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Assessing and Mitigating Municipal Climate Risks and Vulnerabilities in York Region, Ontario

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Project Context and Objectives

Over the last several decades, variations in global climate have exposed many nations to an increased range of risks, forcing them to adapt to emerging conditions. Many local communities have experienced more frequent and intense weather events, such as extreme temperatures, rainstorms, snowstorms, prolonged heat waves and droughts, shifts in seasonality, and other anomalous climate conditions. In addition, due to significant social, economic, and infrastructural development, communities are exposed to numerous cascading impacts initiated by a changing in climate.

Figure 1: **York Region Lower-Tier Municipalities**

Within York Region, Ontario, there are nine municipalities actively adapting to climate change (Figure 1). At the municipal level, climate adaptation is being addressed through a variety of mechanisms, including sustainability plans, community energy plans, and enhanced development standards. The development of an adaptation framework assists York Region and its nine municipalities to move towards creating action plans to specifically address climate adaptation.

With this in mind, the project "Assessing and Mitigating Municipal Climate Risks and Vulnerabilities in York Region, Ontario," which was cooperatively initiated by York Region, the Ontario Climate Consortium (OCC), and Clean Air Partnership (CAP), has the main objective of advancing climate change adaptation action planning in the region and thus enhancing the resilience of local communities, natural systems. and municipal assets.

A comprehensive review of existing climate risk assessment tools was previously conducted as part of the Great Lakes Integrated Sciences and Assessments (GLISA)-funded work with the Region of Peel and OCC. The analysis recognized that each of the reviewed tools, some of which were found to be used by assessments across the Greater Toronto Area (GTA), shared the following fundamental steps:

1. Setting the context
2. Identifying the hazard(s) and systems
3. Estimating and characterizing the "probability" and "consequence"
4. Treating risks.

These steps shaped the project activities, where each step was comprised of several more specific tasks. All phases of work aimed at producing the necessary outputs, while making use of existing tools and information. Due to the iterative nature of certain activities, such as stakeholder engagement and the refinement of risk information, multiple activities fed into each step within the framework and tools development.

The Project Team collaborated with the Joint Municipal Climate Change Working Group in York Region to refine the initial terms of reference and scope the set-up of a Region-wide risk and vulnerability framework. The Project Team also developed background narratives and statistics on significant sectors of York Region's economy, environment and communities to describe the context of this project.

The core objective has been reached by establishing the processes, tailoring the tools and templates, compiling the necessary information, and enhancing staff capacity to conduct risk and vulnerability assessments and resiliency-based adaptation planning. The key project outcomes are:

1. The development of greater awareness and recognition of the importance and nature of climate change risks,

vulnerabilities, and need for adaptation among municipal staff and decision makers in York Region
2. Increased capacity at the staff level to conduct risk and vulnerability assessments and adaptation-planning across municipal management and service areas in York Region
3. More streamlined processes and systems for the execution of risk and vulnerability assessments and having the capability to update information over time and track progress on adaptation initiatives targeted at increasing municipal resilience

As a result of joint efforts, the project is expected to deliver the following items:

- A framework (comprising of a set of processes, tools, and templates) for ongoing risk and vulnerability assessment and adaptive management/resiliency based planning in York Region
- Workshops and surveys to engage staff in risk and vulnerability assessments and adaptation-planning more broadly
- Inventory of municipal management and service area risks in York Region (climate hazards, impacts, and system/components)
- A risk and adaptation (and risk mitigation) database City of Toronto (COT) Tool and research template developed for the Region of Peel (P-CRAFT)) populated with basic information on the management and service area risks identified in the inventory and trends on climate hazards specific for York Region based on risk information compiled from other applicable assessments in the Greater Toronto Area and the Great Lakes Basin
- Climate trends for variables representing weather hazards in York Region
- Detailed characterization of risks in municipal stormwater management systems using established methods and local datasets for a City of Vaughan case study
- Discussion on the opportunity to incorporate the framework guidance documents into the adaptation strategy of York Region.

York Region and the local municipalities have been envisioned to utilize the developed assessment framework and tools in order to undertake future vulnerability assessments and adaptation planning within their respective jurisdictions. Therefore, York Region's municipalities were directly engaged through the Joint Municipal Working Group and Steering Committee that included representatives from the Joint Municipal Working Group. A Project Team was established to ensure project deliverables meet a broad range of local municipal needs.

Building On Existing Adaptation Frameworks and Risk and Vulnerability Assessments

In order to deliver the first item and define a streamlined framework for ongoing risk and vulnerability assessment and adaptive management/resiliency-based planning in York Region, all project activities were built on work that had been previously completed in the area of municipal climate risk and vulnerability assessment in GTA. Emphasis was placed on previously applied tools, information, and lessons learned from risk and vulnerability assessments conducted in the Region of Peel, Durham Region, City of Toronto, and the Lake Simcoe watershed (Appendix A).

Within the suite of reviewed GTA-based risk assessments, a range of municipal systems and asset classes have undergone detailed analysis, and this project took the opportunity to learn from these efforts. More specifically, these assessments helped identify tools used, select climate indicators, delineate impacts of greatest concern, establish methods to differentiate a system into components, and propose adaptation measures. Table 1 presents an overview of the reviewed risk assessments (Appendix A contains additional info on each).

Table 1: Existing GTA Assessments

Jurisdiction / Proponent	Assessment Theme
Region of Peel	• Public health • Natural systems • Hydrology • Economy • Municipal critical infrastructure / services (roadways, electrical distribution, shoreline, private property, public health)
Greater Toronto Airports Authority	• Stormwater infrastructure
Region of Durham	• Municipal service areas (public health, transportation, flooding, electrical grid, agriculture/food)
City of Toronto	• Transportation services
City of Hamilton & Conservation Hamilton	• Hydrology and stormwater
Credit Valley Conservation	• Hydrology and stormwater
Ontario Ministry of Natural Resources and Forestry	• Terrestrial and aquatic ecosystems
WeatherWise Partnership	• Electrical transmission and distribution infrastructure case studies

Initially, the information pulled from these assessments was used to inform the assembly of a framework that could be used across multiple themes and for system-specific assessments. This included the following core components:

- ICLEI Framework (ICLEI, 2010);
- City of Toronto Climate Change Risk Assessment Database (COT) (City of Toronto and Deloitte LLP, 2011); and,
- The Peel Climate Risk Analysis Framework and Templates (P-CRAFT) (Switzman & Hazen, 2015).

The gaps identified through stakeholder engagement were filled through the amalgamation and tailoring process of the framework and tools. The Project Team analyzed how to leverage its strengths and how to integrate them in a manner that was most useful for the stakeholders. For instance, the P-CRAFT templates were incorporated into the COT database. The Project Team liaised with COT staff and the software developer (Deloitte LLP) to obtain required licenses and a one-day "train the trainer" session on the COT database, which helped determine an optimal approach for integrating the P-CRAFT tool.

Adopting a Process-Based Adaptation Framework

Process-based frameworks for risk and vulnerability assessments are intended to guide local practitioners through a process of initiation, research, planning, implementation, and monitoring. Based on the experience leveraged from previous assessments, this project established a framework tailored to the specific needs of York Region that are essential for effective long-term adaptation planning. Therefore, this project adopted the steps presented in ICLEI – Local Governments for Sustainability, Canada 2010 document titled "Changing Climate, Changing Communities: Guide and Workbook for Municipal Climate Change Adaptation" as the basis for adaptation planning and implementation in York Region. This framework provides a milestone based approach to assist local governments in the creation of adaptation plans to address the relevant climate change impacts associated with their communities. It draws from climate change adaptation planning methodologies adopted by specific sectors or departments, municipal operations, communities and specialized adaptation teams throughout Canada and the US. Each milestone represents a step in the adaptation planning process that is completed in sequence and then reviewed and updated:

- **Milestone 1**: Takes a first look at climate change impacts and existing adaptation actions in a region or municipality;
- **Milestone 2**: Supports and prioritizes climate change vulnerability and risk assessments;
- **Milestone 3**: Establishes the adaptation vision with goals and objectives to achieve the vision. Potential adaptation options are identified, assessed for applicability and incorporated into an adaptation plan where suitable;
- **Milestone 4**: Implements this plan;
- **Milestone 5**: Deals with monitoring, evaluation and review of the adaptation actions detailed in the plan, and proposes updates to the actions where necessary.

Most of Milestone 1 was already completed through the draft York Region Climate Change Adaptation plan, and it was reviewed and updated at the outset of the project. Therefore, this project aimed at establishing a framework and tools to conduct Milestone 2 in a consistent manner across York Region. Milestone 3 was addressed only as part of the City of Vaughan's municipal stormwater infrastructure case study.

Tailoring the Risk and Vulnerability Assessment Framework and Tools

As mentioned previously, two tools were selected for customization to facilitate the undertaking of analysis on climate vulnerability and risk in York Region. The first tool was a climate change risk assessment database developed by COT. The second tool, P-CRAFT, was a framework and tool developed for the Region of Peel (Switzman & Hazen, 2015). The Municipal Steering Committee and external experts provided input on how the selected frameworks and tools could be amalgamated in an effective, user-friendly manner. Computational resources were used to conduct the customization necessary to provide York Region with a consistent framework for the vulnerability and risk assessment process.

The COT tool represents an automated Microsoft Access database that stores information and facilitates the evaluation of risk on different municipal assets, management, and service areas. COT was used to provide a consistent, auditable approach to vulnerability and risk assessment. The tool prompts users to define the exposure, measure probabilities, delineate consequences using uniform and consistent scales, document justifications, and score risk. The internal structure was updated with new information as more detailed risk assessments were completed, when risk management measures were implemented, and when risk levels needed to be refined.

However, one of the COT tool limitations was the absence of a structured method to guide the gathering of evidence leading to the definition of vulnerabilities and indicators, as well as the documentation of: a) key assumptions about how vulnerabilities and risks are defined; b) the sources of information used to characterize risks and vulnerabilities; and, c) definitions of quantitative indicators and complex interactions within the pathways that cause impacts – all of which were identified as valuable in risk analysis and risk-based planning by the stakeholders. Work was conducted in collaboration with the developers of the COT database to address this gap using P-CRAFT templates. P-CRAFT templates are essentially a series of structured Excel spreadsheets that guide users on how to extract information from literature and conduct empirical analyses to derive indicators of vulnerability in a transparent, efficient manner.

Furthermore, P-CRAFT templates can be used by the risk assessment team to record and document all observations, assumptions, and conclusions throughout the vulnerability investigation. The P-CRAFT template documentation was incorporated to the comprehensive COT manual to guide the user through the proposed framework and use of the amalgamated tools.

Through the process of evaluation of existing risk and vulnerability assessments conducted across GTA (see Table 2), the information was compiled and populated in the database and P-CRAFT templates. More specifically, populating the database and templates with existing risk information required reviewing risk assessments already finalized in the Toronto region and other Great Lakes Basin municipalities. It also required extracting generic data that is relevant to the systems in York Region, such as asset categories, climate indicator definitions, and climate change adaptation measures (e.g., from literature).

Furthermore, climate information was obtained from an array of climate datasets, including Canadian Gridded Historical Observed data from Natural Resources Canada (McKenney et al. 2011), and a five-model dynamically downscaled ensemble produced from the Ontario Ministry of Environment and Climate Change (Wang et al. 2015). These two databases were used to populate climate indicators of historical and future frequency in the amalgamated tool. Other climate datasets were also used but only for simple comparison and for context. The other datasets included 41-model statistically downscaled ensemble produced by York University (LAMPS 2014), two dynamically downscaled models coupled with a lake-based model to examine the influence of the Great Lakes (Notaro et al. 2015a, 2015b), and climate indicators produced at stations from a study conducted for the COT in a Future Climate Driver study (SENES, 2011).

After populating the database and templates, internal capacity-building for conducting risk assessments in York Region was needed. To facilitate training and understanding of the process and database, a workshop was held where municipal staff were provided the summary information from the survey, climate data analysis, and background research and were asked to discuss the possible inputs that would be inputted in the risk assessment tool for their specific service area. This was done to the extent possible using their professional judgment. This action provided a solid source of information for users, which they could tailor and adjust as necessary in their assessments. Furthermore, this ensures a more consistent approach to risk and vulnerability analysis and, thus, resiliency-based planning across the GTA.

Historical and Future Climate Information for York Region

The Project Team sought to characterize climate trends of perceived importance to a wide range of systems in York Region. Initially, a literature review lead by CAP of historic climate events in Southern Ontario (in the period between 1985 and 2015) and the stakeholders illustrated that this region has observed climate events that may reflect shifts in the timing, magnitude, and frequency of extreme precipitation events, as well as significant temperature variations. In some cases, these events have also been identified to occur simultaneously. The observed changes in climate conditions have been shown to be harmful to human-built systems and local community wellbeing. More broadly, the climate events observed in Southern Ontario can be categorized as temperature fluctuations (observed in years 2003, 2005, 2007, 2009, 2010, 2012, 2013), extreme heat events (years 1999, 2001, 2003, 2005, 2006, 2010, 2011, 2012, 2013), extreme cold and ice storm events (2003, 2013, 2015), extreme precipitation events (1999, 2000, 2004, 2007, 2008, 2009, 2010, 2013, 2014), extreme winds (2006, 2009, 2011, 2013, 2014), and drought events (2001, 2002, 2007).

Based on the review of historical climate events and impacts in Southern Ontario, a list of climate variables was put forward to the Municipal Steering Committee. Only the climate indicators identified to be relevant to stakeholders were included in the analysis (Figure 2 and Table 2). It is anticipated that future assessments will expand on this list by including more detailed indicators and analysis.

In light of the observed events and trends, historical climate data and projected climate model outputs relevant to York Region were utilized to estimate the projected trends for each climate category for the future time period referred to as the "2050's climate normal." Specific climate indicators were defined to represent the events of concern identified by the stakeholders and the literature review. Climate trend information was generated in partnership with GLISA. The raw model outputs of two model ensembles funded by the Ministry of Environment and Climate Change (i.e., Wang et al. 2015, LAMPS 2014) were used for the historical and future periods for a set of precipitation and temperature indicators, although the five-model ensemble created by Wang et al. was used to populate the risk assessment tool.

Figure 2: York Region Municipal Boundaries with Spatial Averaging Box Used in Climate Trend Analyses

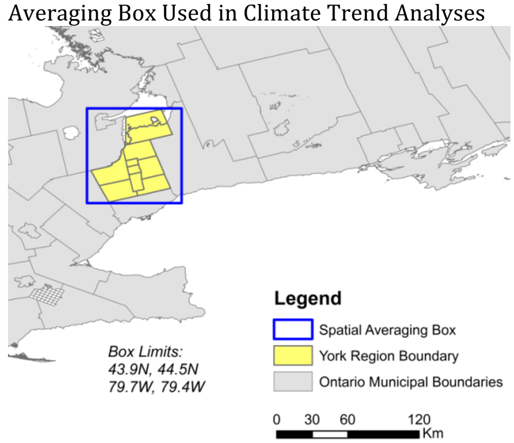

Table 2 Summary of selected climate variables

Climate Driver	Variable
Temperature	Average Maximum
	Average Minimum
	Average Temperature
	Maximum Maximum
	Maximum Minimum
	Minimum Maximum
	Minimum Minimum
	Diurnal Temperature Range
Precipitation	Total Precipitation

	Number of Wet Days
	Consecutive Wet Days
Extreme Precipitation	1-Day Maximum Precipitation
	5-Day Maximum Precipitation
	Simple Daily Intensity Index
	Heavy Precipitation Days
	Very Heavy Precipitation Days
Ice Storms	Ice Days
	Ice Potential
Extreme Cold	Number of Days with Minimum Temperature <-5^{0}C
	Number of Days with Minimum Temperature <-15^{0}C
	Number of Days with Minimum Temperature <-20^{0}C
	Number of Days with Minimum Temperature <-25^{0}C
	Cold Days (% of Days T_{max} <5-day 10^{th} Percentile value)
	Cold Days (% of Days T_{max} <5-day 10^{th} Percentile value)
Extreme Heat	Number of Days with Maximum Temperature >25^{0}C
	Number of Days with Maximum >30^{o}C
	Number of Days with Maximum >35^{o}C
	Number of Days with Maximum >38^{o}C
	Number of Days with Maximum >40^{o}C

Furthermore, GLISA assisted with the generation of indicators obtained from all other climate datasets examined, including the SENES and Notaro datasets. As previously mentioned, these other climate datasets were only used for simple comparison and context. More specifically, two dynamically downscaled climate models from Notaro et al. (2015a, 2015b) were analyzed for context since these two downscaled models included a coupled lake-based model to incorporate the influence of the Great Lakes. However, given that only two models were obtained from this dataset, it was excluded from the tool's ensemble approach. Similarly, the SENES dataset was only included for context because of stakeholder familiarity with this study and its use in risk assessments, but it was not used within the risk framework tool because the climate normal defined is 10 years as opposed to the recommended 30 years (WMO 2007). For all climate datasets examined, a climate trends report prepared for York Region as part of this process describes each dataset and its projected changes in more detail (Fausto et al. 2015).

In general, stakeholder perspectives on local risks and their information needs were critical inputs to this tailoring process. For that reason, regular stakeholder interactions were incorporated in all project activities. In this case, the engaged stakeholders included the Joint Municipal Climate Change Working Group as well as staff and decision makers that were involved in the development of the original York Region adaptation action plan.

Engaging Municipal Staff in Risk and Vulnerability Assessment and Adaptation Planning

A survey was developed and distributed to the Joint Municipal Climate Change Working Group. This survey guided stakeholders through a set of questions that aided gathering information on experienced and expected impacts on various systems due to climate and York Region's the interactions, perceived importance and overall risk tolerance. Approximately 24 percent of all stakeholders completed the survey.

The Project Team used the survey to facilitate a focus group workshop discussion with members of the Joint Municipal Climate Change Working Group and other stakeholders in York Region. At this workshop, participants explored topics covered by the survey in more detail. Moreover, participants had an opportunity to elucidate more information on the impacts and associated vulnerabilities identified and characterize perceived importance of risks. Prior to the workshop, stakeholders were provided with the

Table 3: Systems Affected

Climate Change Impacts of Highest Priority	Systems					
	Premises/ Infrastructure/ Assets	Cost/Time (Including reputation)	Environment	Logistics (Supply chain)	People	Corporate Processes
Infrastructure failure causing flooding	x	x	x	x	x	x
Power outages	x	x	x	x	x	x
Sewer backups and surcharging	x	x	x	x	x	x
Human health impacts	Conditional	x	x	x	x	x
Interruption to public transportation	Depends on scale	x	x	x	x	x
Interruption to telecommunication services	x	x	Conditional	x	X	x
Basement flooding	x	x	x	Conditional	X	Conditional

results of the survey and a summary of historical and future climate trends produced by CAP, GLISA, and OCC. Using focused discussion techniques, the Project Team guided stakeholders to a consensus on the climate change impacts of greatest concern to a range of management and service areas in York Region. Furthermore, the stakeholder group discussed system interactions associated with the impacts and perceived consequences (Table 3). Finally, the workshop allowed for a discussion around climate change preparedness within York Region. As a result, the group identified the following seven impacts as being associated with great levels of concern:

- Infrastructure failure causing flooding
- Power outages
- Sewer backups and surcharging
- Human health impacts
- Interruption to public transportation
- Interruption to telecommunication services
- Basement flooding

The survey and workshop indicated a strong level of agreement that York Region is already experiencing extreme precipitation events, changes in timing of freeze/thaw cycles, changes in average temperature, extreme heat, extreme hot days, and changes in lake water levels. Noteworthy agreement showed that changes in types of precipitation, extreme cold days, changes in growing season, and snow/ice storms are also present in the region.

The results also showed that the following climate event impacts are perceived as more frequent: increased erosion and sedimentation, sewer backups and surcharging, coastal and riverine flooding, infrastructure failure causing flooding, deteriorated water quality, impacts on human health, and interruption to public transportation. Participants also indicated an increased frequency in the number of combined sewer overflows, basement flooding, severe water shortages, reduced agricultural yield, and power outages. A level of unfamiliarity in York Region was presented with the impacts of declining water supplies, increased wildfires, and interruption to telecommunication services. The survey also indicated a level of consensus around the idea of changes that were identified as "most likely" to take place under changing regional climate conditions. More specifically, changes in average temperatures and frequency of extreme precipitation events were identified. According to the survey, climate events perceived as "very likely" to occur in this region included: extreme heat, increased number of hot days, changes in type of precipitation, changes in timing of freeze/thaw cycles, changes in growing season, historical climate loads, lake water levels, extreme cold days, snow/ice storms, and drought.

Furthermore, this workshop initiated a discussion around preparedness within York Region. Participants recognized that the following actions were planned or ongoing in York Region and within its partner municipalities that are relevant to climate change adaptation (including but not limited to):

- York Region Public Health programs:
    - Extreme heat monitoring program
    - Beach water sampling
    - Vector-borne diseases (West Nile virus, Lyme disease, Eastern Equine Encephalitis)
- Urban heat island study in York Region
- Updates to the Ontario Public Health Standards and Protocols
- Updating York Region Greening Strategy
- Sustainable Development initiatives (e.g. LEED standards, Low Impact Development (LID), and updated guidelines)
- Greenlands Strategy
- Monitoring programs reporting;
- Tree planting programs
- Support to business through The Climate Wise Network (Sustainability CoLAB framework)
- Green Parking guidelines
- Updating of design standards for water, stormwater, and wastewater
- Inclusion of LID standards into design standards
- Electric vehicle charging stations deployment
- LED street light replacements
- Incorporation of sustainability metrics
- District energy initiatives
- Adaptation and mitigation inclusive sustainability master plans
- Eco-homes (LEED Homes Platinum)

A Case Study on City of Vaughan Stormwater Municipal Infrastructure

The stormwater system of the City of Vaughan was selected as a case study to utilize the tailored tools and frameworks and delve into Milestone 3 of the ICLEI framework in more detail. This city was selected due to ongoing efforts of the stormwater and sustainability municipal staff to characterize vulnerabilities and risks in light of climate change. The goals of this case study were to support the characterization of vulnerabilities to climate change, further develop the capacity of staff to conduct risk and vulnerability assessments, and support the ongoing adaptation planning efforts in the City of Vaughan by incorporating the adaptation tools developed.

In order to clearly define the system undergoing detailed analysis, the case study team selected three stormwater infrastructure asset categories:

- Stormwater management ponds (wet and dry)
- Stormwater mains
- Ditches, catchbasins, and culverts

A combination of desktop review of academic and grey literature, combined with structured interviews and discussions with selected stormwater experts helped recognize the impacts of interest and supported the definition of vulnerability factors for each of the asset categories. Vulnerability factors refer to the specific asset attributes that make it more or less "vulnerable" to the impact in question. The definitions of these factors support the further understanding of the sensitivity to climate change and the overall adaptive capacity of the system.

The literature review accounted for accredited research on the current state of knowledge regarding stormwater infrastructure vulnerability to climate change, while the expert engagements aimed to validate and expand on the information relevant to the City's system. The documentation of the information found was organized and guided by the P-CRAFT templates, which were then incorporated into the COT database. The literature review and stakeholder engagement provided the scientific background to define vulnerability indicators and perform the analysis/mapping of stormwater system vulnerabilities in the City of Vaughan.

The approach taken through this framework focused on the concepts of vulnerability and adaptive capacity to understand how the system responds to a climate driver and how to define risk and possible adaptation measures. The assumption is that although future climate information is limited and of lower resolution at the local scale, evaluating the system's adaptive capacity is crucial to characterize potential risk in light of uncertainty associated with future climate. Stormwater-specific climatic indicators and trends were developed through series of interviews and expert consultations with municipal stormwater practitioners and based on the reviewed of literature, including past stormwater risk assessments. GLISA and the OCC analyzed the climate data to inform the probability of exposure to extreme climate events in the case study area (Table 4).

Table 4: Sample Climate Indicators Relevant to Stormwater

Climate Indicators	Thresholds
Extreme Heavy 1-day Total Rainfall	Days with rainfall >100mm
Heavy 1-day Total Rainfall	Days with rainfall >50mm
Heavy 5-day Total Rainfall	5-day period with >100mm of rainfall
Rain Frequency	Number of days with >10mm of rain
Winter Rain / Rain-on Snow	Number of days with >25mm of rain during January to March

The COT tool and P-CRAFT templates allowed the working group to collect and analyze information for deriving vulnerability factors and indicators in a transparent way. This approach to determining risk encourages greater transparency and a better understanding of pathways by which climate drivers can result in impacts, which pose risks to the assets undergoing analysis.

To improve the impact of the capacity-building exercise, the case study team included the following: a process lead within a central department, who was focused on the use of the frameworks and tools to guide the process and an expert lead, who guided the technical team through the analysis, ensuring the work's adherence to the discipline's principles and best practices. It is expected that this structure will allow for the process lead to participate in several assessments within the municipality, bringing lessons learned and experience to the multiple expert teams conducting vulnerability and risk assessments.

Summary of Project Outputs

As a result of this collaborative effort, the Project Team focused on developing tools and project deliverables that support the development of an adaptation, risk, and vulnerability framework to assists York Region and each of the nine municipalities.

To support these efforts, the Project Team developed the following resources:

- A detailed and peer-reviewed technical manual outlining the steps involved in the proposed framework, focusing on the COT and P-CRAFT amalgamated tool (comprising of a set of processes, tools and templates)
- A 'primed' tool (COT – P-CRAFT) to facilitate future risk and vulnerability assessments of a variety of systems within York Region. This template was populated with information on climate hazards, management and service areas relevant to York Region, and adaptation measures from previous vulnerability assessments within the GTA
- A detailed peer-reviewed report on climate trends, including historical and future climatological information, focused on variables representing weather hazards in York Region
- Workshops and surveys to engage staff in risk and vulnerability assessment and adaptation planning more broadly
- The result of an annotated literature review of over 100 publications focused on municipal stormwater management systems using the P-CRAFT templates for selected asset categories of the City of Vaughan's stormwater system
- A populated risk and adaptation tool (COT – P-CRAFT) including the results of the process steps followed to conduct a vulnerability and risk assessment on case study (stormwater system of the City of Vaughan).

Lessons Learned

This project has brought numerous benefits to York Region and its municipalities. First, stakeholders were initially intimidated by the complexity of climate data, models, and information:

- Local municipalities perceive lack of climate science and information as a barrier to initiating risk assessment and adaptation planning information.
- However, participants were very comfortable discussing extreme weather events that had already impacted their areas of expertise. Many also had insights on what future impacts were likely.
- Starting vulnerability and adaptation discussions at this very practical level led to greater understanding and acceptance of the regional climate model information.

Second, third-party assistance was also beneficial:

- Having an outside organization (e.g. GLISA) helped all participating municipalities develop a common assessment and planning framework.
- Workshop participants had greater comfort that methodology being developed would meet the needs and be applicable to all organizations.
- Project stakeholders were able to leverage their collaborative efforts to engage climate experts that they might not have had access to individually.
- Stakeholders were also more comfortable that decisions based on climate information and use of a common tool would be more defensible given the expertise that leveraged in this project. There was some discussion that this would potentially make the results of these assessments more readily accepted by municipal councils.
- Dedicated outside resources ensured that the project stayed on track and didn't compete with conflicting priorities (core business) of project stakeholders.

Finally, use of local tools led to greater acceptance:

- Utilizing tools that had been developed by local municipal jurisdictions was beneficial to this project.
- There was greater certainty that these tools worked within the existing administrative, geographical, and legislative context relevant to project stakeholders.
- Utilizing existing tools also created a sense of urgency, whereby project stakeholders were encouraged to respond efficiently and be engaged throughout the process.

Next Steps and Knowledge Transfer

Next steps for this project include completing the outstanding steps for the case study vulnerability analysis and a capacity-building exercise to develop stormwater-specific adaptation recommendations. This portion of the process includes:

- Validation of the vulnerability factors and indicator mapping for the study area
- Identification of priorities within the risks identified
- Integration of the 'lessons learned' and adaptation measures proposed by existing assessments in the adaptation measures discussions

Further efforts are ongoing to maximize the impact of the deliverables and lessons learned from this project in York Region. These efforts and next steps include:

- Discussions on the opportunity to incorporate the framework guidance documents into the adaptation strategy of York Region
- Consultations to define data sharing processes for this framework that are in line with current processes within York Region
- Ongoing effort to formalize and strengthen municipalities through the Joint Municipal Climate Change Working Group, as a place to share and leverage lessons learned from adaptation and mitigation efforts across the region
- Efforts to increase the exposure of the municipalities across the York Region to this project's deliverables
- Support in guiding the training of process experts in local municipalities
- Efforts to leverage opportunities to address compounding risks through collaboration at the region and municipal level

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Appendix A

Table A-1: Reviewed Existing GTA Assessments

Jurisdiction / Proponent	Assessment Theme	Geography	Year Completed	Climate Information	Adaptation Policy / Framework	Assessment Protocol / Tools	Assessment Tier*
Region of Peel	Public Health	Peel	2013	None	ICLEI	WHO (2003)	II
	Agriculture	Caledon, Brampton	2015 (ongoing)	Auld et al. (2015)	ICLEI	P-CRAFT**	II
	Natural Heritage	Peel	2015 (ongoing)	Auld et al. (2015)	ICLEI	P-CRAFT & Gleeson et al. (2011)	II
	Hydrology	Credit Valley Watershed	2015 (ongoing)	TBD	ICLEI	PIEVC***	III
	Economy	Mississauga	2015 (ongoing)	Auld et al. (2015)	ICLEI	-	II
	Municipal critical infrastructure / services(roadways, electrical distribution, shoreline, private property, public health)	Port Credit	2015 (ongoing)	Auld et al. (2015)	ICLEI	P-CRAFT	II
Greater Toronto Airports Authority	Stormwater Infrastructure	Pearson International Airport	2014	CCCSN 2007a, CCCSN 2007b, AR4 2007(TRCA 2009)	Internal risk management	PIEVC	III
Region of Durham	All municipal service areas (Public Health, Transportation, Flooding, Electrical Grid, Agriculture/food,)	Durham	2014	Senes (2011) Senes (2014)	ICLEI	-	I
City of Toronto	Transportation services	City of Toronto	2014	Senes (2011)	Resiliency strategy	Deloitte Tool	III
City of Hamilton & Conservation Hamilton	Hydrology and stormwater	Spencer Creek watershed	2015 (ongoing)	TBD	TBD	TBD	III
Credit Valley Conservation	Hydrology and stormwater	Cooksville Creek watershed	2015 (ongoing)	Auld et al. (2015)	-	PIEVC	III
Ontario Ministry of Natural Resources and Forestry	Terrestrial and Aquatic Ecosystems	Lake Simcoe watershed	2012	McKenney et al. (2011)	Gleeson et al. (2011)	Gleeson et al. (2011)	II
WeatherWise Partnership	Electrical transmission and distribution infrastructure case studies	City of Toronto and Mississauga	2015	(TRCA 2009)	-	PIEVC	III

Notes:
*Assessment Tier definitions based on UKCIP risk assessment types in Willows and Connell (2003):
I – screening assessment; II – semi-quantitative, sector/theme focused; III – full quantitative, sector/theme detailed analysis
** P-CRAFT = Peel Climate Risk Analysis Framework and Templates (for conducting systematic review of risk information)
*** PIEVC = Public Infrastructure Engineering Vulnerability Committee's risk assessment protocol (for detailed engineering assessments)

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Appendix B

The confidence in climate projections varies by climate driver, as well as by model given the inherent assumptions embedded with atmospheric processes being captured. As a result, this report adopts language used in the IPCC's most recent assessment reporting as the basis for describing confidence and uncertainty in a particular climate driver. Confidence wording in the IPCC documents is characterized by the use of specific terms such as 'very likely' or 'virtually certain' (see Table B-1). There has been a gradual increase in confidence of the projections from climate models over time. With each IPCC report there are increasing quantity and higher quality observations of the changing climate and improvements in the model equations, parameterizations, and their spatial and temporal detail. The IPCC reports continue to provide the best science-based information on projected climate change assembled from the best climate researchers worldwide. Generally, evidence is considered to be more robust when there are multiple, consistent, independent sources of high quality information (IPCC 2012) (see Table B-2).

Table B-1: Confidence terminology employed by the IPCC in their official reports (AR5) (from IPCC 2013)

Term	Likelihood of the Outcome
Virtually certain	99 – 100% probability
Very likely	90 – 100% probability
Likely	66 – 100% probability
About as likely as not	33 – 66% probability
Unlikely	0 – 33% probability
Very unlikely	0 – 10% probability
Exceptionally unlikely	0 – 1% probability

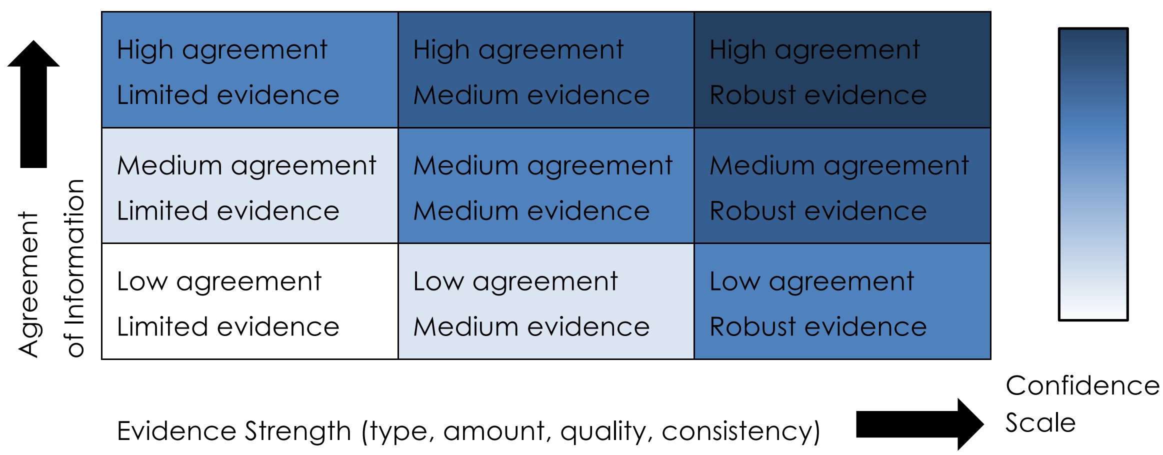

Figure B-1: Conceptual depiction of the relationship between evidence and confidence (adapted from IPCC 2012).

Given that the quantification of uncertainty associated with future climate projections was a key element of the analyses in this project, it was felt that using a large range (from the 10th to the 90th percentile) of climate model projections in an ensemble was the most robust way of capturing the range of uncertainty associated with climate projections in York Region. Both statistical and dynamical downscaling techniques rely on general circulation models (GCMs) to drive local-scale modeling and analysis, and ideally the uncertainty associated with the GCMs should be propagated through the downscaling process. Historical and downscaled local climate estimates of extreme events have been observed in many studies to lie within the uncertainty bounds of raw GCM ensembles.

Analyses in this project were limited to data availability and particularly to those climate datasets which are reputable, commonly known and/or robustly created. While a full climate model ensemble (i.e. CMIP5) was not independently run, other datasets do capture these projections in a more locally-relevant format for York Region. For example, the York University LAMPS dataset accessed (LAMPS 2014) produced climate variables for the 2050s using the full CMIP5 ensemble statistically downscaled format. While it should be noted that statistical downscaling relies on historical relationships among climate variables of various scales, and there is uncertainty as to whether these relationships will hold under evolving conditions associated with climate change, the York University LAMPS dataset provides a valuable initial look at the CMIP5 model ensemble. Further analyses could derive climate variables using a dynamical downscaling approach based on the CMIP5. A climate trends report prepared for York Region describes climate datasets, their projected changes, and uncertainties in more detail (see Fausto et al. 2015).