increase in frost heave and cracking)
	Electrical supply	-damage to hydro equipment[50]	-increased energy demand for	-increased energy demand for	-damage to hydro equipment[54]		-damage to hydro equipment[56]	-shift in energy demand

AGRO-ECOSYSTEM AND RURAL LANDSCAPE SYSTEM		CLIMATE DRIVER*						
Management Theme	***System Component***	***Extreme Precipitation***	***Extreme Heat***	***Extreme Cold***	***Extreme Wind***	***Drought***	***Ice Storms and Freezing Rain***	***Agro-climatic Variability****
		-power outage[51]	cooling [52]	heating[53]	-power outage[55]		-power outage[57]	(cooling and heating requirements)
	Farm structures	-building flooding and structural damage[58]	-increased need for cooling systems	-increased need for heating systems	-structural damage		-structural damage	-shift in timing of storage , heating and cooling requirements
Rural Wellbeing	Human Health	-morbidity or mortality related to flooding and lightning strikes injuries[59] -water-borne pathogens[60] -mould exposure[61] -flooding of health-care facilities and emergency response routes	-heat related morbidity (i.e. heat stress, heat stroke)[62] -mortality[63] - exacerbation of respiratory and cardiovascular disorders[64]	-cold related morbidity (hypothermia , frost bite)[65] -cold related mortality[66]	-morbidity or mortality related to debris -damage to health-care facilities and emergency response routes		-morbidity or mortality related to ice/freezing rain[67] -damage to health-care facilities and emergency response routes	-shifts in heating and cooling requirements for health care facilities[68]

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APPENDIX D: P-CRAFT TEMPLATES AND SYSTEMATIC LITERATURE REVIEW RESULTS

Throughout the duration of this project, literature reviews were conducted multiple times, each with a different duration and objective based on where it occurred throughout the project methodology. These literature reviews aimed to elucidate vulnerability factors, impacts, thresholds, and overall rationales to vulnerabilities that may lead to impacts from extreme precipitation, drought, growing season length and timing, as well as extreme heat.

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

Databases used included:

- Springer Link
- Wiley InterScience
- Oxford Journals
- Science Citation Index Expanded
- Google Scholar
- Biological Sciences
- BioOne

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

- Ontario Soil and Crop Improvement Association (OSCIA)
- Agriculture and Agri-Food Canada (AAFC)
- Grain Farmers of Ontario (GFO)
- Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFA)
- US Department of Agriculture (USDA)
- Food and Agriculture Organization of the United Nations (FAO)
- North American Drought Monitor (NADM)
- Ministry of Environment and Climate Change (MOECC)

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

REFERENCE	INFORMATION	CLIMATE DRIVER					VULNERABILITY INFORMATION		IMPACT	IMPACT LEVEL / IMPACT ESTIMATE
			Seasonality	Intensity	Frequency	Duration	Vulnerability Factor	Vulnerabiltiy Factor Category		
OSCIA, 2008	Soybean planting date trials were conduced from 2002 – 2007 to evaluate representative weather patterns and yield impact over a relatively long period of time. On average the highest soybean yields were achieved when soybeans were planted during the first half of May. This is somewhat earlier than soybeans have traditionally been seeded in Ontario. Waiting from May 10 to May 24 resulted in a yield loss of 4 bu/ac. Planting after the optimal window resulted in a yield loss of 0.3 bu/ac/day in this study.	Growth length	First half of May				Growth period	Plantation date	Yield	Planting after the optimal window resulted in a yield loss of 0.3 bu/ac/day in this study.
OSCIA, 2011	The yield response to 3 soybean varieties will be measured at an early planting date (April 15-May 5), a normal planting date (May 6-20) and a late date (May 21-June 5) over the three years of this study (2010-2012). The 2010 growing season was exceptional. April was warmer and drier than usual allowing very early planting dates at some sites. With above average temperatures and timely rains throughout the year, yields were very high. There was no significant insect or disease pressure at the test locations. Early planting combined with the great growing season meant that early planted soybeans had outstanding yields, although the late planted plots also had above average yields.	Growth length	Early planting date (April 15-May 5)				Timing	General growth over the growth course	Yield	Early planting combined with the great growing season meant that early planted soybeans had outstanding yields, although the late planted plots also had above average yields.
OSCIA, 2011	There was an advantage to planting earlier in this study, about 3 bu/ac more over a normal planting date, and 10 bu/ac compared to a late planting.	Growth length	Early planting date (April 15-May 5)				Growth period	Plantation date	Yield	Early planting resulted in about 3 bu/ac more over a normal planting date, and 10 bu/ac compared to a late planting.
Does Early Planting along with Late Maturing Soybean Varieties Increase Yields? Crop Advances: Field Crop Reports 2011	On average the longest day varieties yielded more than the adapted varieties, however the results were mixed at some sites.	Growth length	Early planting date (April 15-May 5)				Cultivar variation	Maturing period	Yield	Mixed
Does Early Planting along with Late Maturing Soybean Varieties Increase Yields? Crop Advances: Field Crop Reports 2012	In 2009 the weather was largely cool and wet, and was combined with an early killing frost in the fall. In 2009 results were mixed. In some locations the adapted or +200 CHU varieties yielded higher than the +400 CHU varieties, this was the result of an early frost, which prevented the longer day varieties from fully maturing. On average the early planting date out-yielded the late planting date, however, in some locations there was no significance to planting date at all.	Growth length	Early fall frost				Cultivar variation	Relative maturity period	Yield	Mixed
Does Early Planting along with Late Maturing Soybean Varieties Increase Yields? Crop Advances: Field Crop Reports 2012	In 2011 the results were affected by late planting conditions in the province. Yield response to planting date varied across varieties and site locations. Generally, the normal planted date and the early date yielded about the same. In some cases adapted varieties that were seeded early suffered a yield loss compared to normal planting. In some cases late planting yielded the highest. The most likely reason for this is the very dry July experienced in 2011, which meant that beans planted at the normal time were trying to set pods when moisture stress occurred. Later planted beans were still vegetative and so were not as adversely affected by this stress.	Growth length	Summer drought				Cultivar variation	Susceptibility to drought	Yield	Mixed
Does Early Planting along with Late Maturing Soybean Varieties Increase Yields? Crop Advances: Field Crop Reports 2012	An early plating date had an advantage over a later planting date in most cases. Averaged across all three years of the study delaying to plant for 30 days cost an average of 2.5 bu/ac. This is a significant improvement in yield considering it costs nothing to plant early.	Growth length					Growth period	Plantation date	Yield	Averaged across all three years of the study delaying to plant for 30 days cost an average of 2.5 bu/ac.
Double Cropping Soybeans. Crop Advances: Field Crop Reports 2013	Dry conditions during mid-summer seeding can be a challenge in plant establishment but the biggest difficultly to double cropping soybeans is the risk of an early fall frost, which, if temperatures fall low enough will cause the soybean plant to shut down. If this frost occurs before seeds have been formed in the pods, there is nothing to harvest.	Growth length	Early fall frost				Fall frost	Physical damage/grain filling reducation	Yield	-
Double Cropping Soybeans. Crop Advances: Field Crop Reports 2013	soybean plant killed by frost (left), the beans were planted July 23 and frost occurred in early October. Soybean seed in the pod was not fully developed at the time of the killing frost (right).	Growth length	Pod filling				Fall frost	Physical damage/grain filling reducation	Seed quality and Yield	-
Double Cropping Soybeans. Crop Advances: Field Crop Reports 2013	Planting as early as possible is essential for success. Every day counts. In these experiments, trials seeded after July 15th were not successful.	Growth length	Sowing later than July 15th				Growth period	Plantation date	Seed quality and Yield	-
Double Cropping Soybeans in Ontario. Crop Advances: Field Crop Reports 2013	Varieties with a RM (relative maturity) shorter than recommended for a normal planting date tend to yield better and had lower seed moisture at harvest. A variety that is one full RM group shorter (200 CHU's) than used for a normal planting date should be considered if double cropping soybeans.	Growth length					Cultivar variation	Plantation date		-

APPENDIX E: VULNERABILITY FACTOR AND INDICATOR SELECTION CRITERIA AND DATASETS

The following keywords were used in the initial literature search, and represent the system components, climate variables and impacts under consideration:

- soy, soybean, wheat, corn, grains, oilseed
- precipitation, rain, rainfall, rain intensity, drought, temperature, extreme temperature, extreme heat, weather, extreme weather, climate change
- irrigation, soil type, production, agriculture, field, agricultural production, farming
- erosion, insects, pests, erosion, flooding, water-logging, disease, slope, yield, yield loss, pollination, physical damage, flowering

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

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 meet all evaluation questions listed in this table, but that in comparison to all potential indicators examined it is optimal.

NON-WEIGHTED CRITERIA	CASH CROP PRODUCTION SYSTEM VULNERABILITY FACTORS	Cultivar and Phenology	Soil Drainage	Tillage Practices	Field Topography	Pest and Disease Management	Nutrient Management	Existing Plant Damage	Irrigation Technologies
	VULNERABILITY INDICATOR / METRIC	Use of cultivars with high climate tolerance ranges	Soil material	Ratio of area of no-till or zero-till seeding to tilled area (higher is better)	percentage of land in topographic lows	Pest and disease management practices	Nutrient Management practices	Existing plant damage	Irrigation in the year prior to census
	EXTREME HEAT EVENTS	x				x		x	x
	EXTREME PRECIPITATION EVENTS	x	x	x	x	x	x	x	
	DROUGHT EVENTS	x	x	x		x	x	x	x
	CHANGES IN GROWING SEASON LENGTH / DURATION	x	x	x		x	x		x
	UNSEASONAL FROST	x			x			x	

	EXPLANATION	Different crop types/cultivars have different tolerance ranges to climate conditions. Individual crops vary in their vulnerability to climate depending on the phenological development stage	Capacity of soil to hold moisture influences exposure of plants to drought and flooding conditions. Influences erosivity and nutrient availability under varying climate conditions	Soil conservation practices reduce erosion and ensure maximum soil health, ultimately reducing the vulnerability of crops to climate stresses	Low-lying areas are more vulnerable to flooding and exposure to frost	Pest management allows farmers to respond to pest infestations and impacts associated with climate conditions, such as expanded pest habitat	Nutrient management allows farmers to respond to climate impacts to nutrient availability, such as leaching and changes in nutrient cycling	Crops with existing stresses, such as disease or damage from previous climate events, will be more vulnerable to a given climate hazard event	The use of irrigation can reduce crop vulnerability to drought and extreme heat
	DATA SOURCE	No Local Data	LSxK factors within the RUSLE	CANSIM Table: 004-0205	Soil erosion LS data-Topographic Wetness Index based on a 1-m digital elevation model (Beven et al 1979) and LSxK factors within the RUSLE	CANSIM tables 004-0206	CANSIM Table: 004-0208	No Local Data	CANSIM Table: 004-0210
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	A. Is the indicator relevant to the project scope (management of the agricultural system component in question)?	yes	yes	yes	yes	yes	yes	no - this cannot be managed and will uniformly affect the whole system	yes

policy and management adaptation to be effective at the natural heritage component or larger system level (and not the indicator level). In this manner, the indicator is relevant and can be used effectively in further works with the purpose of monitoring and reducing vulnerability of the natural heritage system in Peel Region.									
	B. Is the indicator relevant to agricultural climate vulnerability?	yes - pertains to multiple climate influences on plant physiology and growth	yes - for precipitation-driven impacts, drought and wind-driven erosion	yes - pertains to multiple climate influences	yes - steep slopes for soil erosion and topographic lows for flooding	yes - pertains to multiple climate influences	yes - pertains to multiple climate influences	yes - pertains to multiple climate influences	yes-pertains to multiple climate influences
2. Indicator data are readily accessible, robust, and collected in a manner that is applicable and useful.	A. Are indicator data available for the study areas?	no	yes	yes	yes	no	no	no	yes
	B. Were the indicator data collected using a method or study design such that they are useful and relevant?		yes	yes	yes	yes	yes		yes
	C. Has indicator data been QAQC processed?		yes	yes	yes	yes	yes		yes

	D. Are the indicator data readily accessible?		yes	yes	yes	yes	yes		yes
3. The indicator is simple, such that non-technical decision-makers understand why it was selected.	A. Is the indicator simple, such that non-technical decision makers could understand its use and application?		yes	yes	yes	yes	yes		yes
Importance of Assessing the Indicator									
4. The indicator is widely applicable, such that it is linked to multiple system components. In this manner, the indicator can best represent the larger agricultural system and management in Peel Region.	A. System components represented by the indicator	Crop production	Crop production + soil + drainage infrastructure	Crop production + soil	Crop production + soil + drainage infrastructure	Crop production	Crop production	Crop production	Crop production + soil
Scientific Validity of Assessing the Indicator									

5. The indicator is measurable and sensitive to changes in the vulnerability factor across multiple natural heritage components regardless of impact causality. In this manner, the indicator has likely been empirically studied and sensitivities or tolerances are understood; ignoring specific causality (e.g., climate change or urbanization) allows managers to theoretically monitor for 'all' eventualities that may lead to the natural heritage system becoming vulnerable and impacting important ecosystem service delivery.	A. Is there a known threshold (impact tolerance or sensitivity) associated with this indicator?	yes	yes - already determined through categories of soil drainage capacity	no	no	no	no	no	no

6. To the current state of knowledge, the indicator is accurate, valid and most appropriate based on one or more of the following: published literature, expert opinion or Community of Practice. In this manner, the indicator can be considered robust and scientifically vetted at an acceptable level prior to implementation in Peel Region.	A. Has this indicator been used elsewhere?	no - not that we are aware of	yes - RUSLE modeling is well established and Cansis data is used widely for crop suitability and production modeling	yes - from Swanson et al. (2007)	yes - AAFC LEAR model	yes - from Swanson et al. (2007)	yes - from Swanson et al. (2007)	yes - from Swanson et al. (2007)	yes- from Swanson et al. (2007)

APPENDIX F: DISCUSSION NOTES ON CLIMATE EVENTS/CONDITIONS AND IMPACTS IDENTIFIED BY STAKEHOLDERS

Summary of climate events/conditions and impacts on various farm system components as identified by stakeholders during the focus group workshop. Concerns were predominantly centered on the impacts to the crops and plants themselves.

Climate Event	System Components				
	Crops/Plants	Soil	Harvest	Seeds	Farm Structures
Cold Spring				Late planting	
Drought		Hardened ground as a result of drought - less pervious to rainfall	Growing Season		
Early Frost	Disease/Fungus				
Extreme Cold	Crop damage				
Extreme Rainfall	Crop damage	Erosion			
	Crop productivity	Flooding			
		Soil quality degradation			
Hail	Crop damage				
Late Spring/Spring Frost	Crop damage			Late planting	
	Early growth more susceptible to frost - apple crop in 2013 wiped out				

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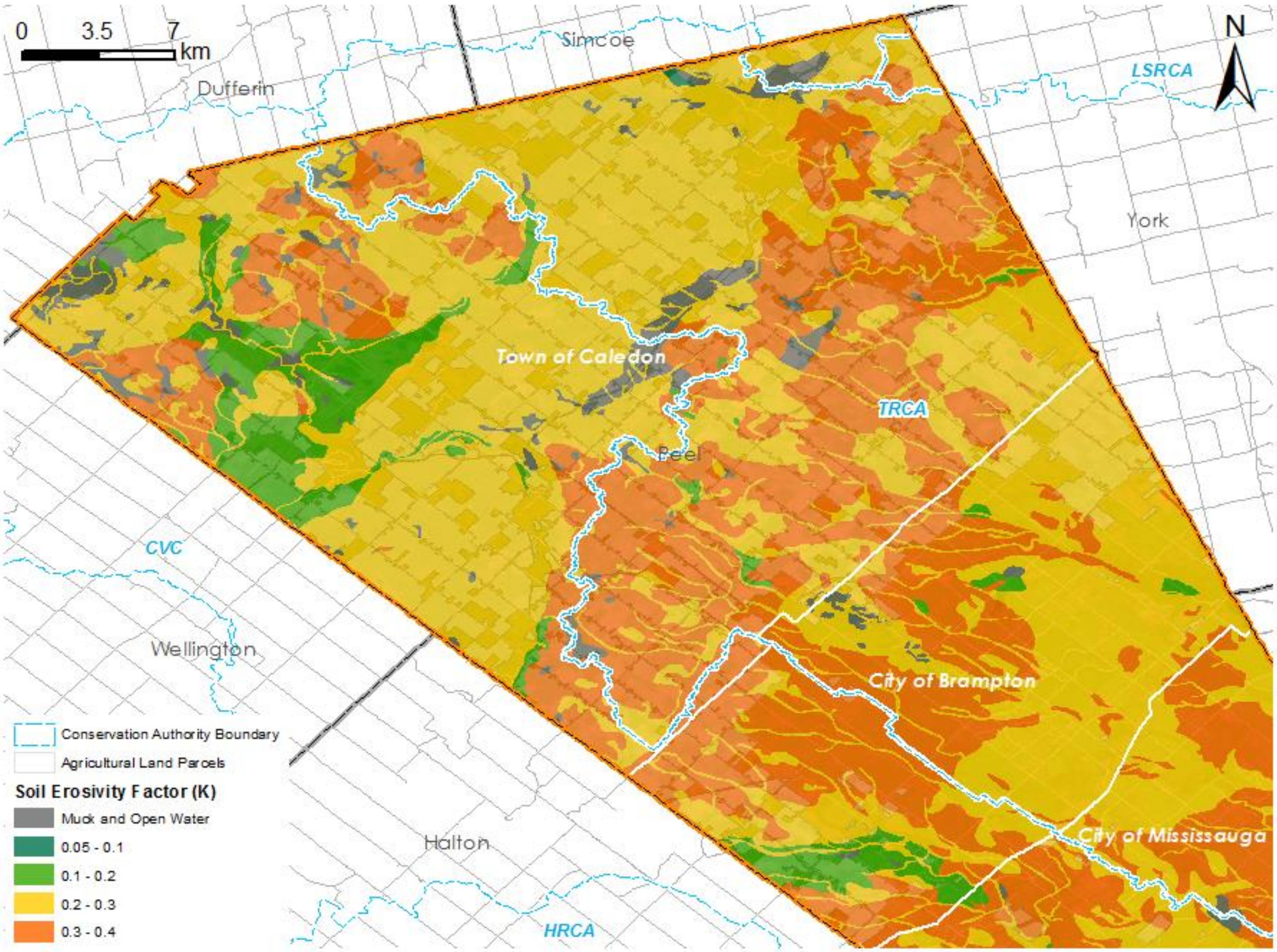
Climate Event	System Components				
	Crops/Plants	Soil	Harvest	Seeds	Farm Structures
Mild Winter	Insects: pressures				Tree survival
		Less snow cover			
Temperature	Growing degree days				
	Heat units for season				
	Low heat units				
	Pests				
Warm Winter	Insects: invasion				
Wet Season	Difficulty harvesting				
Wet Spring				Later planting	
Wind	Drying (ET impact)	Drying (ET impact)			Structural Damage
					Tree limbs rubbing on structures
Not Specified	Crop maturation problems				Structural Damage
	Disease				
	Insects (airborne, spider mites etc.)				

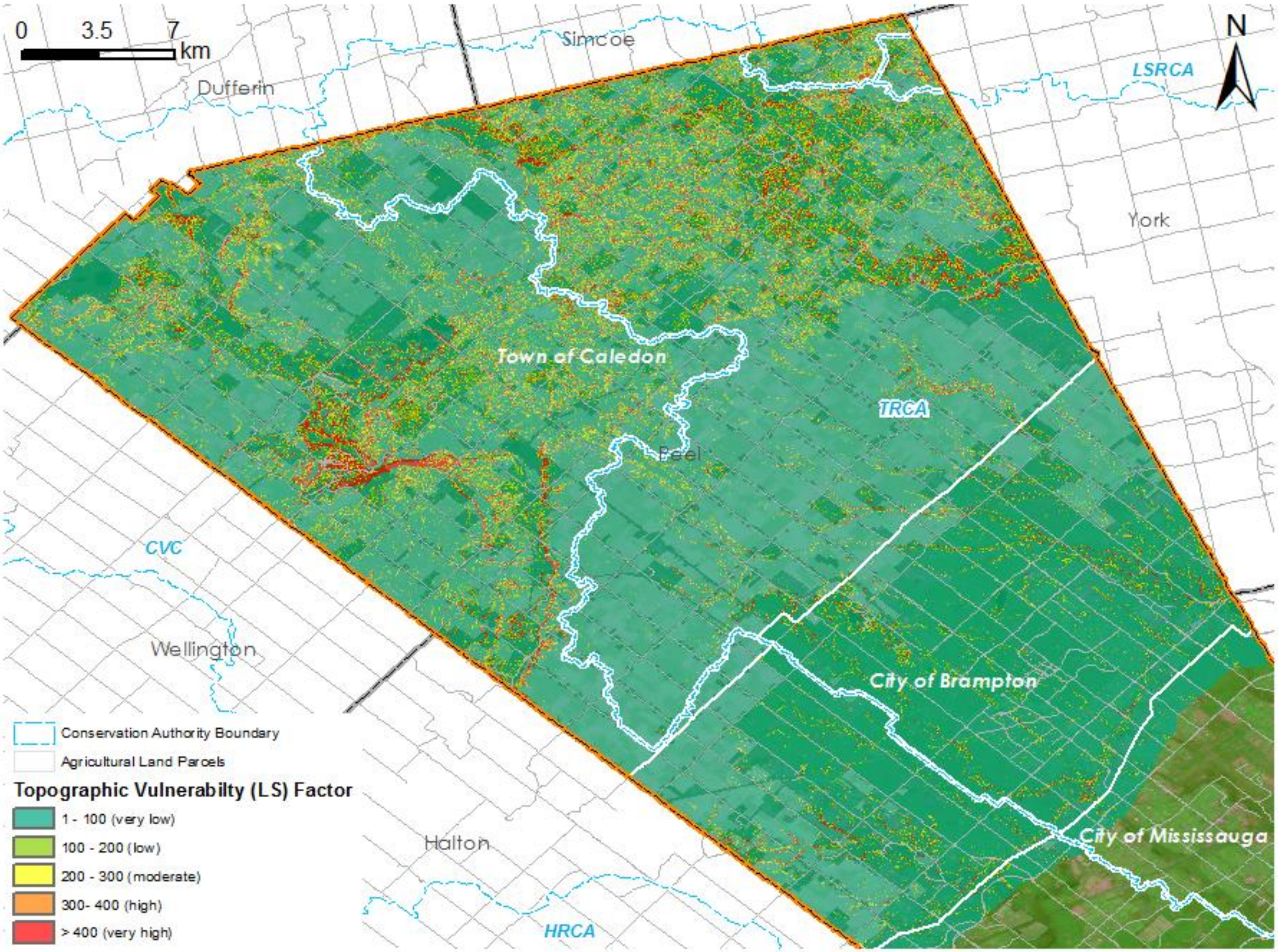
APPENDIX G: SOIL EROSION VULNERABILITY FACTOR MAPS FOR THE LS AND K FACTORS

The Universal Soil Loss Equation (USLE) or the Revised USLE (RUSLE) are both well-defined models used for calculating the potential erosion associated with a given field, based on the following equation: $A = R \times K \times L \times S \times C \times P$

Where: “R is the rainfall-runoff erosivity factor, K is soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is cover management factor, and P is supporting practices factor. This empirically based equation, derived from large mass of field data, computes sheet and rill erosion using values representing the four major factors affecting erosion. These factors are:

- Climate erosivity represented by *R*.
- Soil erodibility represented by *K*.
- Topography represented by *L and S*.
- Land use and management represented by *C and P* (from Renard et al. 1991 p. 775).


0 3.5 7 km
N
Simcoe
Dufferin
LSRCA
York
Town of Caledon
TRCA
Peel
CVC
Wellington
City of Brampton
City of Mississauga
Halton
HRCA
Conservation Authority Boundary
Agricultural Land Parcels
Soil Erosivity Factor (K)
Muck and Open Water
0.05 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4


0 3.5 7 km
N
Simcoe
Dufferin
LSRCA
York
Town of Caledon
TRCA
Peel
CVC
Wellington
City of Brampton
City of Mississauga
Halton
HRCA
Conservation Authority Boundary
Agricultural Land Parcels
Topographic Vulnerabilty (LS) Factor
1 - 100 (very low)
100 - 200 (low)
200 - 300 (moderate)
300- 400 (high)
> 400 (very high)

APPENDIX H: VULNERABILITY FACTORS, RATIONALES

Vulnerability Factors, Rationales

Vulnerability Factor	Rationale
Cultivar and Phenology	**What is it?** Different varieties of the same crop type, crop cultivars can be selected based on desirable characteristics, such as shape, size and yielding properties. Different cultivars, reach various growth stages and maturation at varying times. **Why does it matter?** Various varieties of the same crop type have different crop water requirements, temperature thresholds, resilience levels to pests and diseases and growing lengths/dates to maturation. Crops are more vulnerable to climate drivers and extreme weather events at certain imperative stages of growth, and have different requirements for optimal growth during these stages. Greater functional capacity of diverse agro-ecosystems has been found to protect crop productivity against environmental change by increasing overall resilience. **How does it work?** Growth stages are dependent on the environment, location, planting dates, and planting patterns and type of cultivar. Different cultivars have different agronomic properties such as adaptation to deep flooding or dry land cultivation. Corn, soybeans, and wheat share in common that they are most vulnerable to adverse environmental conditions during their early growth, flowering and grain filling stages.
Soil Drainage	**What is it?** The various characteristics that make up the soil, including Its composition, profile, texture and structure that influence how soil drains. **Why does it matter?** Soil particle size, layer composition (especially the top plough layer), soil type (i.e. san, silt, clay), texture (course or fine) rate of infiltration of water into the soil is dependent on the soil composition and permeability. Soils with poor drainage may be susceptible to water logging, whereas soils that drain quickly may not be able to retain moisture well and may be more vulnerable during drought conditions. **How does it work?** In coarse soils, the rain or irrigation water enters and moves more easily into larger pores; it takes less time for the water to infiltrate into the soil. In other words, infiltration rate is higher for coarse textured soils than for fine textured soils. Soil characteristics affect the amount of water and nitrate that leach through the soil profile, which ultimately impacts crop yield.
Existing Plant Damage	**What is it?** Crops that are considered healthy and in good condition will likely have greater resilience to pest or disease infestation as opposed to crops that are considered to be in poor condition. **Why does it matter?** Healthy crops will likely have a better chance of being hardier and higher yielding. **How does it work?** Poor plant health may increase a crops' vulnerability to impacts such as pests and diseases if the crop is not resilient enough and cannot fight for resources.

Planting Practices	**What is it?** There are different planting practice options available to farmers from mono-cropping, strip cropping, or intercropping. **Why does it matter?** Certain planting practices are known to have benefits over others, some focus on soil health, biodiversity and potential for reduced chemical use. **How does it work?** Some crops are higher yielding when planted together or in proximity to one another.
Tillage Practices	**What is it?** There are many different tillage practice options available to farmers, from conventional and traditional plowing techniques, to more conservation type practices such as no-till, or reduced till. **Why does it matter?** Certain practices can promote the conservation of organic matter, slow soil deterioration, improve drainage, increase water and nutrient holding capacity, and allow necessary soil organisms to thrive. **How does it work?** Crop response to various tillage systems is variable because many factors that directly affect crops are influenced by tillage, such as crop germination, emergence, and the growth are largely regulated by soil temperature, aeration, and moisture content, by nutrient availability to roots, and by the mechanical impedance to root growth. All of these factors are affected by tillage.
Field Topography	**What is it?** Varying field elevations within a location may impact crop yield depending on the fields' properties. **Why does it matter?** Low topographic depressions may be more susceptible to slower draining, depending on the soil characteristics, which could lead to impacts such as water logging and soil erosion, ultimately decreasing yield. **How does it work?** Topographic depressions are low areas in a field where surface drainage away from the area does not occur.
Pest and Disease Management	**What is it?** Farmers employ a host of Integrated Pest Management Strategies (IPMs) to deal with pests and diseases, such as choosing and applying the appropriate fungicides, herbicides, pesticides and insecticides at appropriate times. **Why does it matter?** As the climate and weather become more variable, farmers will need to adapt management practices to deal with an increase or new pest and diseases. For example, longer growing seasons may increase the lifecycles of existing pests while warmer temperatures may introduce a new and invasive species. Using a diverse range of crops promotes a greater ability to suppress pest outbreaks and dampen pathogen transmission **How does it work?** The specific type of practice is dependent on the nature of the pest and diseases being managed. Farmers can tailor their management practices based on crop type and pest and disease risk by implementing best management practices and choosing the appropriate herbicides, pesticides, fungicides and insecticides based on field needs and pressures.

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Nutrient Management	**What is it?** Nutrient management planning is a BMP that aims to optimize crop yield and quality. Similar to pest and disease management practices, farmers manage their soils in order to provide the nutrient requirements for crop growth. **Why does it matter?** In soils, the nutrients most likely to be limiting are nitrogen and phosphorus. Crops have varying nutrient requirements; therefore, if the soils cannot meet these requirements naturally, farmers must add inputs to the soil. **How does it work?** A key part of nutrient management in determining the amount of fertilizer to add is to estimate how much is required for a target yield and determine the current nutrient levels and soil health (done through soil testing). From here, farmers must determine the appropriate input types, amounts, application type, and when to apply, as crops require certain nutrient types at varying growth stages.
Irrigation Technology	**What is it?** Irrigation is the artificial application of water to a field through a variety of techniques including traditional sprinkler irrigation, underground irrigation or water conserving technologies such as drip irrigation. **How does it work?** Irrigation systems such as sprinklers, drip lines or underground pipes are installed on a field to mechanically provide water to crops. **Why does it matter?** Irrigation allows farmers to control when crops receive water and how much. This allows farmers to make sure crops receive optimal precipitation at critical growing points. This is particularly useful if a growing season is dry and not meeting a plants water needs through rainfall alone.