Toward Extreme Weather and Climate Resilience in the Region of Peel

GLISA
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Toward Extreme Weather and Climate Resilience in the Region of Peel:

Analysis of Multiple Hydroclimatic Risks and Vulnerabilities in Two Case Studies (Agriculture and Municipal Services)

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Project Context and Objectives

In 2011, the Region of Peel (a county-level government in Ontario) partnered with local municipalities and natural resource management agencies to develop a climate change adaptation and mitigation strategy, entitled the Peel Climate Change Strategy (PCCS). The PCCS identifies six major overall objectives and employs a risk management approach for establishing specific goals and actions within each objective (Region of Peel et al. 2011). The six major objectives of the strategy are:

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.

This project was developed to support Action 1.1 of the PCCS, which mandates the completion of "a vulnerability risk assessment of all infrastructure, of the community and of natural heritage" as a core goal of "proactive and responsive planning and leadership". Together, this goal and action set the platform for developing, implementing and monitoring the performance of targeted climate resiliency strategies to priority climate impacts within the Region of Peel.

The intent of this project was to provide case study examples of vulnerability and risk analysis methods being used to develop actionable strategies for increasing resilience to priority impacts of climate change and extreme weather with respect to two very different community assets within the Region of Peel: (1) Caledon's agricultural sector, and (2) critical services and infrastructure in Port Credit (see map in Figure 1). The process of conducting these two projects was focused on building local capacity for understanding and managing climate and extreme weather risks – experience that could be used for similar work in the future. This white paper provides an overview of the project, the underlying literature that supported the work, a succinct summary of key activities involved and a high level summary of preliminary findings, lessons learnt as well as directions and suggestions on accessing more detailed information and other resources associated with the project.
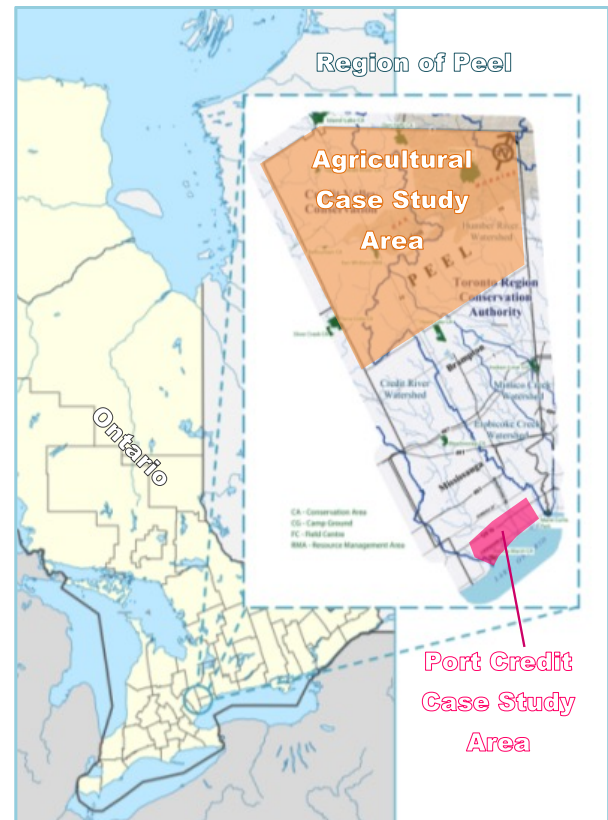

Figure 1. Study area and case studies

Project Approach

The project was completed utilizing the guidance of existing methodologies for conducting risk and vulnerability assessments described in several climate adaptation manuals from across Canada and abroad (e.g., UKCIP 2013; ICLEI 2012; Espeseth et al. 2012; BTA Works 2011; IISD 2006). The cities of Toronto, Chicago, London, Vancouver, Halifax, New York, Los Angeles, and regions such as the State of Wisconsin, the Okanagan Valley and parts of the western Canadian plains all provided helpful guidance in completing climate or extreme weather risk and vulnerability assessments, as they all drew upon the aforementioned documents. 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:

- A reliance on local stakeholders to drive the entire risk assessment process, specifically in identifying climate and extreme weather variables of interest, learning from prior experiences with climate

impacts, risk management, and adaptation, and the prioritization of risks and opportunities for detailed analysis;
- Downscaling a range of climate variables to a local scale, and characterizing visually and narratively the range of uncertainty and variability inherent in these scenarios; and
- Applying a combination of qualitative and quantitative risk and vulnerability scoring and spatial mapping to characterize the relationship between climate, primary physical impacts, and cascading secondary impacts or consequences.

Given the aforementioned needs the goal of the proposed project was to pilot a method for identifying and analysing risks, and scoping adaptation with respect to climate change impacts/hazards for several community assets related to Lake Ontario in the Region of Peel.

This would be carried out in a phased approach with a focus on specifically engaging local stakeholders. Figure 2 provides a more detailed description of the steps involved in this project. It should be noted that certain steps proceeded in tandem. For example, in Port Credit we conducted two separate stakeholder workshops for steps 4 and 6, whereas in Caledon we were restricted to a single session for accomplishing the two key stakeholder workshop objectives (see Tables 1 and 2 for details on the stakeholder engagement conducted). It is also important to note that these phases proceeded iteratively, especially in the identification of impacts and vulnerability indicators.

An Informed Approach to Vulnerability and Risk Analysis: A Review of the Literature

The recently published Fifth Assessment Report (AR5) from the Intergovernmental Panel on Climate Change (IPCC) emphasizes the importance of understanding the linkages between system vulnerabilities and overall climate. A critical aspect of this project was therefore developing a framework for consistently analyzing climate vulnerabilities and risks within each case study, given the scope of the projects and the need to have a replicable analysis methodology. Additionally, although the concepts of "risk" and "vulnerability" are dominant in climate change adaptation (IPCC 2014; 2007) and natural hazards discourse (Wamsler et al. 2013; Adger et al. 2005; Alliance Development Works 2012), there are no uniform definitions for how these apply to a variety of human, built and natural systems (see Lim et al. 2005; Smit et al. 2001; Cutter et al. 2009 for discussions of differences between

risk and vulnerablity). Given this context, early in the project, it was necessary to develop a framework of definitions for these concepts and a system for linking them together.

The United Kingdom Climate Impacts Program (UKCIP) provides a helpful distinction between different kinds of climate risk and vulnerability assessments in a seminal report on this topic prepared in 2003. Within this report, the authors distinguish between three levels (or "tiers") of risk assessment. Each tier results in a more detailed analysis than the tier before it, with selection among tiers mainly a function of information requirements of the decision maker with respect to the characterization of risks (Willows and Connell 2003). Ultimately, this project's framework aligns with a "Tier 2" assessment, which is defined as:

"a semi-quantitative analysis, where some aspects of the risks, costs and benefits are assessed in quantitative terms while others are assessed qualitatively; the assessment would aim to assess uncertainty by placing upper and lower bounds on the risks, costs and benefits" (Willows and Connell 2003).
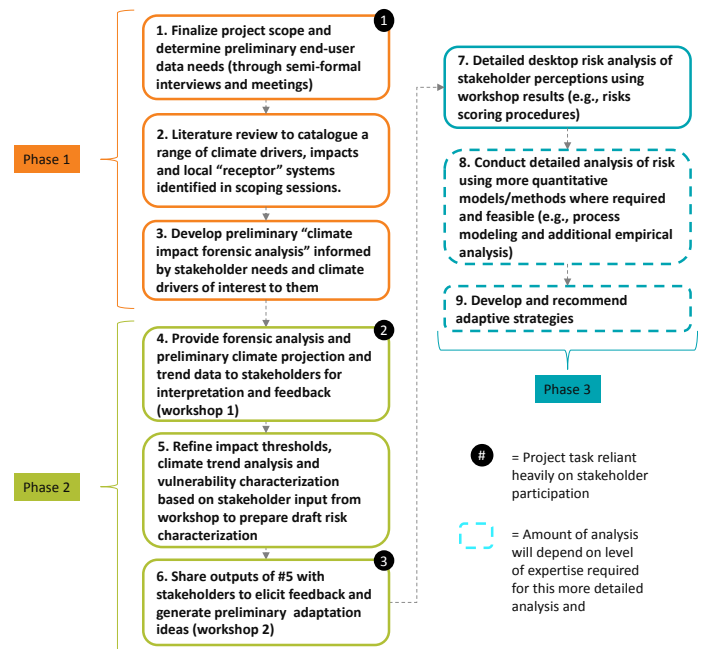

Figure 2. Breakdown of key steps used during the project.

Semi-quantitative risk assessments are common practice in many areas of environmental management, and have proven useful for communicating environmental hazards and their impacts and consequences in fields such as health geography, emergency planning, and water resource management. They have also been used at a global scale to identify "hot-spots" associated with natural hazards (e.g., the World Risk Report). Examples of standardized semi-quantitative risk analysis methods applied at the local scale include the Hazus system employed by the U.S. Federal Emergency Management Agency (FEMA) (http://www.fema.gov/hazus), which is currently being adapted for use in Canada (Nastev et al. 2013); the Municipal Risk Assessment Tool (MRAT) produced by the Insurance Bureau of Canada (IBC) for identifying urban flooding hazards; and Agriculture and Agri-Food Canada's Land and Infrastructure Resilience Assessment (LIRA) and Canpartake tools. There are also a host of examples of agencies using customized quantitative spatio-temporal risk analysis frameworks to understand the relative impact of different climate scenarios on management themes including urban flooding (Peck et al. 2013; Tompkins and Adger 2004); groundwater resource sustainability (Pasini et al. 2012); public health heat emergencies (O'Neill et al. 2009); soil erosion (Blanco and Lal 2010); sea level rise and storm surges (Beach 2013; PlanNYC 2013; Richardson 2010); roadways (U.S. Department of Transportation 2012) and electrical utilities (Reed 2008).

The high value of semi-quantitative risk assessment tools for local decision makers is becoming increasingly apparent, particularly as decision science, our understanding of the limitations of current and future climate information, and abilities to use uncertain information evolves (Weaver et al. 2013). A key element of this project was leveraging information on system vulnerabilities to better characterize local impacts of extreme weather and climate change trends described by climate models. Ultimately it was determined that by understanding and working to reduce system vulnerabilities and risks associated with climate change and extreme weather, local resiliency could be built (Figure 3).

Figure 4 provides a summary of the framework, termed the Peel Climate Risk Analysis Framework and Templates (P-CRAFT), ultimately developed for characterizing risk within the two Peel case studies. This framework bridges the definitions of risk and vulnerability, using the notion that the likelihood of a climate impact is a function of the climate driver itself and the system's vulnerability or resilience relative to that climate driver (Brooks et al. 2005). The consequence is a function of the impact's influence on broader objectives associated with the system's state and/or function.

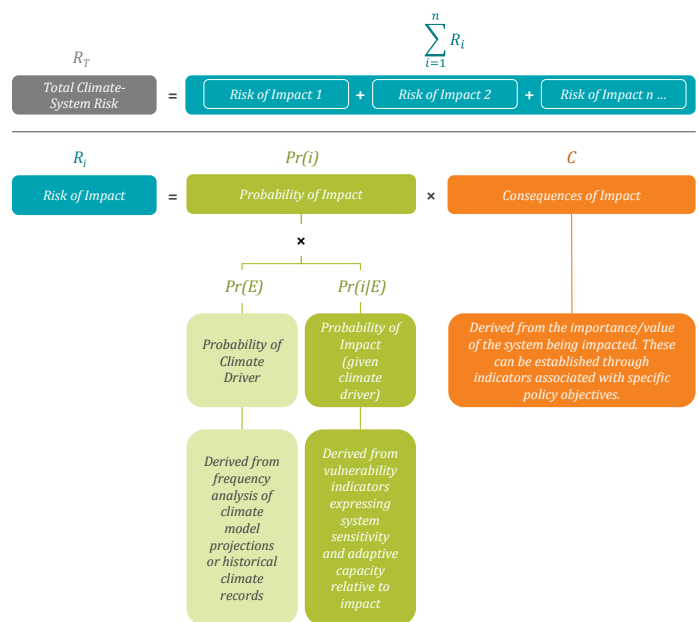Figure 3. Relationship between resilience and vulnerability

Figure 4. Risk and vulnerability analysis and characterization framework employed within the project.

Stakeholder Engagement and Input

Stakeholder engagement and input was significantly used in defining the project scope and in conducting the risk and vulnerability analysis. This was accomplished through a combination of project team meetings, formal and informal interviews and a series of focus-group workshops. Tables 1 and 2 provide a summary of the key stakeholder engagement processes conducted following the initial project scoping phase of each case study.

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.

Subsequently, one focus group workshop was held for each case study and these were focused on identifying climate impacts of concern for the stakeholders. This workshop was used to develop an initial set of climatological variables that could then be used to compare historical and future trends in climate indicators related to specific impacts of concern. The idea was that, within the risk analysis framework, this climate trend data would be combined with information on system vulnerabilities to characterize overall climate risk. After the first focus group workshops, a draft list of climate indicators was created and then circulated to each of the project teams for their feedback. Based on this feedback, the list of indicators were finalized and historical and future trend analysis was conducted (Appendix 1 provides a summary of the climate indicators analysed).

Table 1. 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 councillors 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.
May, 2013	Peel Farm Tour	The project team have endeavoured to maintain connections with the agricultural community and better understand the challenges it faces. Participating in such activities has provided invaluable insights to the project team and positively informed the projects development.
Jun to Sep, 2013	Interviews with local farmers for documentaries	Discussions focused on understanding the role of farms play in 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.

Table 2. Timeline of Municipal Infrastructure and Services Stakeholder Engagement, Port Credit

Jan, 2013	Shoreline meeting	The purpose was to refine the focus of the assessment by hosting a brainstorming session with key stakeholders on the project team, this included a presentation on historical weather/climate issues identified in the Region to date through forensic impact analysis. This was helpful in defining key issues of concern for consideration at the workshop.
Feb, 2013	Shoreline Meeting (teleconference)	Update on the status of the project with key stakeholders to decide upon scope and agenda for the workshop.
Jun, 2013	Workshop I: Issues and Climate Driver Exploration	The lessons learned from the run-through streamlined the workshop and helped us develop a more interactive program that borrowed from elements of *World Café*.
Jul, 2013	Update webinar	With a view to keeping key stakeholders informed of progress to date, the project team provided an update detailing initials findings from the workshop and next steps.
Aug to Oct, 2013	Interviews with municipal staff and stakeholders for documentaries	Interviews focused on a variety of issues identified at the June workshop, including the impact of climate change/extreme weather on Lake Ontario, including recreational/business perspectives; human health risks and the role of climate change on municipal stormwater management infrastructure and ultimately the management of such risks to public and private property.
Nov, 2013	Workshop II: Exploring Risk Results and Developing Adaptation Recommendations	The follow-up Port Credit workshop provided an opportunity to share the results from preliminary literature reviews and analysis of climate risks and vulnerabilities. It also provided the opportunity to discuss potential adaptations and upcoming work focused on natural heritage management and climate change adaptation.

Climate Trend Analysis

For climate indicators based directly on temperature and precipitation, the Government of Canada's CANGRD gridded observed climate data product was used to characterize historical trends in climate (see Figure 5 for a map of the domain for the variable of mean annual temperature). Full details of the CANGRD interpolation procedure can be found in in Hopkinson et al. (2012) and McKenney et al. (2011). In brief, CANGRD uses an ANUSPLINE smoothing-spline technique to interpolate between Environment Canada climate station data to produce a spatially continuous climate surface at daily intervals. This dataset is often used as "assumed" baseline data 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 1971-2010 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, which was identified as a key element of the analysis stakeholders were seeking.

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 most reliable source of station-based information in the study area for these variables (i.e., longest temporal record).

An ensemble approach was used to generate future climate projections for the Region of Peel. The key purpose for using an ensemble is that it captures the full range of uncertainty associated with Global Circulation Models (GCM) that are used as the fundamental input for all other downscaled datasets. Additionally, the ensemble approach allows one to analyse the confidence associated with projecting future climate and is regarded as a reliable method for elucidating regional trends, despite the uncertainty associated with climate prediction. The ensemble used in this study consisted of the GCMs that comprise the Fifth Coupled Model Intercomparison Project (CMIP5), which represents the same dataset used by the Intergovernmental Panel on Climate Change's (IPCC) in its Fifth Assessment Report (AR5). This ensemble consists of forty one (41) different GCMs that are run using four different future climate scenarios, termed Representative Concentration Pathways (RCP). For this project, the two global emissions scenarios were used, as follows:

1. RCP4.5 represents a moderate forcing scenario (moderate rise in emissions through the 2050s; emissions stabilize through mid-century; slight decline through the 2100s), and
2. RCP8.5 to represent a high for a high forcing scenario (emissions)

After aligning the grids for each GCM using a linear re-gridding procedure, 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. To obtain spatially disaggregated information, these deltas were then added to baseline historical spatially gridded data covering the Region of Peel for the corresponding month (or on an annual basis for extreme indicators). The rationale in using 10-year averaging periods was to provide flexibility in the calculation of standard 20 or 30 year normal periods (i.e., any combination of 10-year periods could be used). Figure 6 provides an example of the output generated for stakeholders for analyzing the trends in extreme heat.
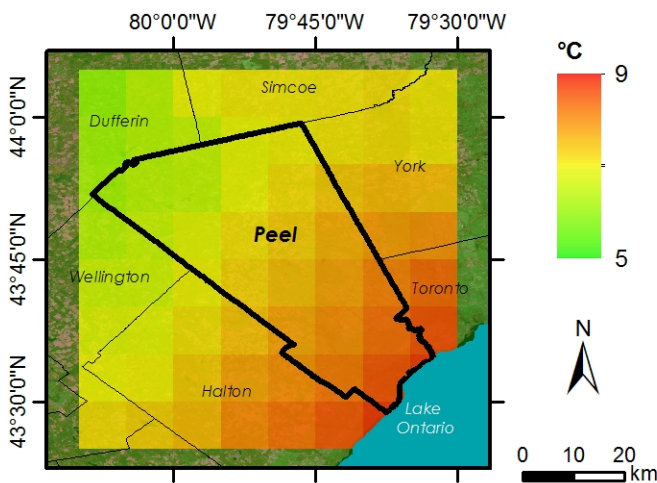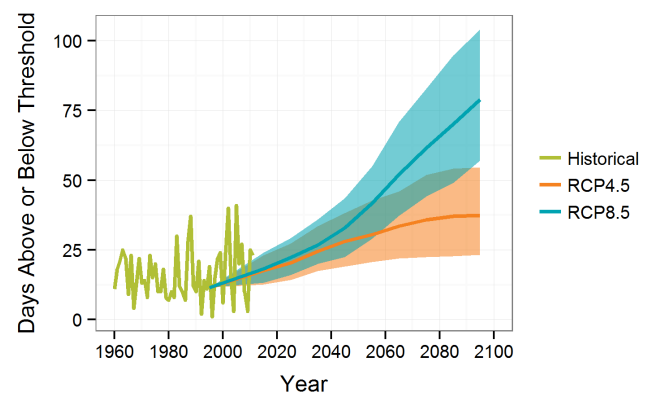

Figure 6. Comparison of historical and future trends in extreme temperature variables for the frequency of days when T_{max} ≥30°C. The shaded area denotes the uncertainty bounds associated with the model ensemble, representing the 10th and 90th percentile of the ensemble.

Figure 5. CANGRD mean annual temperature for the study area domain during the baseline period of 1981-2011

Interaction with GLISA

Throughout the project, GLISA staff provided valuable input by linking the research team with relevant technical guidance and resources, and providing expertise on characterizing risk, structuring focus group workshops and analyzing climate trends. Specific inputs of particular value to the project included:

- Contributing advice on the most defensible methods for developing future climate datasets that satisfied the needs for "decision-ready" information. GLISA staff provided very valuable, technical insight into the limitations and benefits of different future climate datasets and downscaling approaches;
- Actively participating in our Port Credit workshop and sharing the experiences of other stakeholder groups and GLISA projects.
- Learning from the approaches of other projects in tackling similar scientific and stakeholder engagement processes. For example, as part of the agricultural case study, it was useful to discuss approaches for mapping soil erosion with The Nature Conservancy.

Ultimately, interactions with GLISA added to the credibility of the project and analysis techniques with project stakeholders and the climate adaptation community in Ontario. There is substantial capacity and experience in climate adaptation within the U.S. and having an opportunity to be directly exposed to this knowledge base was an way of validating our approach and integrating best-practices, which ultimately added to the credibility of the project. Being exposed to the U.S. network also provided an important way of demonstrating the uniqueness of our project in the Great Lakes basin. Beyond the project specifically, the ongoing relationship we have developed with GLISA has helped us advance our thinking on climate adaptation and is being translated into broader US-Canada collaboration on climate change. For example, we now have an avenue to ensure U.S. input into Ontario-based research that might be useful across the Great Lakes basin.

Risks and Vulnerabilities Characterized and Prioritized by Stakeholders

Prioritization of Impacts and Analysis Scope

During each of the focus group workshops, stakeholders were 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 risks and vulnerabilities:

- What are the priority climate-related impacts of 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?

Figure 5 provides a summary of results from an agricultural focus group exercise where participants were asked to rank recent weather and climate events based on their importance as agricultural production risks. 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 risks – those being drought, hail, extreme rainfall, wind, late spring/spring frost, wet spring and early fall frost. A similar exercise was conducted pertaining to production opportunities, and consensus formed around the most salient opportunities being concurrent precipitation and temperature increases (not-extreme), warmer overall growing season, and normal timing of seasonal changes.

A slightly different process was used in Port Credit, with key stakeholders prioritizing climate hazards before the focus group workshops, and the workshops serving instead to elucidate more details on the nature of community impacts associated with each hazard. The hazards that were explored were extreme heat, extreme wind, weathering processes, and snow/ice storms. Flooding was also explored, but as a separate discussion based on the importance of the issue in the study area.

Analysis of the workshop results for both case studies allowed for a conceptual mapping of specific impacts to climate drivers. Subsequently, detailed analysis was conducted on high-priority impacts to identify critical climate thresholds and vulnerability indicators through literature reviews, modeling and empirical analysis of historical impact data. This detailed analysis is ongoing and provides an opportunity to fully test the framework described above and presented in Figure 2. Table 3 presents a summary matrix of the prioritized interactions between climate drivers and systems impacted.
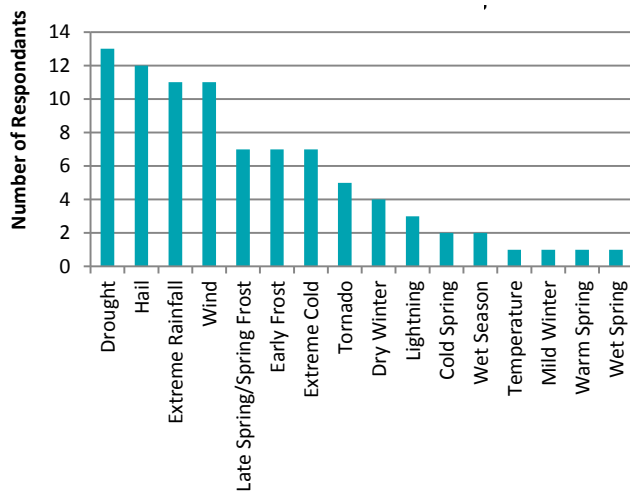
Figure 7. Results of producer perspectives on climate risks in the Region of Peel based on individual worksheets.

Table 3. Detailed climate risk analyses being undertaken following workshops

Agricultural Detailed Analysis		Port Credit Detailed Analysis	
Climate Driver	*System Impacted*	*Climate Driver*	*System Impacted*
Drought	Soy Crop Corn Crop Wheat Crop	Storms	Shoreline Roadways Electrical transmission
Extreme Precipitation	Soil Soy Crop Corn Crop	Extreme Heat	People / public health Electrical transmission
Seasonality	Soy Crop Corn Crop	Lake Level Variability	Shoreline

Validation of Vulnerability Indicators and Risk Analysis

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. Figure 6 presents results from the individual ranking sheets for the example of "storms + shoreline", and demonstrates that this information alone can provide significant insight into the weight of importance of different factors for decision makers. In this example, the presence of a building or infrastructure within existing hazard limits was identified as the most important system characteristic. This is tied to infrastructure and property damage, which has

significant economic and social consequences. Conversely, the factor pertaining to whether shoreline reach is isolated was ranked much lower by participants. This factor relates to the resilience of the natural shoreline, wherein isolated natural reaches are less able to withstand erosive forces because natural sediment dynamics are interrupted compared to longer contiguous reaches. When participants were asked to rank the impact of climate hazards on broad consequence categories using a 5-point Likert scale, economic and social dimensions ranked higher than environmental ones, which may explain the ranking of literature results (Figure 7).
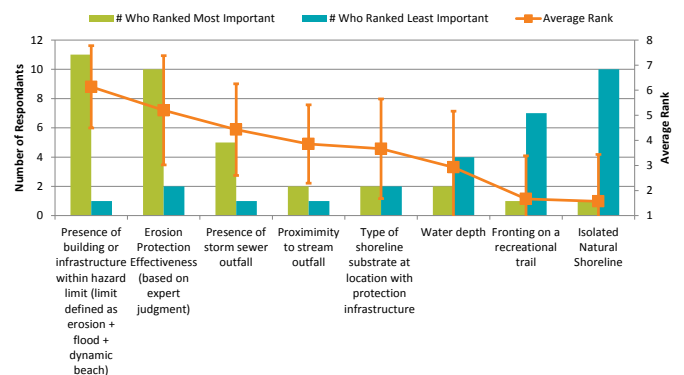

Figure 8. Results of individual worksheet ranking for vulnerability indicators for the storms + shoreline impact scenario.
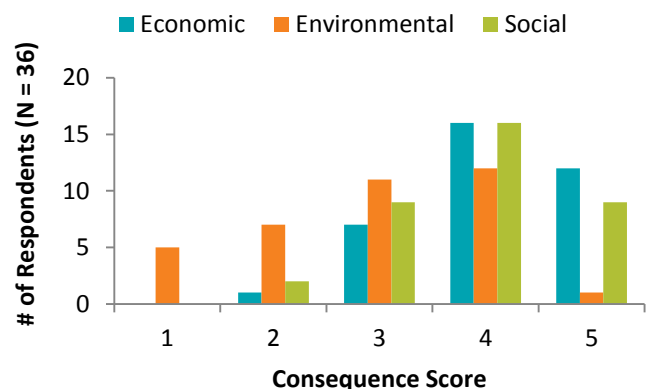

Figure 9. Results from Likert scale consequence scoring exercise where participants were asked to rank the importance of perceived consequences for each impact scenario on a scale of 1-5 (1 being least important, 5 being most important).

Summary of Project Outputs

Over the duration of this study the project team focused on developing materials and project deliverables that supported work associated with each case study, but also subsequent climate change risk assessment work to be undertaken by the Region of Peel and its partners.

To support these aims the project team developed the following resources, which are currently completed or being finalized:

- A complete set of downscaled local climate data and an accompanying technical report [completed];
- A detailed and peer reviewed technical methodology report on the research for conducting risk analysis shown in Figure 4 [completed];
- Case study summary reports and climate risk analysis research templates for Caledon and Port Credit [being finalized];
- The completion of 3 brief video documentaries, one focused on Caledon, the other on Port Credit and the third focused on an overall description of the project as a whole [completed] available at http://climateontario.org/wp/?page_id=699&preview=true; and
- A project website hosted at www.ontarioclimate.org which included project specific information and links to case study materials which included [completed]:
    - o Project overviews
    - o Workshop materials (agendas/workshop activities) and presentations from speakers
    - o Regular updates to project partners through in-person meetings, update emails and updates in the OCC newsletter [completed].

Lessons Learnt

Funding provided by the Region of Peel, GLISA and other in-kind support has allowed the project team to conduct a highly detailed study of climate change vulnerability in Peel. Only a limited numbers of examples pertaining to specific impact assessment have been showcased in this report as detailed above. However, the outputs, notably localised climate data, associated analysis and stakeholder engagement have provided extensive insights and lessons critical to undertaking subsequent high resolution climate vulnerability analysis in the Region. Broadly speaking the project has served to identify a broad range of opportunities for advancing climate adaptation in the

Region of Peel and other municipalities. Nevertheless it is important to keep the following considerations in mind:

Risk analysis is iterative: A key lesson from this project was the shear amount of effort required to probabilistically characterize risks in the manner proposed within the P-CRAFT. The process of identifying and validating all the indicators required for a full a P-CRAFT analysis (i.e., climate, vulnerability, and consequences) is highly iterative and resource intensive. To fully engage and honour the needs of decision-makers, multiple rounds of literature review and stakeholder input are needed to refine a set of indicators that is of value locally. Nonetheless, engaging stakeholders in the process of risk analysis provided highly valuable guidance and feedback on the applicability of indicators locally.

Avoiding the "data availability" trap: It is necessary to ensure that perceptions of indicator validity are not based solely on data availability, but rather the importance of a given indicator as a determinant of the impact in question. This is an important way of ensuring that the final list of indicators is comprehensive and to identify gaps in local monitoring and data collection, which are critical to adaptive management.

Importance of "general" versus "specified" resilience: A common criticism of risk management as an approach to climate adaptation and resiliency-building is that high degrees of uncertainty, both in regards to future climates and system responses to impacts, does not allow for risks to be managed in targeted ways. This is a valid criticism of the majority of the impacts assessed through this project. In many cases, literature, modeling, and datasets for empirical analysis to identify thresholds and system responses were not available. While the identification and stakeholder validation of indicators from the literature is still useful in increasing an understanding of risk and vulnerability, this information is insufficient for recommending robust and targeted local resiliency-building strategies. This concern was raised at several points throughout the project, both in the development of P-CRAFT and in stakeholder consultations. The concept of "general resilience" presented in Folke et al. (2010) proved to be a useful tool in overcoming stalled dialogue and progress associated with using highly uncertain information.

Next Steps and Knowledge Transfer

Next steps for this project includes completing the outstanding deliverable materials and working closely with stakeholders to develop consensus around adaptation recommendations. Critical among this work are the following tasks:

- Complete a review of relevant literature and utilize stakeholder input to develop lists of vulnerability indicators for the major impacts being assessed (i.e., see Table 2);
- Collecting data on indicators and using modeling and quantitative tools to better quantify the risks;
- Analysis of overlaps and interdependencies among risks;
- Identification and recommendation of adaptation strategies; and
- Integration of 'lesson's learned' into the next iteration of the climate risk assessment underway in the Region of Peel with a specific focus on natural heritage.

Currently the outputs and lessons from this project are being used directly in the following local climate adaptation planning studies within the Region of Peel:

- Economic assessment of climate change in the City of Mississauga (using climate projections data)
- Mississauga community energy and sustainability planning (using climate projections data)
- Natural Heritage Vulnerability and Risk Assessment across the Region of Peel (using climate projection data and risk analysis protocol)

The experience is also feeding into the development of climate risk and vulnerability assessments and adaptation planning within other local Ontario municipalities more indirectly, with proponents regularly consulting with our team on our experience and approach.

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Appendix 1: Climate indicators produced to represent specific system impacts

Climatic Impact	Climate Indicator Produced [unit]	Future Climate Raw Dataset Source
Multiple	Average Maximum Temperature, T_{max} [°C]	*tasmax (GCM ensemble)*
Multiple	Average Minimum Temperature, T_{min} [°C]	*tasmin (GCM ensemble)*
Multiple	Average Temperature, T_{mean} [°C]	*Calculated from tasmin/tasmax (GCM ensemble)*
Multiple	Total Precipitation [mm]	*pr (GCM ensemble)*
Multiple	Windspeed [m/s]	*Calculated from wind components: uas /vas (GCM ensemble) & Calculated from CanRCM daily dataset*
Multiple	Humidity/spec humidity [kg/kg]	*hurs (relative humidity) / huss (specific humidity) (GCM ensemble) & Calculated from CanRCM daily dataset*
Agricultural productivity	Crop Heat Units [CHU]	*Calculated from ts (GCM ensemble)*
Agricultural productivity	Growing Season Length (frost-free period) [days]	*Calculated from tasmin (GCM ensemble)*
Agricultural productivity	Growing Season Start Date [date of year]	*Calculated from tasmin (GCM ensemble)*
Agricultural productivity	Growing Season End Date [date of year]	*Calculated from tasmin (GCM ensemble)*
Frost risk	Days per month with $T_{min} \leq X$, where X = {5, 3, 0, -2, 1.7} [°C]	*Calculated from tasmin (GCM ensemble)*
Extreme heat	Days per month with $T_{max} \geq$ 30°C, 35°C, 40°C [days]	*Calculated from tasmax (GCM ensemble)*
Extreme cold	Days per month with $T_{min} \leq X$, -5°C, where X = {-5, -10, -15,} [°C]	*Calculated from tasmin (GCM ensemble)*
Drought / lack of moisture	Days per month with no precipitation [days]	*Calculated from pr (GCM ensemble)*
Freezing rain	Ice Potential: number of freezing rain events. Freezing rain definition will be defined as a day with precipitation AND where T_{max} < 2°C and T_{min} > -2°C [days]	*Calculated from pr, tasmin, tasmax (GCM ensemble)*
Freeze-thaw weathering processes	Number of freeze-thaw cycles, where $T_{max} \leq$ 0°C and T_{min} > 0°C [days]	*Calculated from tasmax and tasmin (GCM ensemble)*
Indicator of 'good' growing season climate	Number of years when both growing season precipitation and CHUs are between 5 and 10% ABOVE historical monthly [years]	*Calculated from CanRCM4 pr and ts daily dataset*
Extreme precipitation	1-day maximum precipitation accumulation [mm]	*r1d (GCM ensemble) & Calculated from CanRCM daily dataset*
Extreme precipitation	5-day maximum precipitation accumulation	*r5d (GCM ensemble) & Calculated from*

GLISA

Climatic Impact	Climate Indicator Produced [unit]	Future Climate Raw Dataset Source
	[mm]	*CanRCM daily dataset*
Extreme precipitation	Simple daily Intensity index (SDII) [mm/day]	*SDII (GCM ensemble) & Calculated from CanRCM daily dataset*
Extreme precipitation	95th Percentile Daily Precipitation [mm]	*r95t (GCM ensemble) & Calculated from CanRCM daily dataset*
Extreme precipitation	99th Percentile Daily Precipitation [mm]	*r99t (GCM ensemble) & Calculated from CanRCM daily dataset*
Extreme precipitation	Number of days with daily precipitation >= 20 mm [days]	*Calculated from CanRCM daily dataset*