Distribution System Climate Risk and Vulnerability Assessment

Final Report

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Executive Summary

Over 330,000 residences and businesses in the City of Ottawa and the Village of Casselman depend on Hydro Ottawa Limited (Hydro Ottawa) to supply continuous and reliable electrical service. In recent years, notably in 2018, Hydro Ottawa distribution infrastructure has been subjected to particularly extreme weather events that caused severe damages to their system. These events resulted in widespread outages and costly recoveries. In an effort to maintain reliable service in the coming years, Hydro Ottawa has retained Stantec Consulting Ltd. to conduct a climate risk and vulnerability assessment (CRVA) and provide recommendations for adaptation and risk mitigation within their operation, design, and business functions to help protect their infrastructure, service delivery and occupational health and safety. This assessment generally follows the guidelines set in the Canadian Electricity Association’s guide “Adapting to Climate Change, A Risk Management Guide for Utilities” and identifies climate-related risks that exposed infrastructure are expected to face moving forward. Of particular interest to Hydro Ottawa, are three significant weather events that occurred in 2018, including a freezing rain event in April, a heavy wind event in May, and a series of tornados that touched down in September in the Ottawa region.

This work and the associated adaptation plan (submitted under a separate cover) will help drive continuous improvement to Hydro Ottawa’s Asset Management System and will highlight climate risks and recommended mitigation measures related to Hydro Ottawa’s policies, operations and maintenance, design, and emergency response practices.

The scope of work for the Hydro Ottawa Distribution System CRVA includes the following:

- Review of available information and documents including Hydro Ottawa’s Corporate Risk Management Plan, Asset Management Plans, and outage reports;
- Facilitation of a series of interviews with Hydro Ottawa staff to help identify which weather events have caused disruptions and or failures and pose issues for Hydro Ottawa assets and service;
- Assessment of past weather events and an analysis of available climate data for the region and its projection into the future using internationally accepted Intergovernmental Panel on Climate Change (IPCC) projection data;
- Forensic evaluation of climate conditions that led to the development of three damaging weather events that took place in 2018, as described above;
- Identification of vulnerable infrastructure associated with Hydro Ottawa’s distribution network and other supporting infrastructure and services as well as the climatic or weather events that are expected to impact these infrastructure systems;
- Workshop with Hydro Ottawa staff to validate assumptions related to their system and to assist in the completion of the risk assessment by identifying the level of impact on an asset should the climate event unfold, creating the climate risk profile; and,
- Preparation of a climate risk and vulnerability assessment report.

The CRVA evaluates the future climate impacts on Hydro Ottawa’s electrical distribution system and supporting infrastructure and identifies the potential risks associated with future changes in climate and extreme weather events. The assessment identifies risks to the infrastructure, buildings or facilities due to extreme weather and climate uncertainty based on current climate and future climate projections in the region. Extreme weather events include, but are not limited to high wind events, freezing rain, temperature and precipitation extremes, as well as complex events (i.e. climate events that are driven by the interaction of multiple climate parameters).

The CRVA uses Engineers Canada’s Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol – an assessment methodology that conforms to the International Organization for Standardization (ISO) 31000:2018 Risk Management Standard, to identify relevant climate parameters and infrastructure responses, set up the risk evaluation worksheet, and assign risk ratings to each response to relevant climate considerations. This assessment is compatible with Hydro Ottawa’s Asset Management Risk Procedure (AMRP); the project team selected the following performance criteria from the AMRP to assess the impacts of climate events on the infrastructure.

Response Category	Description
Level of Service: System Accessibility	Risk or opportunity impacting the connection of load and energy resource facility customers.
Level of Service: Service Quality	Risk or opportunity impacting the delivery of electric power in a form which meets customer's needs.
Resource Efficiency	Risk or opportunity impacting the additional use of internal or external resources.
Asset Value: Financial	Risk or opportunity impacting the realization of value from assets through resulting financial expense.

The infrastructures relied upon by Hydro Ottawa to deliver its services are comprised of substations, communication systems, the smart grid (e.g., telemetry, sensors, SCADA, internet) metering, third party services, overhead and buried power distribution as well as the service personnel who maintain and upgrade the system components on a regular basis. These assets are the backbone of Hydro Ottawa and are the focus of this study in order to determine the effects of climate on the infrastructure. The report provides a detailed description of these assets. Another vital part of the infrastructure is the administrative buildings (including the System Office that provides real time management of the distribution system) that are operated by Hydro Ottawa which are utilized for office and field personnel alike. These buildings are mainly utilized for administrative tasks such as client management, planning, detailed design and dispatching field personnel as required. As part of their distribution infrastructure, Hydro Ottawa also has operational buildings which are mainly located within their substations. These buildings are utilized to house switchgear, controls, batteries, and other essential elements to ensure the safe and reliable power distribution to their clients.

Changes in climate translate into direct and indirect impacts to municipal services, critical public infrastructure, spaces and assets/facilities, and community networks. Climate risks and hazards can be associated with two types of climate or weather events analogous to “shock” vs. “stress”: (1) rare, extreme and rapid/sudden-onset extremes or “shock events” and (2) slow onset or “creeping” threats or “stress events”. Extreme events are factored into building codes and practices through the use of extreme value or return period climate probabilities. Alternatively, many of the slow onset or recurring climate events that can be expected to occur several times annually are important when maintaining the service life and durability of structures and are sometimes included in standards. Studies indicate that damages to infrastructure from extreme events tend to increase dramatically above critical climate thresholds, even though the extreme weather events associated with these damages may not be much more severe than the type of storm intensity that occurs regularly each year. Impacts of climate change on assets can include structural damage, the reduced service life of assets and their components, and increased stress to systems and operations. These impacts can, for example, result in higher repair and maintenance costs, loss of asset value, strain resources and cause service interruptions.

The development of climate data for this climate vulnerability risk assessment of Hydro Ottawa’s distribution system involved three main activities:

- Identify climate parameters (e.g. temperature, precipitation, winds) and threshold values at which infrastructure performance would be affected (i.e. climate hazards);
- Project the probability of occurrence of climate hazards for future climate (i.e. 2050s); and,
- Convert projected probability of occurrence of future climate parameters into the five-point scoring scale used in Hydro Ottawa’s Asset Management System Risk Procedures.

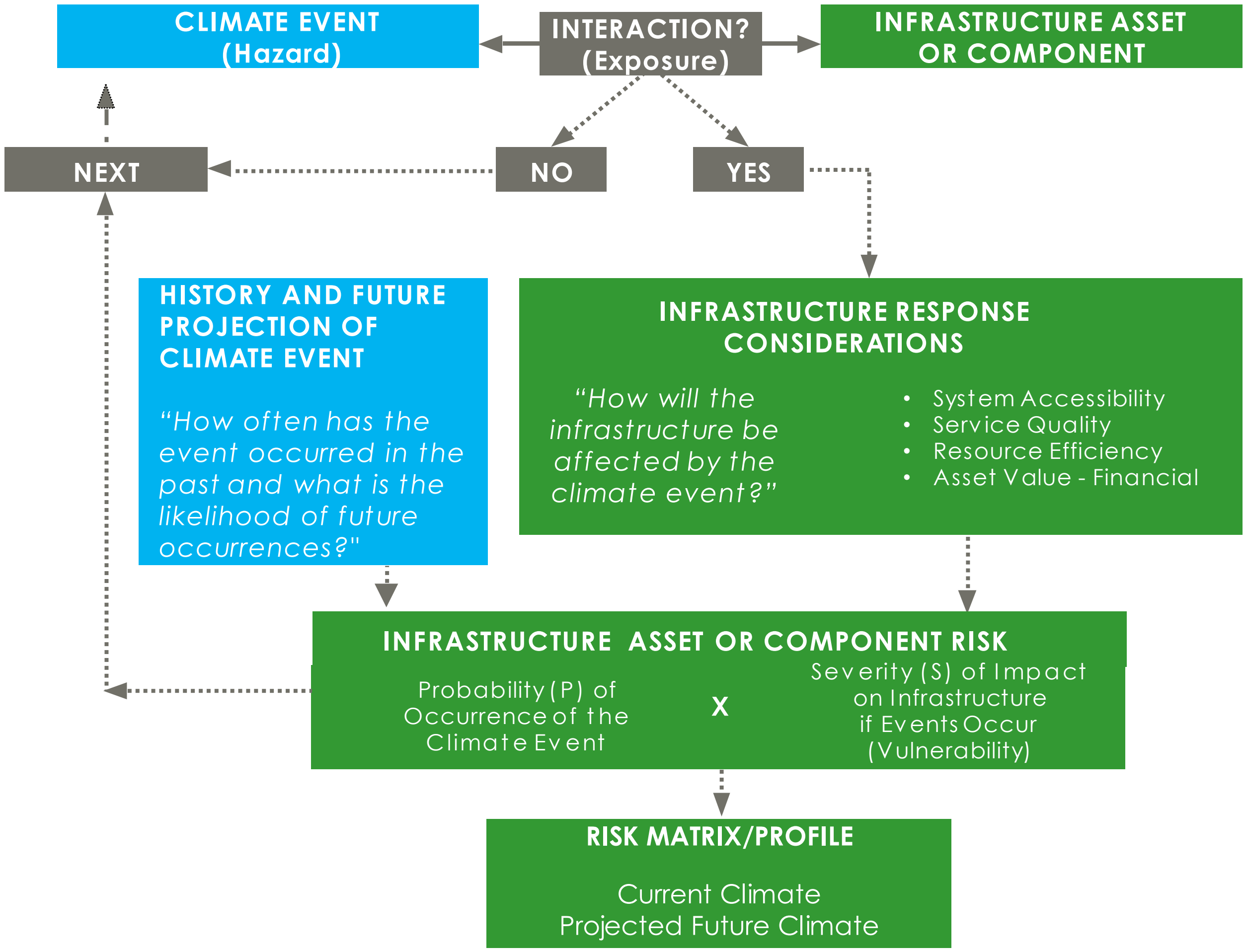
The procedures used to perform this analysis, and the associated analytical results, are detailed in the report. Climate analyses in this study use projections for the “business-as-usual” Representative Concentration Pathway emissions scenario – RCP8.5 – and for the 2050s (2041-2070).

The climate parameters retained by the project team for this risk assessment and the projected future climate changes are presented in the table below.

Climate Parameter	Projected Climatic Changes by Mid-Century
Temperature – Extreme Heat	• Increased frequency and intensity • Increased frequency and length of heat waves
Temperature – Extreme Cold	• Decreased frequency and intensity • Occurrence of extreme cold outbreaks (“Polar Vortex” winters) likely to continue
Rain (Short Intensity – High Duration)	• Increased intensity of events • Reduced return periods (e.g. 20-yr return period event becoming a 10-yr return period event)
Freezing Rain & Ice Storms	• Increased frequency • Increased winter season (e.g. January) events
Snow	• Likely decrease in annual total accumulation • Continued occurrence and steady frequency of larger individual events

Climate Parameter	Projected Climatic Changes by Mid-Century
High Winds	• Slight increase in frequency of high wind events (e.g. 90 km/hr; 120 km/hr)
Lightning	• Increased frequency (by about 12% per degree Celsius of warming) • Increased length of the higher frequency lightning season
Tornadoes	• Increased frequency (25% increase by mid-century) • Increase (near 2x) in number of severe thunderstorm days by mid-century (capable of possibly producing tornadoes, hail, extreme winds, and extreme rainfall events)
Fog	• Likely increase
Frost (Freeze-Thaw Cycles)	• Decrease in annual total number of freeze-thaw days • Increase in monthly totals in the shoulder seasons (e.g. November and March)

The risk assessment followed the process illustrated next page.



In current climate conditions, very high risks were identified to power distribution lines and poles under extreme (> 120 km/h) wind conditions; these risks remain very high in future projected climate. Projected changes to climate in the Hydro Ottawa service area, under the RCP 8.5 GHG emissions scenario, are expected to increase risks to very high as follows:

- Daily maximum temperatures of 40°C or higher are expected to occur annually, impacting field staff; and,
- Freezing rain storms resulting in 40mm or more of ice accumulation are projected to occur more frequently in a 30-year period, resulting potentially in damage to a wide range of Hydro Ottawa's assets, disruptions in service, and impacts on staff.

The report also provides the forensic analysis of three high-impact severe weather events as part of the overall scope of the PIEVC assessment. The forensic assessment was conducted by combining information on both infrastructure impacts and meteorological data, with the intent of establishing the following: event timelines (understanding the progression of events leading up to, during, and immediately following major outage events; meteorological/climate diagnosis (determine the type, extent, and severity of weather/climate event responsible for outages); and develop adaptation recommendations (determine actions that can be taken to assist in the preparation and response to similar events in the future - discussed in the Adaptation report under separate cover).

- April 15-16, 2018 – ice and wind storm: A combined wind and ice storm resulted in a total of 73,797 customers losing power during this event. Ottawa airport reported a total of 16 hours of freezing precipitation between noon EDT on April 15th and 10 AM EDT April 16th. The freezing rain and drizzle resulted in ice accumulations on overhead electrical infrastructure and adjacent vegetation exceeding 10 mm in total thickness, which was accompanied by strong winds gusting to 67 km/h on April 15 and 74 km/h on April 16. Total estimated ice accumulations by midnight on April 15th were likely around 10 mm, resulting in a small number of scattered power outages. However, between 7 AM and 2 PM on April 16th, the total number of outages increased from approximately 4,000 customers to over 43,000 customers.
- May 4, 2018 – wind storm: An intense low-pressure system tracked across a large portion of southern Ontario through to southern Quebec and adjacent areas of the United States, resulting in power outages for approximately 45,000 Hydro Ottawa customers. Damage reports, mainly consisting of large branches and individual trees being uprooted, were first confirmed in eastern Michigan in the Detroit area at 1:09 PM EDT. As the storm moved across southern Ontario, wind gusts approaching or exceeding 120 km/h were recorded at several locations. Widespread wind damage was reported across the Kitchener-Waterloo and Golden Horseshoe regions beginning after 3 pm EDT, including three fatalities attributed to the storm, as well as damage consisting of large branches and/or large trees snapped or uprooted, shingles and portions of roofs removed from homes and commercial buildings, and tens of thousands of electrical distribution customers in multiple jurisdictions losing power.
- September 21, 2018 – tornado outbreak: The September 21, 2018 tornado outbreak consisted of at least 7 separate tornadoes, with Hydro Ottawa's service area suffering impacts from the two strongest confirmed tornadoes within the outbreak, the long-tracked Kinburn-Dunrobin-Gatineau tornado, rated EF-3 on the 0 to 5 EF-scale of tornado intensity, and the Nepean-South Ottawa tornado, rated EF-2. The Kinburn-Dunrobin-Gatineau tornado formed at approximately 4:32 PM EDT, tracking roughly northeast until crossing the Ottawa River at approximately 4:52 PM EDT. Approximately one hour later, at 5:51 PM EDT, the Nepean tornado formed in association with a second line of storms. This tornado impacted the Merivale Transmission Station (TS) at almost exactly 6:00 PM EDT, resulting in a significant proportion of outages triggered in this event, and dissipated shortly after at approximately 6:09 PM EDT. All damage associated with these tornadoes, resulting in over 174,000 customers being affected, occurred in a time span of approximately 38 minutes.

Abbreviations

AMP	Asset Management Plan
AMRP	Asset Management Risk Procedure
CRMS	Corporate Risk Management System
CRVA	Climate Risk and Vulnerability Assessment
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
O&M	Operations and Maintenance
PIEVC	Public Infrastructure Engineering Vulnerability Committee
TGICA	IPCC Task Group on Data and Scenario Support for Impact and Climate Analysis
UWO	University of Western Ontario

1.0 INTRODUCTION

Over 330,000 residences and businesses in the City of Ottawa and the Village of Casselman depend on Hydro Ottawa Limited (Hydro Ottawa) to supply continuous and reliable electrical services. In recent years, notably in 2018, Hydro Ottawa distribution infrastructure has been subjected to particularly extreme weather events that caused severe damages to its electricity distribution system. These events resulted in widespread outages and costly recoveries. In an effort to secure reliable service in the coming years, Hydro Ottawa retained Stantec Consulting Ltd. to conduct a climate risk and vulnerability assessment (CRVA) and provide recommendations for risk mitigation and adaptation within their operation, design, and business functions to help protect their infrastructure, service delivery and occupational health and safety. This assessment generally follows the guidelines set in the Canadian Electricity Association's guide "Adapting to Climate Change, A Risk Management Guide for Utilities" and identifies climate-related risks that exposed infrastructure is expected to face moving forward. Hydro Ottawa also had a particular interest in assessing three significant weather events that occurred in 2018, including a freezing rain event in April, a heavy wind event in May, and a series of tornados that touched down in September in the Ottawa region.

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- Workshop with Hydro Ottawa staff to validate assumptions related to their system and to assist in the completion of the risk assessment by identifying the level of impact on an asset should the climate event unfold, creating the climate risk profile; and,
- Preparation of a climate risk and vulnerability assessment report.

This study considers the entire geographic extent of the Hydro Ottawa's service area which includes a vast portion of the City of Ottawa and the Village of Casselman, and includes both aboveground and underground electrical distribution assets. Hydro Ottawa's service territory is shown graphically in Figure 1.

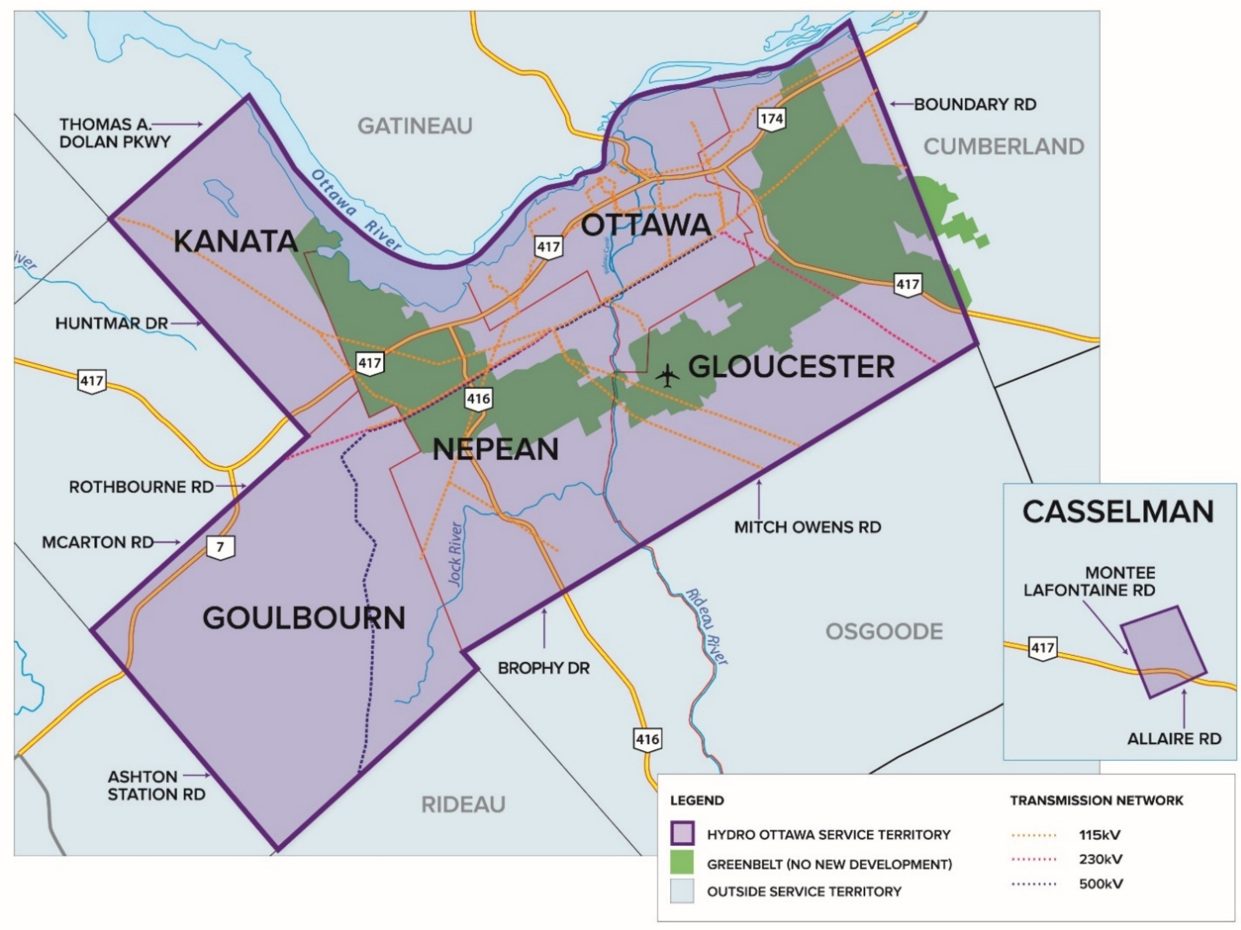

Figure 1 Map of Hydro Ottawa Service Territory[1]

[1] Hydro Ottawa. 2018. <https://hydroottawa.com/about/governance/overview>

2.0 METHODOLOGY

This section outlines the methodology used to complete the climate risk and vulnerability assessment.

2.1 GENERAL

The CRVA evaluates the future climate impacts on Hydro Ottawa's electrical distribution system and supporting infrastructure and identifies the potential risks associated with future changes in climate and extreme weather events. The assessment identifies risks to the infrastructure, buildings or facilities due to extreme weather and climate uncertainty based on current climate and future climate projections in the region. Extreme weather events include, but are not limited to high wind events, freezing rain, temperature and precipitation extremes, as well as complex events (i.e. climate events that are driven by the interaction of multiple climate parameters).

The CRVA uses Engineers Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol – an assessment methodology that conforms to the International Organization for Standardization (ISO) 31000:2018 Risk Management Standard, to identify relevant climate parameters and infrastructure responses, set up the risk evaluation worksheet, and assign risk ratings to each response to relevant climate considerations. This assessment is compatible with Hydro Ottawa's Asset Management Risk Procedure (AMRP), the details of which are illustrated in **Figure 2.**

Risks / Opportunities			Impact				
	Health, Safety & Environment	Safety	Should the main risk or opportunity be classified as a Safety risk, PRO-MS-001.04 shall be evaluated through notifying the Manager, Occupational and Public Safety				
	Health, Safety & Environment	Environment	Should the main risk or opportunity be classified as an Environmental risk, PRO-MS-001.04 shall be evaluated through notifying the Manager, Environment and OHSE Management System				
	Compliance	Compliance	N/A	Noncompliant with corporate regulation/policy	Noncompliant with municipal regulation	N/A	Noncompliant with federal/provincial regulation
	Levels of Service	System Accessibility	N/A	N/A	Load demand is exceeding planning limits	Load demand is exceeding thermal limits	Unable to service new load
	Levels of Service	System Accessibility	N/A	N/A	Generation is exceeding planning limits	Generation is exceeding thermal limits	Unable to service new ERFs
	Levels of Service	Service Quality	Service interruption resulting in <10,000 customer minutes interrupted	Service interruption resulting in >10,000 customer minutes interrupted	Service interruption resulting in >500,000 customer minutes interrupted	Service interruption resulting in >3,000,000 customer minutes interrupted	Service interruption resulting in >10,000,000 customer minutes interrupted
	Levels of Service	Service Quality	Service quality resulting in customer complaint, but meets CSA standards	Service quality resulting in customer escalation, but meets CSA standards	N/A	N/A	Service quality resulting in not meeting CSA standards
	Resource Efficiency	Resource	Requires <10 hours of overtime to complete O&M work or undergo training	Requires >10 hours of overtime to complete O&M work or undergo training	Requires >250 hours of overtime to complete O&M work or undergo training	Requires >1,500 hours of overtime to complete O&M work or undergo training	Unable to complete work with internal and/or external resources due to volume or skill gap
	Resource Efficiency	Resource	Requires <100 hours of overtime to complete capital work	Requires >100 hours of overtime to complete capital work	Requires >2,500 hours of overtime to complete capital work	Requires >15,000 hours of overtime to complete capital work	
	Asset Value	Financial	Financial risk resulting in an O&M expense of <$1k	Financial risk resulting in an O&M expense of >$1k	Financial risk resulting in an O&M expense of >$50k	Financial risk resulting in an O&M expense of >$300k	Financial risk resulting in an O&M expense of >$1M
	Asset Value	Financial	Financial risk resulting in a capital expense of <$10k	Financial risk resulting in a capital expense of >$10k	Financial risk resulting in a capital expense of >$500k	Financial risk resulting in a capital expense of >$3M	Financial risk resulting in a capital expense of >$10M
	Corporate Citizenship	Corporate Brand	N/A	Negative publication on social media (remains local)	Negative publications at a municipality level	Negative publications at a provincial level	Negative publications at a national level
	Corporate Citizenship	Corporate Brand	N/A	Negative customer satisfaction survey results, while above comparators	Negative customer satisfaction survey results, while below comparators	N/A	N/A
			1	4	9	16	25
			Insignificant	Minor	Moderate	Extensive	Significant

Likelihood	Probability			Insignificant	Minor	Moderate	Extensive	Significant
	(May occur only in exceptional circumstances)	1	Rare	0	0	0	0	0
	>5% (Could occur)	2	Unlikely	2	8	18	32	50
	>35% (Might occur)	3	Possible	3	12	27	48	75
	>65% (Will probably occur)	4	Likely	4	16	36	64	100
	>95% (Is expected to occur)	5	Almost Certain	5	20	45	80	125

Figure 2 Hydro Ottawa Asset Management Risk Procedure Matrix

A description of the PIEVC Protocol and discussions regarding the timescale of assessment and jurisdictional considerations are provided in the following subsections.

2.1.1 The PIEVC Protocol

The PIEVC Protocol ("Protocol") is a risk assessment tool developed by Engineers Canada in 2008 and has since been applied to over 70 vulnerability risk assessments both within Canada and internationally. This risk assessment process involves the systematic review of historical climate information and the projection of the nature, severity and probability of future climate changes and events. This assessment of climatic changes is completed alongside an exposure assessment of infrastructure systems to these climate variables to determine whether or not there is an interaction between the climate event and the infrastructure components (Figure 3**)**. The consequence of a particular damaging or disruptive climate event is then quantified by a severity score which ultimately informs the risk rating for a particular climate-infrastructure interaction. This process is reiterated for all applicable infrastructure elements to produce the full risk profile. Adaptation recommendations are then proposed to mitigate the consequence of the risk. Furthermore, this process is extended to the future climate in order to see how the risk profile has changed with climate change. The Protocol is depicted as a flow chart in Figure 4; version VA 10.1 of June 2016 was used for this assessment.

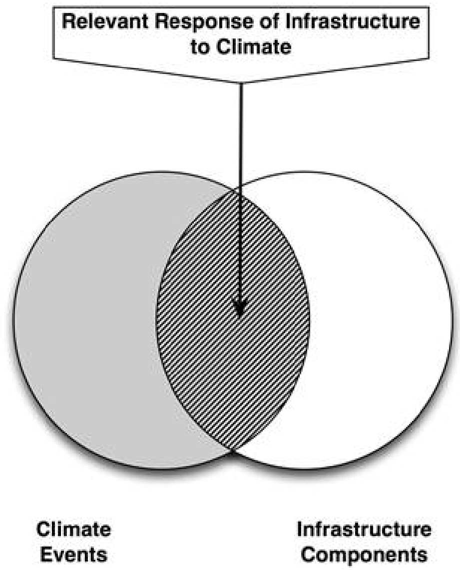

Figure 3 Diagram representing the interaction between climate events and infrastructure components

This CRVA did not include the optional Step 4 – Engineering Analysis of the PIEVC Protocol (this step is recommended when the team needs a more in-depth analysis of the particular infrastructure-climate interaction where the team feels additional climate or engineering data is needed). The use of the Triple Bottom Line module was not part of this assignment, although risk mitigation and adaptation measures were developed and provided in a separate report.

The methodology of the Protocol includes five key steps to ensure the assessment is consistent and rigorous. The five key steps are:

1. Project Definition;
2. Data Gathering and Sufficiency;
3. Risk Assessment;
4. Engineering Analysis (optional as necessity and resources permit); and,
5. Recommendations and Conclusions.

The risk assessment identifies notable risks within Hydro Ottawa's infrastructure system. 'Moderate', 'High', and 'Very High' risks are used to represent the distribution system's risk profile. Risk mitigation and adaptation measures are recommended under a separate report for those risks identified to pose a significant threat to Hydro Ottawa's operations and service provision.

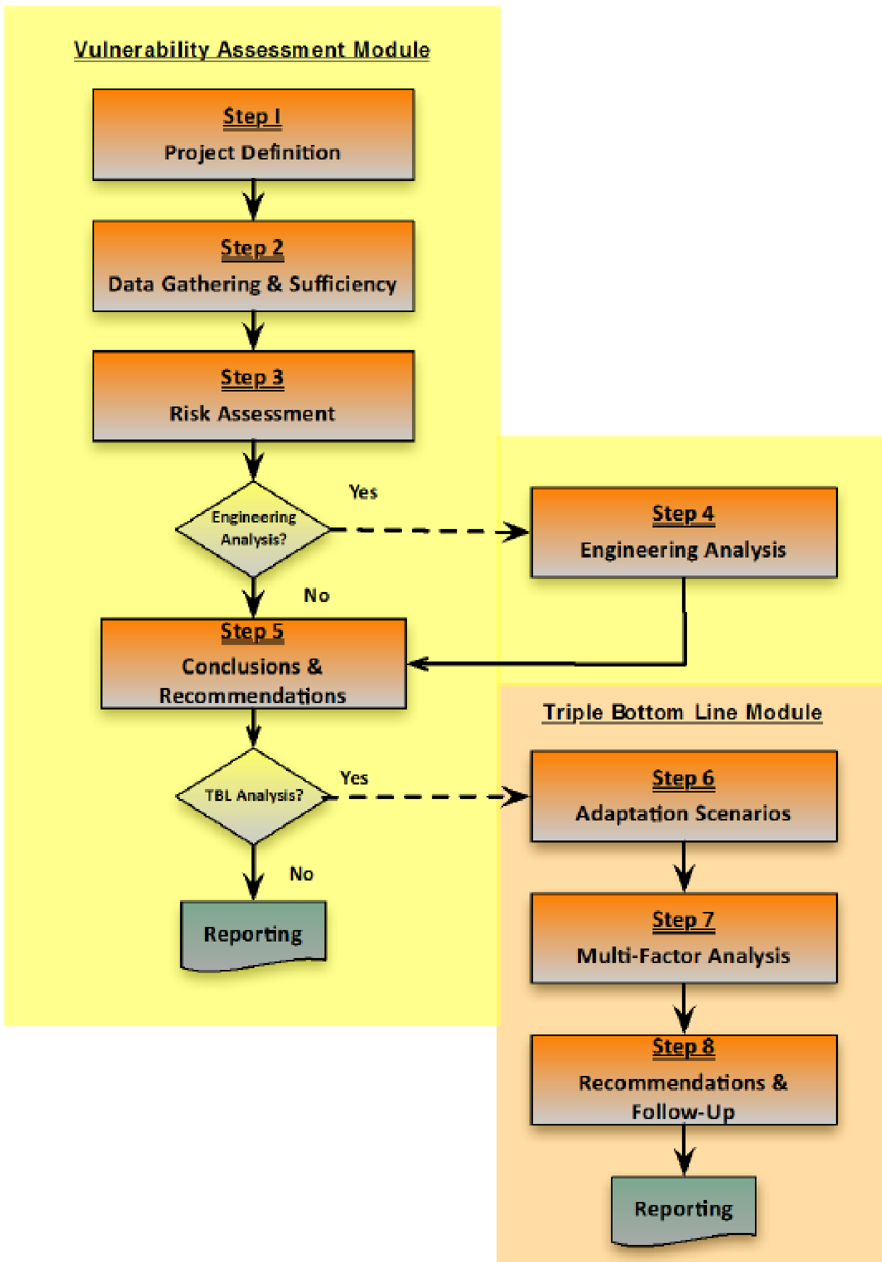

Figure 4 Flow Chart Illustrating the PIEVC Protocol Process

2.1.2 Time Horizon

In addition to the current climate baseline (1981 to 2010), climate projections were produced for the 2020s (2011 to 2040), 2050s (2041 to 2070) and to 2080s (2071 to 2100) time horizons. For this assessment, based on the life-cycle of assets considered, future climate risks are evaluated for the 2050s time horizon.

2.2 PROJECT TEAM

A number of key experts played a role in this project, including risk, resilience, and adaptation expertise from Stantec and climatology expertise from Risk Sciences International (RSI). A list of the project team who contributed to this work is provided in Table 1.

Table 1 Summary of Project Team Members Who Contributed to This Work

Team Member	Role
Matthew McGrath	Hydro Ottawa, Project Manager
Greg Bell	Hydro Ottawa, Manager, Distribution Operations (Underground)
Ed Donkersteeg	Hydro Ottawa, Supervisor - Standards
Ben Hazlett	Hydro Ottawa, Manager, Distribution Policies and Standards
Nicole Flanagan	Stantec, Project Manager
Guy Félio	Stantec, Climate Change Resilience Advisor
Daniel Hegg	Stantec, Climate Change Adaptation Advisor
Riley Morris	Stantec, Environmental Engineer
Eric Lafleur, P.Eng.	Stantec, Senior Electrical Engineer
Heather Auld	RSI, Climatologist
Norman Shippee	RSI, Climatologist
Simon Eng	RSI, Climate Analyst
Katherine Pingree-Shippee	RSI, Climatologist

A list of interview participants is provided in Table 6 under **Section 5.1**.

2.3 SCHEDULE

This CRVA is part one of two components to a larger study, the second component being an assessment of risk mitigation and adaptation recommendations. The CRVA (part one) took place within a 5-month timeframe which generally followed the timeline presented in Table 2.

Table 2 Generalized Risk Assessment Schedule

Project Tasks	Timeframe
Project Initiation	January 2019
Document review, data collection and initial analysis	January-March 2019
Interviews with Hydro Ottawa Stakeholders	March 2019
Risk assessment and analysis	March-May 2019
Risk assessment workshop with Hydro Ottawa Stakeholders	April 2019
Risk assessment review and report production	April-May 2019

2.4 LIMITATIONS

This climate risk and vulnerability assessment was completed using the best information available to the assessment team at the time of the study. The focus of the assessment presented in this report is on the existing electrical distribution system within the service territory of Hydro Ottawa, including areas within the City of Ottawa and the Village of Casselman. Due to the scale of Hydro Ottawa's infrastructure system and the complexity of third-party interactions, this assessment represents a relatively high-level assessment of climate-related risks to Hydro Ottawa infrastructure where asset systems are grouped by function, impact and/or region.

The climate data and trends (current and future projections) used in this study were obtained through various sources (as described in **Section 4.1.1**) and analyses were carried out by Risk Sciences International's climatology services. Cross-verification between climate information sources was conducted where possible to identify possible discrepancies between the data sources used.

Information regarding past system outages was provided by Hydro Ottawa and the identification of impacting historical weather and/or climate-related events was gathered and validated during interviews and a workshop with Hydro Ottawa stakeholders. Stantec did not conduct inspections or review incident reports to validate this information.

3.0 INFRASTRUCTURE

This section outlines Hydro Ottawa's infrastructure, assets and third-party interactions that all work together and are the key elements to the company's success as a growing service provider.

3.1 GENERAL

Hydro Ottawa's electrical infrastructure is utilized to safely and reliably support the transformation and delivery of electricity to customers throughout the service territory which includes the Ottawa region and the village of Casselman. The services provided are an essential element to local residence, businesses and organizations that rely on the electricity for improved quality of life and economic growth.

The infrastructures relied upon to deliver these services are comprised of substations, communication systems, the smart grid (e.g., telemetry, sensors, SCADA, internet), metering, third party services, overhead and buried power distribution as well as the service personnel who maintain and upgrade the system components on a regular basis. These assets are the backbone of Hydro Ottawa and are the focus of this study in order to determine the effects of climate on the infrastructure.

Another vital part of the infrastructure are the administrative buildings (including the System Office that provides real time management of the distribution system) that are operated by Hydro Ottawa which are utilized for office and field personnel alike. These buildings are mainly utilized for administrative tasks such as client management, planning, detailed design and dispatching field personnel as required. It is vital to the success of the overall operations at Hydro Ottawa. As part of their distribution infrastructure, Hydro Ottawa also has operational buildings which are mainly located within their substations. These buildings are utilized to house switchgear, controls, batteries, and other essential elements to ensure the safe and reliable power distribution to their clients.

3.1.1 Sources of Information

In order to determine all the components and outline each individual asset at Hydro Ottawa's disposal, Stantec reviewed their Asset Management System Risk Procedure as well as the individual Asset Management Plans (AMP) for each asset.

3.1.2 Shared Assets and Third-Party Interactions

It is understood that shared assets and third-party interactions are required in order for Hydro Ottawa to be successful and continue to service their clients. In order to better understand each of them, please find below a small description on how they directly impact Hydro's infrastructure:

1. Hydro One: provides main incoming power supply to Hydro Ottawa's substations in various locations which include shared infrastructure and termination points;
2. The City of Ottawa and the village of Casselman: provides a drainage system through the city to limit rising water levels in hydro infrastructure as well as ensure proper road maintenance throughout all seasons;
3. Telecommunications Companies: provide telephone and fibre optic lines to various assets in order to allow communication from remote site; and,
4. Fuel Suppliers: allows for backup generators and fuel driven equipment to remain functional during normal operations and power outings.

3.2 INFRASTRUCTURE ELEMENTS

Table 3 below presents a list of infrastructure elements that were reviewed during the risk assessment as part of the information provided by Hydro Ottawa. Note that this list is a collapsed version to show the main pieces of equipment and not their individual components.

Table 3 List of Main Infrastructure Elements Considered in This Study

City of Ottawa	Village of Casselman
Buildings	**Substations**
Administrative and Operational Buildings	Buildings and Structural Components
Substation Buildings	P&C Buildings
Substations	Station Capacitor Voltage Transformers
Buildings and Structural Components	Station Circuit Breakers
Station Load Break Switch	Indoor Breakers
Station Capacitor Voltage Transformers	Core, Windings, Oil
Station Circuit Breakers	Station Metering
Station Power Transformers	Microprocessor Relays
Station Metering	Bar Conductors, Connections, Whips to Equipment
Station P&C Cabinets and Batteries (non-A/C spaces)	**Power Distribution - Overhead (East-West Orientation)**
Station Grounding and Ground Grid	Distribution Lines
Station Miscellaneous Equipment	Poles
Service and Personnel	Overhead Transformer
Service Vehicles	Overhead Load Breaker Switch
Service Equipment	Ground Connection
Staff and Occupational Health and Safety	Surge Arrestors
Communications, Smart Grid and Metering	Fused Cut Out
Hydro fiber	**Power Distribution - Overhead (North-South Orientation)**
Residential Metering	Distribution Lines

City of Ottawa	Village of Casselman
Third Party Services and Interactions	Poles
Hydro One	Overhead Transformer
City of Ottawa	Overhead Load Breaker Switch
Telecommunications	Ground Connection
Fuel Supply	Surge Arrestors
Hydro Ottawa Subsidiaries	Fused Cut Out
Emergency Resources	**Power Distribution - Underground**
Old Subdivisions, Rural and Transmission	Civil Structures
Power Distribution - Overhead (East-West Orientation)	Underground Cables
Distribution Lines	Underground Primary Switchgear
Poles	Underground Transformers
Overhead Transformer	**Power Distribution - Vaults**
Ground Connection	Vault Transformers (Located in Third Party Buildings)
Surge Arrestors	
Fused Cut Out	
Power Distribution - Overhead (North-South Orientation)	
Distribution Lines	
Poles	
Overhead Transformer	
Ground Connection	
Surge Arrestors	
Fused Cut Out	
Power Distribution - Vaults	
Vault Transformers (Located in Third Party Buildings)	
New Subdivisions	
Power Distribution - Underground	
Civil Structures	
Underground Cables	
Underground Primary Switchgear	
Underground Transformers	
Power Distribution - Vaults	
Vault Transformers (Located in Third Party Buildings)	

4.0 CLIMATE

This section will discuss the general climate profile for both current and future conditions within the Hydro Ottawa service territory and will describe climate parameters that will be considered in the risk assessment. Furthermore, a forensic evaluation of significant weather events from 2018 is provided at the end of this section. These items are discussed in more detail in the Climate Change Hazards Report, provided as **Appendix A** and is summarized, in part, in the following subsections.

4.1 GENERAL

Changes in climate translate into direct and indirect impacts to municipal services, critical public infrastructure, spaces and assets/facilities, and community networks. Climate risks and hazards can be associated with two types of climate or weather events analogous to “shock” vs. “stress”: (1) rare, extreme and rapid/sudden-onset extremes or “shock events” and (2) slow onset or “creeping” threats or “stress events”. Extreme events are factored into building codes and practices through the use of extreme value or return period climate probabilities. Alternatively, many of the slow onset or recurring climate events that can be expected to occur several times annually are important when maintaining the service life and durability of structures and are sometimes included in standards. Studies indicate that damages to infrastructure from extreme events tend to increase dramatically above critical climate thresholds, even though the extreme weather events associated with these damages may not be much more severe than the type of storm intensity that occurs regularly each year (Freeman and Warner, 2001; Coleman, 2003; Auld and MacIver, 2007; Auld, 2008). For instance, analyses of insurance loss data and other impact information, together with detailed analyses of extreme winds, indicate that losses to buildings in Southern Ontario are likely highly sensitive to increasing extreme wind speeds above threshold values. A detailed analysis of building damages and insurance claims within the City of Toronto and other Ontario municipalities indicate that damages and losses to buildings begin to increase significantly (nearly exponentially) when wind gusts exceed 90 km/hr (Auld, 2008).

Impacts of climate change on assets can include structural damage, the reduced service life of assets and their components, and increased stress to systems and operations. These impacts can, for example, result in higher repair and maintenance costs, loss of asset value, and interruption of services.

The development of climate data for this climate vulnerability risk assessment of Hydro Ottawa’s distribution system involved three main activities:

- Identify climate parameters (e.g. temperature, precipitation, winds) and threshold values at which infrastructure performance would be affected (i.e. climate hazards);
- Project the probability of occurrence of climate hazards for future climate (i.e. 2050s); and,
- Convert projected probability of occurrence of future climate parameters into the five-point scoring scale used in Hydro Ottawa’s Asset Management System Risk Procedures.

following subsections, following an overview of the local climate of the Greater Ottawa Region. Additionally, forensic analyses of three high impact events in that impacted the Hydro Ottawa distribution system in 2018 are provided.

4.1.1 Sources of Information

Climate analyses in this study use projections for the "business-as-usual" Representative Concentration Pathway emissions scenario – RCP8.5 – and for the 2050s (2041-2700). Current greenhouse gas concentrations correspond to the RCP8.5 projected trajectory (Figure 5).

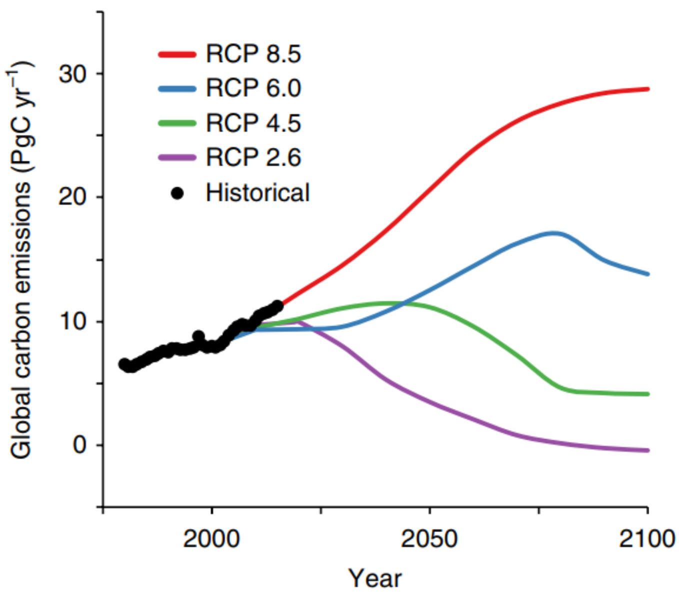

Figure 5 Historical CO_2 emissions for 1980-2017 and projected emissions trajectories until 2100 for the four Representative Concentration Pathway (RCP) scenarios. Current global emission trends have very closely followed the "business-as-usual" RCP8.5 scenario trajectory. Figure from Smith and Myers, 2018.

In this study, the "Delta Approach" is used to generate localized climate change projections (IPCC-TGICA, 2007). The Delta Approach method is one of the simplest and most straightforward approaches available for obtaining downscaled projections of future climate conditions. This approach consists in applying the average projected difference (the "delta") for a given climate parameter to the historical average or baseline value. The Delta Approach generally provides more useful data when it is coupled with the use of many models (ensembles; e.g. CMIP5 GCMs) to generate projections than when coupled with a single or small set of models, regardless of model spatial and temporal resolution. A detailed description of the Delta Approach and how it is used in this assessment is provided in **Appendix A**.

4.1.1.1 Specialized Studies

Some climate parameters are not well handled by climate modeling at any temporal or spatial resolution (e.g. severe and complex events such as ice storms and tornadoes). For these climate parameters, scientific literature is reviewed for any available guidance on the direction and magnitude of potential changes in these complex variables under a changing climate. The challenges posed in understanding future changes in complex events requires the application of detailed and time-consuming techniques to better reflect the scale and complexity of these hazards, and to increase confidence in analytical results. In these cases, projections were derived from applicable specialized studies available in the published literature, such as research addressing local changes in ice storm activity (Cheng et al., 2011) or high winds in the form of damaging wind gusts (Cheng et al, 2012; Cheng 2014).

In other cases, location-specific studies may not be available, but research into the potential effects of climate change on specific hazards can still provide guidance on future changes which can be applied to the study location. For example, ongoing research is refining our understanding of the links between air temperature and rainfall rates (Westra et al., 2014; Barbero et al., 2017), results of which can be used to develop tailored projections for the Greater Ottawa Region. Recent research on trends in tornado activity in the United States (Strader et al., 2017; Gensini and Brooks, 2018) also indicates both recent and future shifts in tornado occurrence which are potentially relevant to the Greater Ottawa Region and surrounding areas. These and other studies are an ongoing area of active investigation and RSI provides insight into these types of phenomena to the best of its ability. Climate hazards where specialized studies are applied in the calculation of future climate projections are identified within each section, and references to literature and studies are provided within the references section of the report.

4.1.1.2 Climate Analogue

Climate projections can also be used to identify a “climate analogue” for the Greater Ottawa Region. Climate analogues are simply geographical locations that currently exhibit average climate conditions that are similar to those projected for future time periods in the location of interest. Ideally, climate analogues currently have the same annual average temperature and precipitation values as the future projected climate for the Greater Ottawa Region, and also exhibit similar elevation and topography and exposure to atmospheric circulation patterns (e.g. lake and ocean influences). This method can inform the assessment in many ways, including evaluation of potential viable adaptation options which may be already in place at analogue locations (Ramírez-Villegas et al., 2011). In general, climate analogues can provide potential clues regarding new or emerging hazards which have not yet been experienced in the study location, offering a window into impacts and needed adaptation actions that could reasonably be anticipated under future conditions. They can also provide useful insights into hazards that are not well handled by climate modeling alone, especially when location and hazard specific studies are not readily available in the literature. For this study, a climate analogue location of Pittsburgh, Pennsylvania was identified for the Greater Ottawa Region. Pittsburgh, PA corresponds to the projected future annual average temperatures expected in the Greater Ottawa Region in the 2050s under the RCP8.5 scenario and has roughly similar city and elevation characteristics to those of Ottawa. This climate analogue provides general, “order of magnitude” comparisons which help further determine if climate change projections are in fact realistic and represent potentially “real” climates.

4.1.1.3 Professional Judgment

"Perfect" or "ideal" information and data for given hazard usually do not exist, and assessments always require the application of professional judgement from interdisciplinary teams to make use of the data and information available. While sometimes referred to as a source of risk assessment information, professional judgement is better characterized as the process applied to the best available information; i.e., how is all available information weighted, interpreted, and applied within the assessment using the expertise of assessment team members. The PIEVC Protocol, for example, states that "Professional Judgment is the interpretation and synthesis of data, facts and observations collected by the team and the extrapolation of that analysis to provide a judgment of how the infrastructure may respond to a specific set of conditions." (Engineers Canada, 2016). Within the context of an assessment, this refers to the use of professional judgement to interpret and apply what is often incomplete – but still the best available – data and information. The discussion and decision-making process surrounding the application of professional judgement is also documented in detail for the purposes of traceability, so that future review and application of any analytical results can be understood within the proper context.

4.1.2 Climate Parameters

The climate parameters and thresholds established for analysis in this study were assembled and analyzed through a combination of the following:

- Climatic design values in engineering codes and standards;
- Practitioner experience (especially in managing past impacts and risks);
- Literature review;
- Forensic investigation of past events; and,
- Stantec interviews with Hydro Ottawa personnel.

In some cases, multiple thresholds were developed for the same parameter, either because multiple thresholds held some significance for one or more of the assets in the Hydro Ottawa electrical distribution system, or because the threshold was different for each asset. Climate parameters and thresholds were then verified and refined, as needed, based on the experience and knowledge of Hydro Ottawa personnel at the 12 April 2019 workshop.

Identified climate hazards relevant to Hydro Ottawa's electrical distribution system are outlined below in Table 4, ranging from short duration and sudden onset weather events (e.g. tornadoes) to gradual onset climate events (e.g. gradually increasing temperature extremes). Performance considerations and selection rationale are also outlined below.

Table 4 List of Climate Parameters Considered in this Study

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Temperature			
Extreme Heat	$T_{max} \geq 30°C$	Level of Service – High heat days; danger to workers on site Resource Efficiency – Higher demand on grid for cooling; reduced time for cooling of electrical components	Tmax ≥ 30°C identified as a personnel issue (associated with physical exertion and risk of heat exhaustion); Tmax of 40°C used as a design value; Higher temperature thresholds lead to extra loading on the system from increased commercial and residential air conditioner use; Thermal stress can result in cracking and fissuring in materials (e.g. polymer-based materials).
	$T_{max} \geq 35°C$		
	$T_{max} \geq 40°C$	Asset Value – High temperature operating threshold	
	$T_{mean} \geq 30°C$	Level of Service – High heat days; danger to workers on site Resource Efficiency – Higher demand on grid; reduced time for cooling of electrical components	
Heat Waves	Consecutive Days with $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$	Level of Service – Consecutive high heat days; danger to workers on site Resource Efficiency – Prolonged and (very) high demand (near capacity) on grid for cooling (nights not cooling); reduced time for cooling of electrical components	System overloading common after 3 days of consecutive heat due to high demands on electrical grid (e.g. transformers) by increased air conditioning use; Equipment unable to cool properly reducing functionality.
	Consecutive Days with $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$		
Extreme Cold	$T_{min} \leq -35°C$	Level of Service – Extreme cold days; danger to workers on site Resource Efficiency – Higher demand on grid for heating Asset Value – Approaching low temperature operating threshold	Identified as a personnel issue; Older sections of Ottawa may experience overcapacity due to extensive use of electric baseboard heating; Tmin of -40°C used as a design value; Extreme cold can result in underperformance of vehicles and outdoor infrastructure.
Rain			
Extreme Rain	50 mm in 1 hour	Level of Service – Localized flooding; flooding of low-lying areas and subterranean infrastructure (e.g. underground vaults) possible	Design threshold; Hydro Ottawa personnel have indicated extreme rainfall has not significantly impacts on Hydro Ottawa infrastructure, although low-lying equipment, such as vaults, may be more vulnerable (particularly in older neighbourhoods); Extreme rain can result in reduced accessibility to assets (e.g. flooded roadways).

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Freezing Rain & Ice Storms			
Ice Accumulation	25 mm	Level of Service, Resource Efficiency – Local to regional power outages	Design threshold is 25 mm (corresponding to 12.5 mm of radial ice accretion on overhead lines); Most common damage to infrastructure related to ice accretion and accumulation on tree branches and resulting breaks; Combined ice accretion and wind is a concern.
	40+ mm	Asset Value, Level of Service, Resource Efficiency – Major and widespread outages possible; prolonged events	
Snow			
Snow Accumulation	Days with ≥ 5 cm	Level of Service – Snow clearing begins, could impact poles/infrastructure; salt use	Equipment issues mostly related to snow plow damage (transformer pads, transformers, and switchgear all potentially impacted); Issues with access to assets.
	Days with ≥ 10 cm	Level of Service – Snow clearing, could impact poles/infrastructure; salt use; access issues	
	Days with ≥ 30 cm	Level of Service – Snow clearing, could impact poles/infrastructure; salt use; access to lines and vaults; requires extra clearing	
High Winds			
Seasonal	60+ km/hr gust (Summer)	Level of Service – Lower wind speeds required to cause issues when trees have foliage; easterly winds are of particular concern	Hydro Ottawa personnel have noted wind intensity and frequency has increased in recent years; North-south power lines identified as vulnerable, particularly to prevailing winds; Potential damage to infrastructure due to tree and limb falls and wind-swept debris and reduced access due to debris deposits
	80+ km/hr gust (Winter)	Level of Service – Higher wind speeds result in issues when trees are bare; easterly winds are of particular concern	
Annual	90+ km/hr gust	Asset Value – Design threshold (corresponds to wind pressure values)	
	120+ km/hr gust	Asset Value – Wider spread of damage; straight line wind gusts	

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Lightning			
Lightning	Strikes near infrastructure	Level of Service – health and safety risk Resource Efficiency – direct strike could result in damage and loss of functionality	Hydro Ottawa personnel have noted thunderstorm duration and frequency are increasing; Lightning strikes may blow transformers, breakers, fuses, and arrestors (1-2 instances per year noted); Lightning protection system design frequency of 1 flash/km^2/yr; Some substations have lightning rods.
Tornadoes			
Tornadoes	EF1+ in Hydro Ottawa service area (City of Ottawa) EF1+ point probability (i.e. tornado striking a specific asset, e.g. a substation, in the City of Ottawa service area)	Asset Value, Level of Service, Resource Efficiency – Significant damage and major outages possible; prolonged events	Rare, but severe impacts to Hydro Ottawa infrastructure (e.g. 2018 tornado outbreak – damage due to tree and limb falls and flying debris, direct hit of Merivale transmission station, disruption of transportation corridors impacted response efforts).
Invasive Species			
Emerald Ash Borer (EAB)	T_{min} ≤ -30°C	Asset Value – Damage to hydro poles and other vulnerable infrastructure	Hydro Ottawa personnel report increased damage to hydro poles by both EAB and the spike in woodpecker population following the introduction of EAB to the Greater Ottawa Region; EAB infestation makes trees vulnerable to breakage which can lead to damage to power lines; Tmin ≤ -30°C is the kill threshold for EAB mature, non-feeding larvae.
Giant Hogweed	3 Days T_{max} ≤ -8°C	Level of Service – Significant human health risk upon exposure	Upon contact, a severe occupational hazard for workers – sap can cause serious skin inflammation on contact, exposure to sunlight results in more serious reaction (e.g. blisters, discolouration, scars), contact with eyes can result in loss of vision, blindness, or damage; 3 days with Tmax ≤ -8°C required for germination of Giant Hogweed seeds.
Fog			
Fog	Days in Winter (Nov.-March)	Asset Value – Damage to hydro poles and other vulnerable infrastructure	Aerosolizing of salts can cause corrosion and moisture in winter; Salt spray on insulators and conductors can cause pole fires and flashovers.

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Frost			
Freeze-thaw Cycles	Daily T_{max} T_{min} temperature fluctuation around 0°C	Asset Value – Freeze-thaw cycles can result in weathering and damage to hard infrastructure (minimum of 30 cycles/year required to damage concrete) Level of Service – Freeze-thaw cycles can lead to icy conditions which become a health and safety concern	Hydro Ottawa personnel have noted more mid-winter events, resulting in more pole fires; Freezing moisture known to cause failure in underground cabling, has increased incidents of pole fires, and limits access by crews; Associated thermal stresses and frost weathering can result in cracking and fissuring in materials (e.g. polymer-based materials); Large temperature ranges in freeze-thaw cycles can result in increased weathering and damage.

4.2 CURRENT AND FUTURE CLIMATE PROFILE

As with the rest of globe, Canada, and Southern Ontario, the climate of the Greater Ottawa Region has been changing. Figure 6 presents the annual mean temperature in Ontario over the 1951-1980 and 1981-2010 periods. The change in mean annual temperature can be inferred from comparison of the plots (i.e. the difference in the coloration) with observed increases in temperature throughout the province, Southern Ontario, and in the Greater Ottawa Region. Using data collected at the Ottawa International Airport, observed annual daily mean, maximum, and minimum temperatures have risen over the 1981-2010 time period by 0.9°C, 1.0°C, and 0.8°C, respectively (**Figure 7** 1981-2010 Annual Mean, Maximum, and Minimum Temperature Data and Trends at Ottawa Airport

). The long observation record at the Ottawa Airport weather station (1939-present) further indicates the overall increase in temperature (OCCIAR, 2011). Furthermore, this long record highlights that the greatest temperature change has occurred during the winter months with an average mean increase of 2.2°C at the Ottawa Airport (OCCIAR, 2011) over the 1939-2010 time period. Of the three temperature variables (mean, maximum, and minimum), the greatest changes in a single season have been observed for the average winter minimum temperature over this long record, with an increase of 2.5°C at the Ottawa Airport (OCCIAR, 2011) during the 1939-2010 time period. The overall annual temperature trend for the Greater Ottawa Region appears to indicate an increase of 1.7°C per century (ECCC, 2016). Previous work in Ontario supports the increasing temperature trends and also suggests that certain areas within Southern Ontario could have summers that are 2-3°C warmer by the mid-century and potentially 4-5°C warmer by as early as 2071 (MNR, 2007).

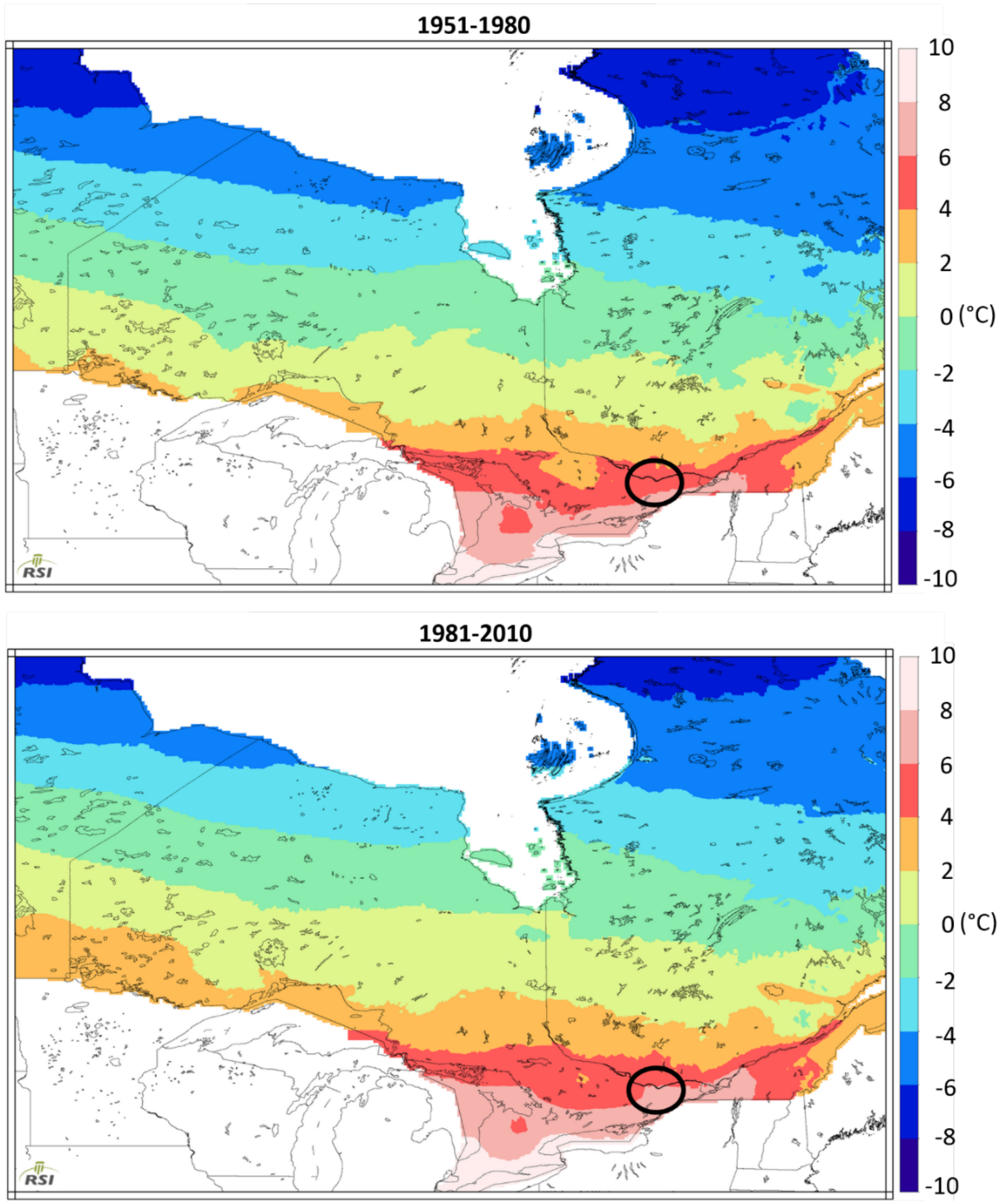

Figure 6 Observed annual mean (2m) air temperature over the 1951-1980 (upper) and1981-2010 (lower) periods. The change in mean annual temperature can be inferred from comparison of the plots (i.e. the difference in the colouration), with observed increases in temperature throughout Southern Ontario. Annual mean temperatures in the Greater Ottawa Region (located within the black circle) have increased from 4-6°C during the 1951-1980 period to 6-8°C during the 1981-2010 period. (Data from ECCC/NRCan Canadian Gridded Temperature and Precipitation Data [CANGRD], 10 km horizontal resolution, using the ANUSPLIN climate modeling software [McKenney et al., 2011]; plots produced by Risk Sciences International.)

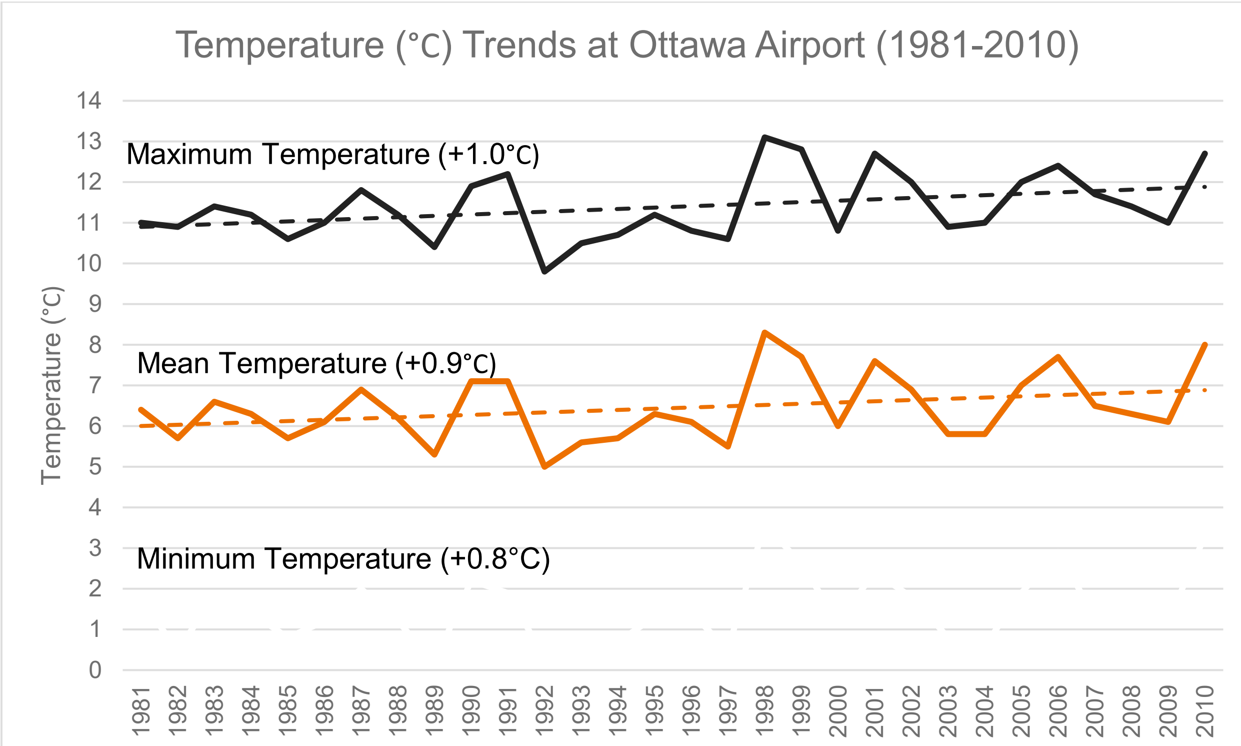

Figure 7 1981-2010 Annual Mean, Maximum, and Minimum Temperature Data and Trends at Ottawa Airport

The warming of the climate system has also led to important changes in temperature extremes. Since 1950, the number of cold days and nights has decreased while the number of warm days and nights has increased in Canada (Bush et al., 2014). As a result, a decrease in the frequency and intensity of extreme cold events has been observed in the Greater Ottawa Region. Nevertheless, extreme cold events still continue to occur in association with wintertime southward dips in the Polar Vortex, such as those in recent winters (2012-13, 2013-2014, 2017-18, and 2018-19). Alternatively, an increase in the frequency and intensity of extreme heat events has been observed. For instance, at the Ottawa Airport, the average annual number of days with a maximum temperature of 30°C or greater has increased from 13.4 days to 15 days over the 1981-2010 time period. Similarly, an increase in the frequency and duration of heat waves has also been observed in the region.

Precipitation trends in the region also appear to be changing, though less steadily than temperature. The Greater Ottawa Region has experienced an overall increase in observed total annual precipitation, with total precipitation increasing 25.9 mm at the Ottawa Airport during the 1981-2010 time period (Figure 8). The long observation record at Ottawa Airport further indicates an overall increase in total annual precipitation (+142 mm over the 1939-2010 time period) (OCCIAR, 2011). While this long-term increase in total annual precipitation is coupled with a long-term slight decrease in the annual winter precipitation (-9 mm over the 1939-2010 time period) (City of Ottawa, 2011; OCCIAR, 2011), average December-January-February rainfall total has increased at the Ottawa Airport from 69.1 mm to 80.6 mm during the 1981-2010 time period.

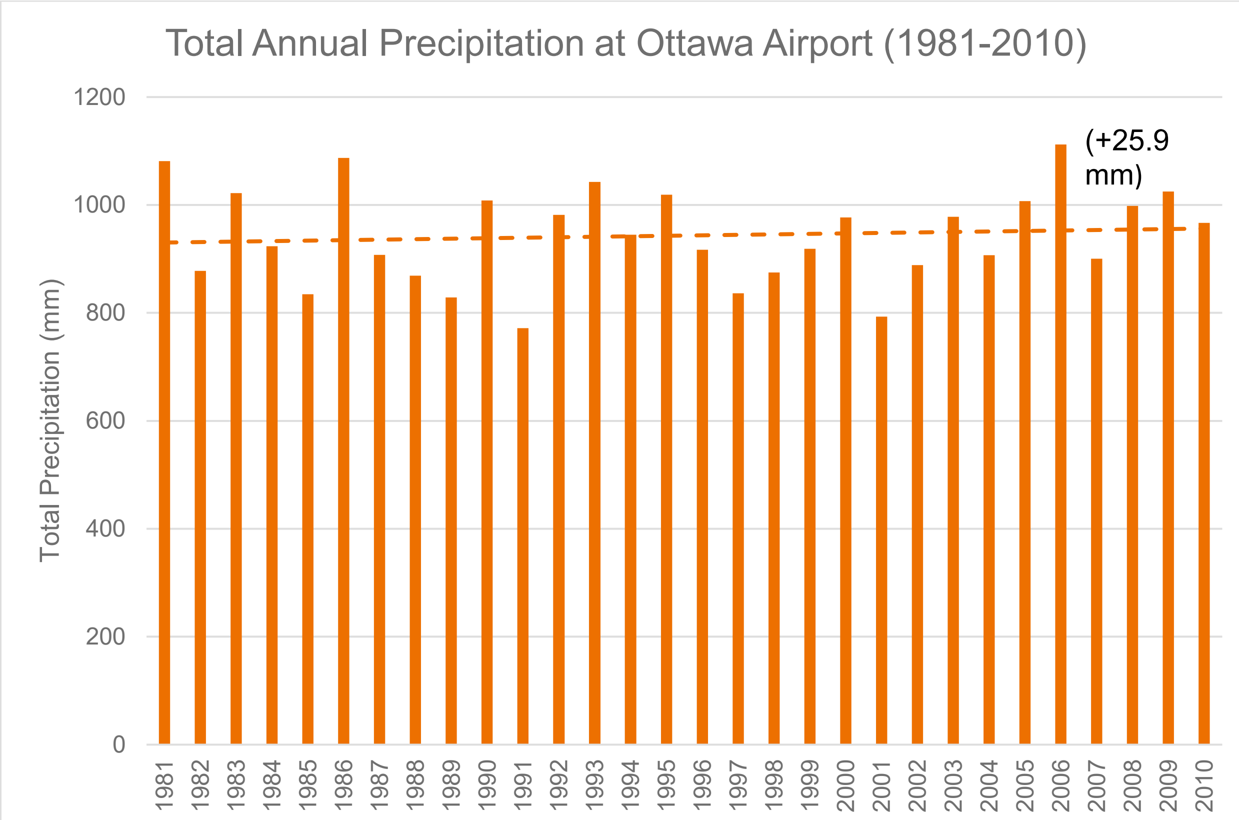

Figure 8 1981-2010 Total Annual Precipitation Data and Trend at Ottawa Airport

Trend analysis of changes in Canadian precipitation and, in particular, extreme precipitation is challenging due in part to the low spatial density of the precipitation data and especially the rate-of-rainfall (tipping bucket rain gauge) station network, with many rate-of-rainfall station records being considerably out-of-date (e.g. by a decade). Subsequently, statistically significant and conclusive evidence on changes in (extreme) precipitation are difficult to obtain from Canadian stations. Nevertheless, an overall increase in total annual rainfall has been observed for Southern Ontario since the 1950s (Mekis and Vincent, 2011; Bush et al., 2014), with more increasing (though often not statistically significant) trends than decreasing trends in extreme rainfall having also been detected (Bush et al., 2014; Shephard et al., 2014; Mekis et al., 2015; Vincent et al., 2018).

Regional trend analyses (regionally averaged station data) have been found to detect stronger trends compared to the use of individual station records (Shephard et al., 2014; Soulis et al., 2016). For instance, Soulis et al. (2016) determined that extreme rainfall, averaged for all of Ontario, has increased by 1.8% per decade for 24-hr duration events and by 1.25% per decade for 30-minute duration events during the 1960-2010 period. In contrast to Canadian extreme precipitation research results, U.S. studies have been more conclusive in showing statistically significant increasing regional trends in extremes (e.g. in the US Northeast and Midwest; Figure 9) (Walsh et al., 2014; Easterling et al., 2017). In part, these trend differences can be linked to geographical regions and indicators and their threshold levels, although differences in the density of the observing networks may be a main contributor. Many of these increasing trends are being observed in states directly bordering Canada, including Southern Ontario (Figure 9), and there is no reason to believe that similar (i.e. increasing) trends to these detected US trends would not also be evident north of the border but are masked by the observation network data itself.

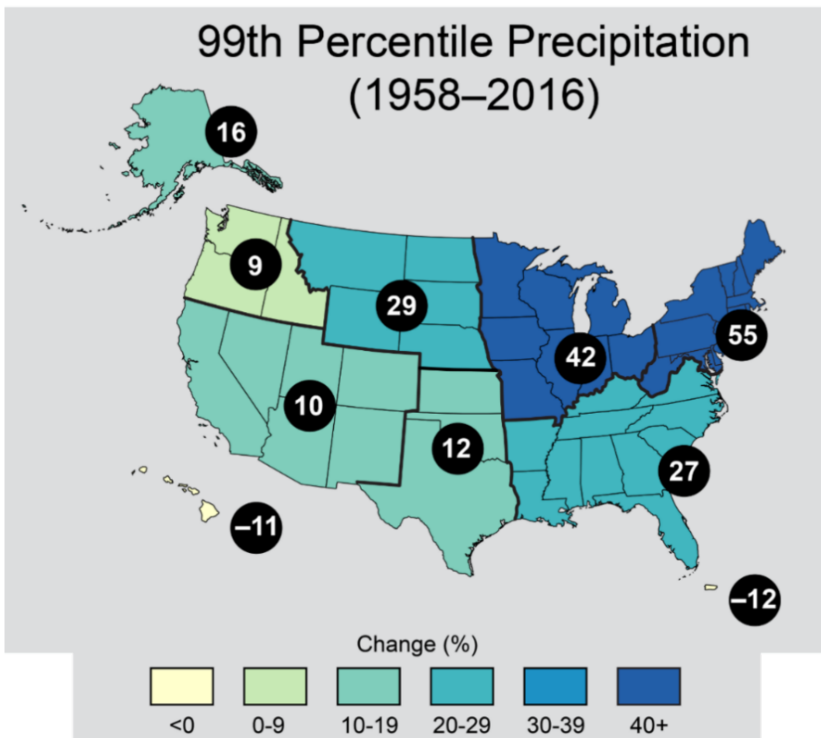

Figure 9 Percent increases in the amount of precipitation falling in daily events that exceed the 99th percentile of all days with precipitation (i.e. the total precipitation falling in the top [heaviest] 1% of daily precipitation events) in the United States, 1958-2012, calculated from daily precipitation total observations. Figure from Easterling et al., 2017.

Severe weather extreme events, such as freezing rain and ice storms, lightning, high winds and tornadoes, can result in significant impact and damage to electrical infrastructure and are influenced by the changing climate. Historical research was able to confirm four major freezing rain and ice storm events, i.e., those which resulted in long term and widespread power and communication outages, affecting the Greater Ottawa Region since 1940, including the most recent April 2018 event as well as the infamous January 1998 ice storm (Klaassen et al., 2003; Local media sources). Across the Greater Ottawa Region, lightning flash density varies from approximately 1.0 to 1.2 flashes per square kilometer (ECCC National Lightning Database). Eastern Ontario and Western Quebec have also historically been subject to periodic significant tornado outbreaks, including the recent September 21, 2018 tornado outbreak which included three significant (EF2 and EF3) tornadoes impacting the Greater Ottawa Region. Gensini and Brooks (2018) also report an observed increase in days with potential for significant tornado development in northeastern North America over the past ~40 years.

Under climate change, observed trends are projected to continue. Table 5 outlines general projected changes in climate parameters of interest to Hydro Ottawa's electrical distribution system, services, and operations.

Table 5 Summary of Potential Climatic Changes By Mid-Century in the Greater Ottawa Region

Climate Parameter	Projected Climatic Changes by Mid-Century
Temperature – Extreme Heat	• Increased frequency and intensity • Increased frequency and length of heat waves
Temperature – Extreme Cold	• Decreased frequency and intensity • Occurrence of extreme cold outbreaks ("Polar Vortex" winters) likely to continue
Rain (Short Intensity – High Duration)	• Increased intensity of events • Reduced return periods (e.g. 20-yr return period event becoming a 10-yr return period event)
Freezing Rain & Ice Storms	• Increased frequency • Increased winter season (e.g. January) events
Snow	• Likely decrease in annual total accumulation • Continued occurrence and steady frequency of larger individual events
High Winds	• Slight increase in frequency of high wind events (e.g. 90 km/hr; 120 km/hr)
Lightning	• Increased frequency (by about 12% per degree Celsius of warming) • Increased length of the higher frequency lightning season
Tornadoes	• Increased frequency (25% increase by mid-century) • Increase (near 2x) in number of severe thunderstorm days by mid-century (capable of possibly producing tornadoes, hail, extreme winds, and extreme rainfall events)
Fog	• Likely increase
Frost (Freeze-Thaw Cycles)	• Decrease in annual total number of freeze-thaw days • Increase in monthly totals in the shoulder seasons (e.g. November and March)

4.3 SPECIAL EVENT FORENSICS

4.3.1 Climate Event Forensic Analysis

Individual high-impact severe weather events can produce disproportionate amounts of damage to electrical distribution systems. These events test the capacity and limitations of response crews, often necessitating prioritization of repairs and leaving some customers without power for several days. However, by conducting investigations of these events, particularly by combining infrastructure impacts information and weather observations, lessons can be learned, and response strategies can be developed to increase the resiliency of the electrical distribution network to help bolster resilience.

Hydro Ottawa identified three high-impact severe weather events as part of the overall scope of the PIEVC assessment:

- April 15-16, 2018 – ice and wind storm;
- May 4, 2018 – wind storm; and,
- September 21, 2018 – tornado outbreak.

The forensic assessment was conducted by combining information on both infrastructure impacts and meteorological data, with the intent of establishing the following:

- **Event Timelines –** Understanding the progression of events leading up to, during, and immediately following major outage events;
- **Meteorological/Climate Diagnosis** – Determine the type, extent, and severity of weather/climate event responsible for outages; and,
- **Develop Adaptation Recommendations –** Determine actions that can be taken to assist in the preparation and response to similar events in the future.

A summary of each case study is provided below, followed by a list of adaptation actions stemming from this review. A much more detailed description of forensic assessment methodology, case study analyses and results are provided in **Appendix A**. Possible adaptation actions related to these events will be included in the adaptation report.

4.3.2 Ice and Wind Storm - 15 - 16 April 2018

A combined wind and ice storm resulted in a total of 73,797 customers losing power during this event. Ottawa airport reported a total of 16 hours of freezing precipitation between noon EDT on April 15th and 10 AM EDT April 16th. The freezing rain and drizzle resulted in ice accumulations on overhead electrical infrastructure and adjacent vegetation exceeding 10 mm in total thickness, which was accompanied by strong winds gusting to 67 km/h on April 15 and 74 km/h on April 16. Total estimated ice accumulations by midnight on April 15th were likely around 10 mm, resulting in a small number of scattered power outages. However, between 7 AM and 2 PM on April 16th, the total number of outages increased from approximately 4,000 customers to over 43,000 customers.

Since combined loading from wind and ice are challenging to assess, efforts have been made in other jurisdictions to estimate the potential impacts from various combinations of wind and ice loads. The Sperry-Piltz Ice Accumulation (SPIA) Index (Figure 10), a combined ice and wind load scale, is increasingly being used for such events by meteorologists and contains 6 categories of increasing severity (0-5).

The April 15 - 16 2018 event would have been ranked a "4" on the 0-5 scale, corresponding to much more severe impacts than what was observed. This is likely due to the SPIA Index's development in the central United States (originally the Tulsa, Oklahoma local weather office), and therefore impact statements correspond to infrastructure designed to lower ice and wind combination thresholds.

The Sperry-Piltz Ice Accumulation Index, or "SPIA Index" – Copyright, February, 2009

ICE DAMAGE INDEX	* AVERAGE NWS ICE AMOUNT (in inches) *Revised-October, 2011	WIND (mph)	DAMAGE AND IMPACT DESCRIPTIONS
0	< 0.25	< 15	Minimal risk of damage to exposed utility systems; no alerts or advisories needed for crews, few outages.
1	0.10 – 0.25	15 - 25	Some isolated or localized utility interruptions are possible, typically lasting only a few hours. Roads and bridges may become slick and hazardous.
	0.25 – 0.50	> 15	
2	0.10 – 0.25	25 - 35	Scattered utility interruptions expected, typically lasting 12 to 24 hours. Roads and travel conditions may be extremely hazardous due to ice accumulation.
	0.25 – 0.50	15 - 25	
	0.50 – 0.75	< 15	
3	0.10 – 0.25	> = 35	Numerous utility interruptions with some damage to main feeder lines and equipment expected. Tree limb damage is excessive. Outages lasting 1 – 5 days.
	0.25 – 0.50	25 - 35	
	0.50 – 0.75	15 - 25	
	0.75 – 1.00	< 15	
4	0.25 – 0.50	> = 35	Prolonged & widespread utility interruptions with extensive damage to main distribution feeder lines & some high voltage transmission lines/structures. Outages lasting 5 – 10 days.
	0.50 – 0.75	25 - 35	
	0.75 – 1.00	15 - 25	
	1.00 – 1.50	< 15	
5	0.50 – 0.75	> = 35	Catastrophic damage to entire exposed utility systems, including both distribution and transmission networks. Outages could last several weeks in some areas. Shelters needed.
	0.75 – 1.00	> = 25	
	1.00 – 1.50	> = 15	
	> 1.50	Any	

Figure 10 SPIA Index (Sperry, 2009) describing combination of wind and ice loading and expected impacts. Note that the scale currently over-estimates the severity of associated impacts to the Hydro Ottawa system and would require further tailoring for use in eastern Canada.

Main impacts were the result of trees and branches impacting lines; however, several utility poles (33 in total) also suffered structural failures. It is notable that many poles did not fail at the ground line in this case but rather several meters above the ground line. This may be due to significant lateral loading from wind action on ice covered lines, in which case the highest fiber stress within a utility pole can occur above the ground line. We also note that Hydro Ottawa's post storm investigation indicated a small number of the poles were also potentially aged and degraded, which may have further contributed to failures.

4.3.3 High Wind Event - 4 May 2018

An intense low-pressure system tracked across a large portion of southern Ontario through to southern Quebec and adjacent areas of the United States, resulting in power outages for approximately 45,000 Hydro Ottawa customers. Damage reports, mainly consisting of large branches and individual trees being uprooted, was first reported in eastern Michigan in the Detroit area at 1:09 PM EDT. As the storm moved across southern Ontario, wind gusts approaching or exceeding 120 km/h were recorded at several locations. Widespread wind damage was reported across the Kitchener-Waterloo and Golden Horseshoe regions beginning after 3 pm EDT, including three fatalities attributed to the storm, as well as damage consisting of large branches and/or large trees snapped or uprooted, shingles and portions of roofs removed from homes and commercial buildings, and tens of thousands of electrical distribution customers in multiple jurisdictions losing power.

High winds and associated customer outages occurred in two distinct "waves" which were associated with different portions of the weather system (Figure 11). Several locations southwest of the City of Ottawa first reported wind related power outages after 7 PM EDT, with a total of 11,000 customers losing power in Kanata, Stittsville, Richmond and Munster by 7:48 PM. This first wave of high winds continued east-northeast, triggering similar outages in the Finlay Creek area by 8:50 PM. The second period of high winds, which also appeared to be more severe than the first, began in in the late evening, with most damage occurring roughly between 10 and 11:30 PM EDT. By 11:40 PM EDT, Hydro Ottawa reported that in excess of 30,000 customers had lost power. The worst affected areas in the City of Ottawa following the second, late evening period of high winds required more than a day of repair work to fully restore power.

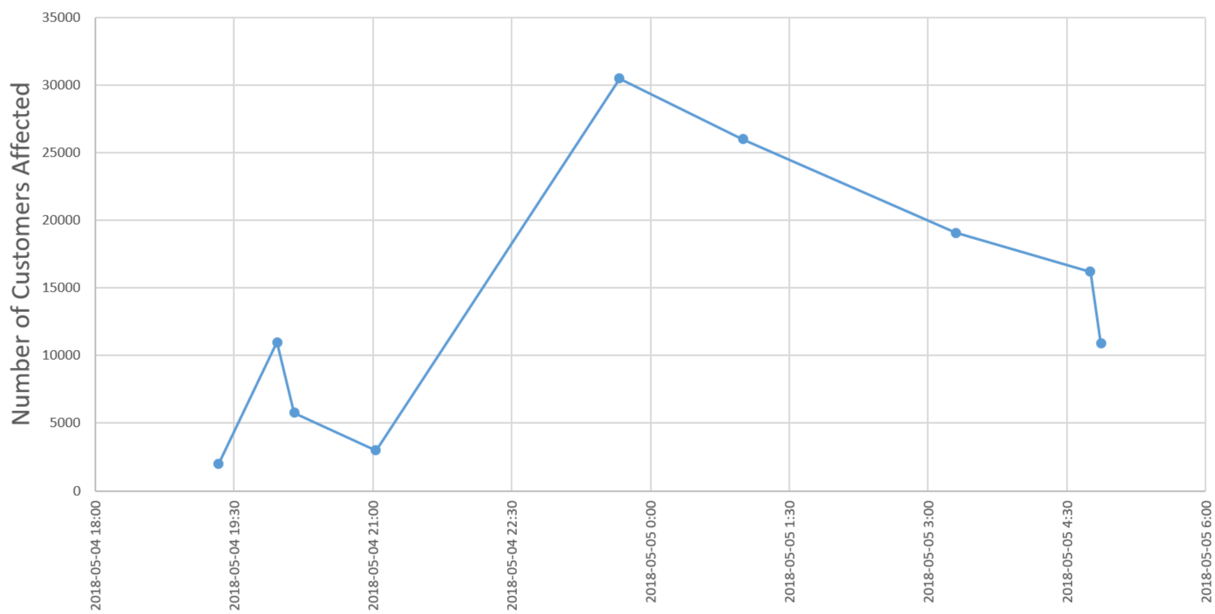

Figure 11 Timeline describing number of customers affected during May 4, 2018 windstorm. Note small peak of ~11,000 between 7:30 and 8:00 PM EDT, followed by much larger peak of >30,000 later in the evening. Total number of customers affected based on outages reported by Hydro Ottawa's Twitter account.

With such a large-scale wind event, the potential existed for understanding potential impacts to Hydro Ottawa's electrical system by monitoring upstream utilities and meteorological data. In addition to high winds reported at various airports across southern Ontario, local utilities suffered widespread outages several hours prior to Hydro Ottawa, including utilities in the Kitchener-Waterloo region (~35,000 customers) Toronto Hydro (over 30,000), and Hydro One's rural distribution network (over 126,000 customers affected). Damage reported by media and Hydro Ottawa staff also suggest that winds were likely stronger in some parts of the City of Ottawa than those measured at the airport. A peak gust of 96 km/h was recorded in the late evening, but cladding and shingle damage to homes, as well as some more intense damage to trees and branches in some areas, suggest winds exceeded 105 km/h in some isolated locations within the service area.

4.3.4 Tornado Outbreak - 21 September 2018

The September 21, 2018 tornado outbreak consisted of at least 7 separate tornadoes, with Hydro Ottawa's service area suffering impacts from the two strongest confirmed tornadoes within the outbreak, the long-tracked Kinburn-Dunrobin-Gatineau tornado, rated EF-3 on the 0 to 5 EF-scale of tornado intensity, and the Nepean-South Ottawa tornado, rated EF-2. The Kinburn-Dunrobin-Gatineau tornado formed at approximately 4:32 PM EDT, tracking roughly northeast until crossing the Ottawa River at approximately 4:52 PM EDT. Approximately one hour later, at 5:51 PM EDT, the Nepean tornado formed in association with a second line of storms. This tornado impacted the Merivale Transmission Station (TS) at almost exactly 6:00 PM EDT, resulting in a significant proportion of outages triggered in this event, and dissipated shortly after at approximately 6:09 PM EDT. All damage associated with these tornadoes, resulting in over 174,000 customers being affected, occurred in a time span of approximately 38 minutes (Figure 12).

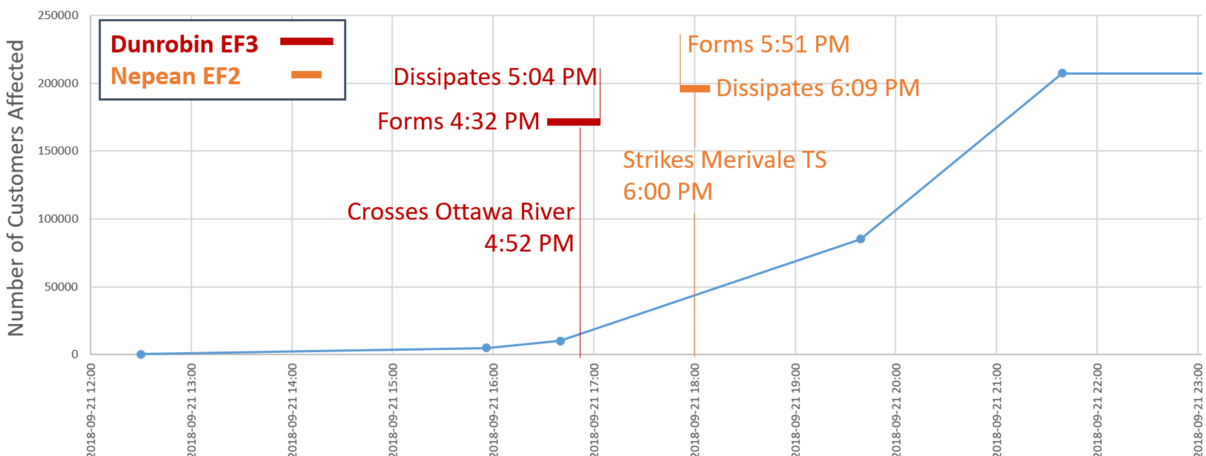

Figure 12 Timeline comparing the total number of reported customers affected versus the occurrence of the Kinburn-Dunrobin-Gatineau tornado (red) and the Nepean-South Ottawa tornado (orange). Outage totals are based on those reported by Hydro Ottawa's Twitter account and the final total based on post-event reports.

Based on a review of historical events, this appears to be the first day in recent history in which two significant (i.e., EF-2 or stronger) tornadoes affected Hydro Ottawa's service area on the same day. Damage surveys conducted by teams from Environment and Climate Change Canada (ECCC) and the University of Western Ontario (UWO) wind engineering group helped better clarify what occurred at Merivale TS. In spite of the widespread impacts of this direct strike on the station, the tornado was likely at EF-1 intensity when these impacts occurred, suggesting maximum winds of around 170 km/h.

5.0 RISK ASSESSMENT

As discussed previously, the risk assessment is an iterative and highly participatory process that identifies risks through the use of data and other available information which is then validated by key stakeholders, and a strong focus on local knowledge. The following sections outline the components of the risk assessment and the process by which the final risk profile was developed.

5.1 INTERVIEWS

A series of interviews with Hydro Ottawa staff within their Operations, Engineering and Design, and Emergency Planning and Response divisions was completed to provide detailed information to inform the climate risk assessment. Three 1.5-hour interviews took place on March 7th and 8th, 2019 and each included 3-4 participants from Hydro Ottawa. A full list of interview participants is provided in Table 6. Discussion during these interviews was guided by a prepared list of questions but was encouraged to wander when relevant points arose. The information provided during these interviews helped to identify the climate risks that Hydro Ottawa is exposed to and introduced an appreciation for the challenges and vulnerabilities that could potentially be mitigated through changes in their operations, design, and response policy and practices. A summary of the discussion that took place during these interview sessions is provided in **Appendix B**.

The following participants attended the interview sessions that took place on March 7-8, 2019.

Table 6 List of Interview Participants and their Roles

Participant	Role
Guy Felio	Interviewer (Stantec)
Riley Morris	Interviewer (Stantec)
Matthew McGrath	Project Manager (Hydro Ottawa)
Operations Staff – March 7, 2019	
Greg Bell	Manager, Distribution Operations (Underground)
Brent Fletcher	Manager, Program Management and Business Performance
Jeff Bracken	Manager, Distribution Operations (Overhead)
Engineering and Design Staff – March 7, 2019	
Margret Flores	Supervisor, Asset Planning
Jenna Gillis	Manager, Asset Planning
Tony Stinziano	Manager, Distribution Design
Ben Hazlett	Manager, Distribution Policies and Standards
Emergency Planning and Response – March 8, 2019	
Doug Baldock	Manager, System Operations
Brian Kuhn	Manager, Distribution Operations (Overhead)
Adam MacGillivray	Business Continuity Management Specialist

5.2 INFRASTRUCTURE

The following subsections outline the main components of the risk assessment as they relate to the infrastructure.

5.2.1 Infrastructure List Validation

Validation is a key step in the risk assessment process. The infrastructure list was validated through a number of means, listed as follows.

- Consultation with a subject matter expert;
- Validation through Hydro Ottawa project manager; and,
- Validation through the climate risk and vulnerability workshop.

At each of these revision steps, individuals provided comments that were incorporated into the list of infrastructure.

5.2.2 Performance Criteria

The performance criteria are variables that describe different perspectives from which we can assess risks to the system's infrastructure. A summary of performance criteria response categories is provided along with their descriptors in Table 7. These performance criteria were selected by the Project Team to match Hydro Ottawa's Asset Management Risk Procedure (see Figure 2), thus allowing the use of the PIEVC assessment results to inform corporate risks and decision-making.

Table 7 Performance Criteria Considered in the Risk Assessment

Response Category	Description
Level of Service: System Accessibility	Risk or opportunity impacting the connection of load and energy resource facility customers.
Level of Service: Service Quality	Risk or opportunity impacting the delivery of electric power in a form which meets customer's needs.
Resource Efficiency	Risk or opportunity impacting the additional use of internal or external resources.
Asset Value: Financial	Risk or opportunity impacting the realization of value from assets through resulting financial expense.

5.2.3 Severity Ratings

More than simply understanding that an interaction between the climate and infrastructure components exists, it is important to assess the consequence (impact) on the assets should the climate or weather event occur. The ratings place numerical values on the severity that a climate event would have on an infrastructure component. Similar to the performance criteria (**Section 5.2.2**), the severity scoring system was selected to readily integrate into the AMRP, as summarized in Figure 2. The 1- to 25-point severity scale and the descriptions used in defining the performance descriptors were extracted directly from Hydro Ottawa's AMRP.

Table 8 Severity Ratings used in the Risk Assessment

Severity Score and Descriptor		Infrastructure Performance and Severity Rating			
		Level of Service: System Accessibility	Level of Service: Service Quality	Resource Efficiency	Asset Value - Financial
Insignificant	**1**	N/A	Service interruption resulting in <10,000 customer minutes interrupted. Service quality resulting in customer complaint, but meets CSA standards	Requires <10 hours of overtime to complete O&M work or undergo training. Requires <100 hours of overtime to complete capital work.	Financial risk resulting in an O&M expense of <$1k. Financial risk resulting in a capital expense of <$10k.
Minor	**4**	N/A	Service interruption resulting in >10,000 customer minutes interrupted. Service quality resulting in customer escalation, but meets CSA standards	Requires >10 hours of overtime to complete O&M work or undergo training. Requires >100 hours of overtime to complete capital work.	Financial risk resulting in an O&M expense of >$1k. Financial risk resulting in a capital expense of >$10k.
Moderate	**9**	Load demand/generation is exceeding planning limits.	Service interruption resulting in >500,000 customer minutes interrupted.	Requires >250 hours of overtime to complete O&M work or undergo training. Requires >2,500 hours of overtime to complete capital work.	Financial risk resulting in an O&M expense of >$50k. Financial risk resulting in a capital expense of >$500k.
Major	**16**	Load demand/generation is exceeding thermal limits.	Service interruption resulting in >3,000,000 customer minutes interrupted.	Requires >1,500 hours of overtime to complete O&M work or undergo training. Requires >15,000 hours of overtime to complete capital work.	Financial risk resulting in an O&M expense of >$300k. Financial risk resulting in a capital expense of >$3M.
Catastrophic	**25**	Unable to service new load/ERFs	Service interruption resulting in >10,000,000 customer minutes interrupted. Service quality resulting in not meeting CSA standards.	Unable to complete work with internal and/or external resources due to volume or skill gap.	Financial risk resulting in an O&M expense of >$1M. Financial risk resulting in a capital expense of >$10M.

5.3 CLIMATE CHANGE

This section provides an overview of the climate probability scoring methodology and parameter threshold values used in the risk assessment. These items are discussed in more detail in the Climate Change Hazards Report, provided as **Appendix A**.

5.3.1 Climate Probability Scoring

Statistical information for both historical (1981-2010) and projected (2050s) event frequencies of the identified climate parameters and the five-point scoring scale used in Hydro Ottawa's Asset Management System Risk Procedures (Table 9) were used to develop probability scores for this study. A score of 1 refers to a climate event that is "rare" and has a very low likelihood of occurring during the time period of interest, while a score of 5 refers to an event that is "almost certain" and highly likely to occur in the period.

Table 9 Probability Scoring Scale Used in Hydro Ottawa's Asset Management System Risk Procedures

Probability Score	Descriptor	Detailed Description	Probability Range
1	Rare	May only occur in time period under exceptional circumstances	p ≤ 5%
2	Unlikely	Could occur in time period	5% < p ≤ 35%
3	Possible	Might occur in time period	35% < p ≤ 65%
4	Likely	Will probably occur in time period	65% < p ≤ 95%
5	Almost Certain	Is expected to occur	95% < p

In this study, the probabilities of an event directly impacting the Hydro Ottawa service area – both on an annual basis and over the future 30-year time horizon, are used. The annual probability of an event occurring provides insight for functional and operational (O&M) impacts while the probability over a 30-year period provides insight for structural impacts.

5.3.2 Climate Thresholds

Historical baseline (1981-2010) and projected climate change (2050s) information under the RCP8.5 scenario for the identified climate parameters is presented in Table 9 below. The Table also provides a summary of the analytical results (annual and 30-year probabilities and scores). Annual averages (frequencies) for each parameter are provided in terms of events per year (yr^{-1}). Probability values (%) are calculated based on the probability of an event directly impacting the Hydro Ottawa service area. The probability scores, ranked from 1 to 5, are used to calculate risk values and will appear in the risk assessment worksheet summarizing the overall results of the risk assessment. Detailed discussions for each climate parameter are provided in **Appendix A**.

Table 10 Annual and 30-Year Probabilities and Scores for the Historical Baseline (1981-2010) and Future Climate (2050s) under the RCP8.5 Scenario

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)				Change in Probability Score	
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	30-Year Probability
Temperature – Extreme Heat										
Daily maximum temp. of 30°C and higher	100% (~14-15 yr^{-1})	5	100%	5	100% (~42 yr^{-1})	5	100%	5	No change	No change
Daily maximum temp. of 35°C and higher	50% (< 1 yr^{-1})	3	>99%	5	100% (~6 yr^{-1})	5	100%	5	+ 2	No change
Daily maximum temp. of 40°C and higher	6% (< 1 yr^{-1})	2	84%	4	100% (~1-2 yr^{-1})	5	100%	5	+ 3	+ 1
Daily average temp. of 30°C and higher	3% (< 1 yr^{-1})	1	60%	3	100% (~1-2 yr^{-1})	5	100%	5	+ 4	+2
Heat wave: Consecutive days with $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$	7% (< 1 yr^{-1})	2	89%	4	100% (~2 yr^{-1})	5	100%	5	+ 3	+ 1
Heat wave: Consecutive days with $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$	0% (0 yr^{-1})	1	0%	1	37% (<1 yr^{-1})	3	>99%	5	+ 2	+ 4
Temperature – Extreme Cold										
Daily minimum temp. of -35°C and colder	3% (< 1 yr^{-1})	1	60%	3	0.1% (Rare)	1	3%	1	No change	- 2
Rain										
50 mm of rainfall in 1 hour	1% (< 1 yr^{-1})	1	~25%	2	4.5% (< 1 yr^{-1})	1	75%	4	No change	+ 2

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)				Change in Probability Score	
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	30-Year Probability
Freezing Rain & Ice Storms										
Ice accumulation of 25 mm	5% (< 1 yr^{-1})	1	79%	4	6% (< 1 yr^{-1})	2	84%	4	+ 1	No change
Ice accumulation of 40 mm	2.5% (< 1 yr^{-1})	1	>50%	3	3.8% (< 1 yr^{-1})	1	~70%	4	No change	+ 1
Snow										
Days with 5 cm or more of snowfall	100% (~15 yr^{-1})	5	100%	5	100% (~15 yr^{-1})	5	100%	5	No change	No change
Days with 10 cm or more of snowfall	100% (~5-6 yr^{-1})	5	100%	5	100% (~5 yr^{-1})	5	100%	5	No change	No change
Days with 30 cm or more of snowfall	13% (< 1 yr^{-1})	2	98%	5	10% (< 1 yr^{-1})	2	>95%	5	No change	No change
High Winds										
Annual wind speeds of 60 km/hr or higher	100% (~14-15 yr^{-1})	5	100%	5	100% (~16 yr^{-1})	5	100%	5	No change	No change
Easterly winds of 60 km/hr or higher (warm season [April - Sept.])	28.9% (< 1 yr^{-1})	2	100%	5	32.4% (< 1 yr^{-1})	2	>99%	5	No change	No change
Easterly winds of 60 km/hr or higher (summer [June-Aug.])	2.6% (< 1 yr^{-1})	1	55%	3	2.9% (< 1 yr^{-1})	1	~60%	3	No change	No change
Annual wind speeds of 80 km/hr winds or higher	100% (~1-2 yr^{-1})	5	100%	5	100% (~1-2 yr^{-1})	5	100%	5	No change	No change

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)				Change in Probability Score	
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	30-Year Probability
Easterly winds of 80 km/hr or higher (cool season [Oct.-March])	5.3% (< 1 yr^{-1})	2	80%	4	6.3% (< 1 yr^{-1})	2	85%	4	No change	No change
Easterly winds of 80 km/ hr or higher (winter [Dec.-Feb.])	2.6% (< 1 yr^{-1})	1	55%	3	3.2% (< 1 yr^{-1})	1	>60%	3	No change	No change
Annual wind speeds of 90 km/hr or higher	23% (< 1 yr^{-1})	2	>99%	5	29% (< 1 yr^{-1})	2	>99%	5	No change	No change
Annual wind speeds of 120 km/hr or higher	2.5% (< 1 yr^{-1})	1	53%	3	3.1% (< 1 yr^{-1})	1	61%	3	No change	No change
Lightning										
Strikes near infrastructure (flashes/ km^2/ year)	1.1% (< 1 yr^{-1})	1	28%	2	1.5% (< 1 yr^{-1})	1	36%	3	No change	+ 1
Tornadoes										
EF1+ in Hydro Ottawa service area (City of Ottawa)	14.6% (< 1 yr^{-1})	2	>99%	5	18.2% (< 1 yr^{-1})	2	>99%	5	No change	No change
EF1+ point probability (i.e. striking a specific asset in City of Ottawa service area)	0.018% (Rare)	1	0.6%	1	0.023% (Rare)	1	0.7%	1	No change	No change
Invasive Species										
Emerald Ash Borer (Daily min. temp. of -30°C or colder [kill temp.])	53% (< 1 yr^{-1})	3	>99%	5	3% (< 1 yr^{-1})	1	60%	3	- 2	- 2
Giant Hogweed (3 consecutive days of -8°C or colder [gemination requirement])	100% (25 yr^{-1})	5	100%	5	100% (17 yr^{-1})	5	100%	5	No change	No change

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)				Change in Probability Score	
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	30-Year Probability
Fog										
Season with ≥ 50 fog days (Nov.-March)	37%	3	100%	5	*Likely increase*	3-4	100%	5	Possibly + 1	No change
Frost										
Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation around 0°C	100% (~2-3 yr^{-1})	5	100%	5	100% (~2 yr^{-1})	5	100%	5	No change	No change
Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C	30% (< 1 yr^{-1})	2	>99%	5	38% (< 1 yr^{-1})	3	>99%	5	+ 1	No change

5.4 RISK WORKSHOP

A climate risk workshop took place on April 12, 2019 where the risk assessment team worked with Hydro Ottawa staff and representatives from the City of Ottawa to acquire input on the assessment. The purpose of the workshop was to: (1) validate any assumptions made in the work done thus far and (2) seek guidance on assigning severity ratings to climate-infrastructure interactions. The assessment components validated during the risk workshop are listed as follows:

- Risk assessment process
- Severity ratings
- Climate probability scoring system
- Infrastructure response criteria (derived from the Hydro Ottawa Risk Management Plan)
- List of infrastructure
- Climate parameters and threshold values

Comments made towards these risk assessment components were later incorporated into the assessment.

The risk evaluation process is depicted graphically in Figure 13.

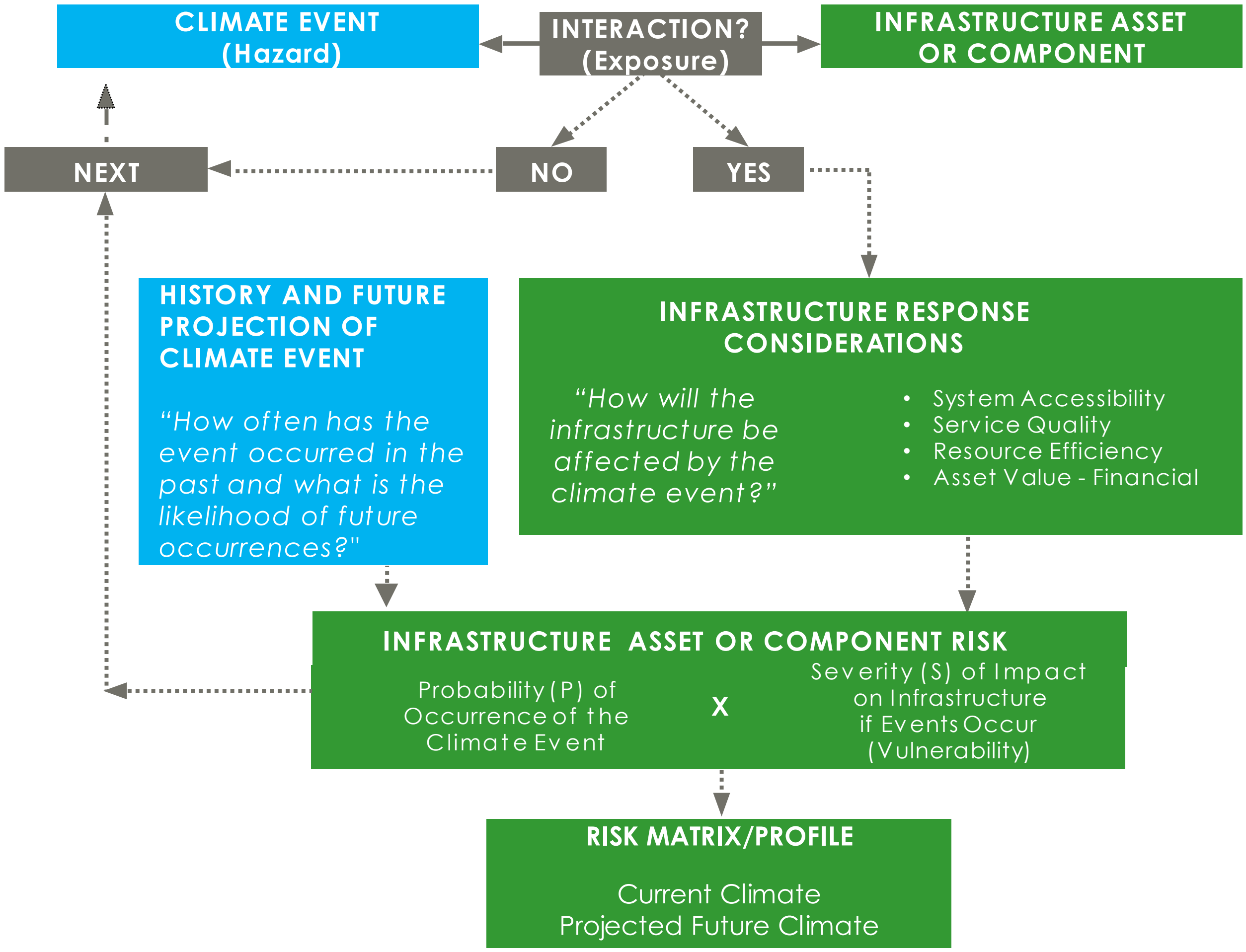

Figure 13 Flow Chart Descripting Risk Evaluation Process

For the second portion of the risk workshop, the participants and facilitators broke off into two working groups of 8-10 individuals per group. This step involved the completion of a 'yes/no' analysis where the working group identifies which infrastructure elements are exposed to each climate parameter. From here, only those climate-infrastructure interactions associated with a 'yes' will be considered in the risk assessment. The working groups then began assigning severity ratings to those climate-infrastructure interactions that remained in the assessment. These severity scores are established by considering the consequence on the infrastructure elements when a climate event, at the selected intensity threshold, occurs. In most instances, the groups noted 'no' to 'low' impact to the asset, however, some higher order impacts were noted.

This input was documented on the risk worksheet which will be described in detail under **Section 5.5** and notes taken during the risk assessment workshop are provided in **Appendix C**. A list of participants who attended the risk assessment workshop is summarized in Table 11.

Table 11 List of Participants Who Attended the Risk Assessment Workshop

Participant	Role
Facilitators	
Nicole Flanagan	Stantec, Project Manager
Guy Félio	Stantec, Climate Change Resilience Advisor
Riley Morris	Stantec, Environmental Engineer
Eric Lafleur	Stantec, Electrical Engineer, Subject Matter Expert
Heather Auld	RSI, Climatologist
Norman Shippee	RSI, Climatologist
Simon Eng	RSI, Climate Analyst
Katherine Pingree-Shippee	RSI, Climatologist
Workshop Participants	
Matthew McGrath	Hydro Ottawa, Project Manager
Greg Bell	Hydro Ottawa, Manager, Distribution Operations (Underground)
Margret Flores	Hydro Ottawa, Supervisor, Asset Planning
Tony Stinziano	Hydro Ottawa, Manager, Distribution Design
Ben Hazlett	Hydro Ottawa, Manager, Distribution Policies and Standards
Adam MacGillivray	Business Continuity Management Specialist
Greg Van Dusen	Hydro Ottawa, Director, Regulatory Affairs
Joseph Muglia	Hydro Ottawa, Director, Distribution Operations
Ed Donkersteeg	Hydro Ottawa, Supervisor, Standards
Tammy Rose	City of Ottawa, Water Services
Jennifer Brown	City of Ottawa, Project Manager, Climate Change and Resilience Unit
David Lapp	Engineers Canada, Manager, Globalization and Sustainable Development

A follow-up working session comprised of select members of the workshop team took place on May 8, 2019 to complete severity scoring work that could not be completed during the workshop. The final risk worksheet was then circulated to Hydro Ottawa staff for further comments and validation.

5.5 RISK WORKSHEET

The risk worksheet used to assess the severity of impacts of climate events on the infrastructure was based on the original PIEVC Protocol template, adapted to the performance criteria and ratings selected for the Hydro Ottawa assessment. One worksheet was prepared for each the current and future projected (2050s) climate assessments.

Figure 14 shows a cut-out of the worksheet which contains three main elements:

1. The asset/infrastructure list broken down in major components that may be affected differently by climate events of various intensity;
2. The climate events selected for the assessment, including a description of the selected intensity threshold and the probability (likelihood) of occurrence (current or future climates);
3. The climate-infrastructure interactions assessment:
   a. Exposure (Yes/No);
   b. Severity of impact (S) and risk (R) following the selected performance criteria:

      - Sa/Ra: Level of Service: System Accessibility
      - Sq/Rq: Level of Service: Service Quality
      - Se/Re: Resource Efficiency
      - Sf/Rf: Asset Value - Financial

Asset/Infrastructure Element	Climate 1									Climate 2								
Current Climate	Daily maximum temp. of 35°C and higher									Daily maximum temp. of 40°C and higher								
	Probability = 3									Probability = 2								
	Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																		
a) General System-Wide Assets																		
Substations																		
Buildings and Structural Components																		
P&C Buildings																		
Switchgear Buildings																		
Equipment Support Structures																		
Station Yard																		
Station Load Break Switch																		
Station Capacitor Voltage Transformers																		
Station Circuit Breakers																		
Indoor Breakers																		
Outdoor Breakers (Metalclad)																		
Station Power Transformers																		
Surge Arrestors																		
Bushings																		
Radiators																		
Fans																		
Control Cabinet																		

Figure 14 Extract from the Risk Worksheet Used During the Assessment Workshop

At the risk assessment workshop, the participants followed the process illustrated in Figure 13 above.

5.5.1 Special Cases

In this assessment, certain climate parameters were excluded from the typical PIEVC risk worksheet process outlined above, since they are either extreme events (e.g., tornadoes) or indirect risks due to a combination of climate events (e.g., wild fires due to drought and high temperatures, lightning strikes, or human activities).

5.5.1.1 Tornadoes

The climate study performed for this assessment indicated a high likelihood of an EF1 or greater tornado affecting the Hydro Ottawa service area over the 30-year time horizon. The September 2019 tornadoes in Ottawa illustrate the damages that such meteorological event can cause to the system and its components if a direct strike occurs. The Hydro Ottawa *After Action Report* of October 18, 2018 summarizes how the utility reacted to this event and recommendations for improvements.

Potential actions to mitigate risks and adaptation to future tornado strikes will be assessed in the next phase of the study.

5.5.1.2 Wild Fires

Wildfires can occur due to various combinations of natural and/or man-made events, and aggravated by factors such as high winds that spread the fires across large areas. Hydro Ottawa has policies and procedures in place for vegetation control along its distribution lines and corridors and around its substations and major equipment components.

Potential actions to mitigate wild fires risks, reviewing existing policies and procedures in regard to vegetation control, and possible changes in these will be assessed in the next phase of the study.

5.5.1.3 Invasive Species

The impacts of invasive species on Hydro Ottawa's assets and operations retained by the assessment team concerned the emerald ash borer and giant hogweed.

- In regard to the emerald ash borer, the assessment team identified this as a risk to trees close to lines and equipment that, if infected, would be weaker and could cause damages under less intense meteorological events than healthy trees. As winter temperatures become warmer in the future, it is likely that the emerald ash borer larvae would survive winters increasing the potential of weakening trees near Hydro Ottawa infrastructure.

  Potential actions to mitigate these risks and adaptation to future ash borer infestations will be assessed in the next phase of the study.

- Giant hogweed is described by the City of Ottawa (https://ottawa.ca/en/residents/water-and-environment/plants-and-animals/invasive-species) as "a serious invasive plant that poses a moderate threat to human health and safety. Giant Hogweed is primarily found along roads, streams and open areas. Plants reproduce well on disturbed sites, and prefer full sun and open habitat common along roadsides and ditches in rural areas. This plant is poisonous. Hollow stem, leaves and plant hairs produce a sap if broken. Sap can cause serious skin inflammation on contact. If contaminated skin is exposed to sunlight a more serious reaction can occur including blisters, discoloration, and scars. If sap has contact with eyes, loss of vision, blindness or damage to eyes can occur."

  Giant hogweed, which was first reported in the Ottawa area approximately 10 years ago (see: https://www.cbc.ca/news/canada/ottawa/toxic-weed-discovered-in-ottawa-1.883529) requires precautions from Hydro Ottawa crews that work in an area – particularly along roads and ditches) where this plant is present are required to take precautions.

6.0 SUMMARY OF THE RISK PROFILE

This section presents the risk profile for Hydro Ottawa electrical distribution infrastructure and third-party assets from the perspective of climate change within the Hydro Ottawa service territory.

As indicated earlier in this report, the risk scores in the table below are the sum of the individual risks related to each of the infrastructure performance criteria selected by the project team; these criteria are:

- Level of service - system accessibility
- Level of service - service quality
- Resource efficiency
- Asset value - Financial

6.1 HIGH AND VERY HIGH RISKS

The significant current and future climate related risks (High: 31 – 60; Very High: ≥ 61 – these are highlighted in bold, red in the table) to the infrastructure identified by the assessment team are presented in the Table 12 below.

In current climate conditions, very high risks were identified to power distribution lines and poles under extreme (> 120 km/h) wind conditions; these risks remain in future projected climate. Projected changes to climate in the Hydro Ottawa service area, under the RCP 8.5 GHG emissions scenario, are expected to increase risks to very high as follows:

- Daily maximum temperatures of 40°C or higher are expected to occur annually, impacting field staff.
- Freezing rainstorms resulting in 40mm or more of ice accumulation are projected to occur more frequently in a 30-year period, resulting potentially in damage to a wide range of Hydro Ottawa's assets, disruptions in service, and impacts on staff.

Table 12 Significant Current and Future Climate Related Risks

Climate Parameter	System/Component Affected	Risk Rating		Asset Performance Affected	Impacts	Result / Consequence
		Current Climate	Future Climate			
Daily maximum temp. of 40°C and higher	Operators Powerline Maintenance Staff	26 26	**65** **65**	Resource Efficiency Asset Value - Financial	• Potential heat stress impacts on personnel working outdoors. • Exacerbated by humidex.	• Health and safety concerns requiring precautionary measures such as more frequent resting periods, hydration, etc. • Delay in restoration • Loss in productivity
Annual wind speeds of 120 km/hr or higher (30-year occurrence)	Operators Powerline Maintenance Staff	36 36	36 36	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Instability of equipment (lift buckets), flying debris, or broken tree limbs hazards	• Health and safety concern for personnel working outdoors
	Power Distribution: East-West lines and poles	**81**	**81**	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Damage to poles and lines from high wind events. • Risk of damages from falling trees, broken tree limbs or flying debris.	• Loss of assets • Disruption of service • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines • Impact on scheduling/productivity/ resources • Loss of assets • Disruption of service • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines
	Power Distribution: North-South lines and poles	**108**	**108**	Level of Service: System Accessibility Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Damage to poles and lines from high wind events. • Risk of damages from falling trees, broken tree limbs or flying debris.	• Loss of assets • Disruption of service • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines • Impact on scheduling/productivity/ resources • Loss of assets • Disruption of service • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines

Climate Parameter	System/Component Affected	Risk Rating		Asset Performance Affected	Impacts	Result / Consequence
		Current Climate	Future Climate			
Easterly winds of 80 km/hr or higher (cool season [Oct.-March])	North-South lines and poles	32	32	Level of Service: System Accessibility Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Guy wires in legacy north-south lines are installed to support against prevailing westerly winds; poles and lines are therefore damaged from to high easterly winds • Risk of damages from falling trees or broken tree limbs.	• Loss of assets • Disruption of service • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines • Public safety concern is falling branches • Loss of assets • Disruption of service • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines
Ice accumulation of 40mm (30-year occurrence)	Third Party Services and Interactions: Hydro One	54	72	Level of Service: Service Quality Asset Value - Financial	• Loss of supply to Hydro Ottawa Damages to poles shared between Hydro One and Hydro Ottawa • Loss of transmission • Loss of redundancy • Damage to equipment	• Disruption of service • Inability to restore service • Loss of redundancy • Loss of efficiency • Potential damage to Hydro Ottawa equipment (attached to Hydro One poles) • Damage to shared facilities
	Administrative and Operational Buildings	24	32	Resource Efficiency Asset Value - Financial	• Access to the building is hindered due to heavy ice accumulation • Increase in load on building due to ice accumulation, particularly if event occurs at a time where abundant snow on the roof • Ice accumulation on building mounted equipment (roof, exterior walls)	• Health and safety concerns for staff, contractors and/or public • Potential structural and/or functional damage to roof elements (e.g., membrane on flat roofs) • May result in blocked roof drains • Possible ice damming • Potential loss of assets • Reduced efficiency and/or functionality, and failure of equipment affected
	Substations - Buildings and Structural Components	24	32	Resource Efficiency Asset Value - Financial	• Access to the building is hindered due to heavy ice accumulation • Increase in load on building due to ice accumulation, particularly if event occurs at a time where abundant snow on the roof • Ice accumulation on building mounted equipment (roof, exterior walls)	• Health and safety concerns for staff, contractors and/or public • Delay in restoration • Potential structural and/or functional damage to roof elements (e.g., membrane on flat roofs) • May result in block drains • Possible ice damming • Potential loss of assets • Disruption of service • Reduced efficiency and/or functionality, and failure of equipment affected
	Operators Powerline Maintenance Staff	39 39	52 52	Resource Efficiency Asset Value - Financial	• Difficulty accessing areas needing repair due to icy conditions; e.g., ice on roadways and walkways, equipment.	• Potential delays in arriving to work site • Potential delays in performing work due to ice accumulation on equipment • Health and safety concerns

Climate Parameter	System/Component Affected	Risk Rating		Asset Performance Affected	Impacts	Result / Consequence
		Current Climate	Future Climate			
	Power Distribution: East-West lines and poles	51	**68**	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Damage from increased weight on overhead lines • Ice falling off of lines • Ice accretion on lines in excess of 12.5 mm (0.5 inches) accompanied by a 90km/h wind could result in structural failure and uneven ice accretion could cause swinging or 'galloping' in the lines • Damage to poles and attached equipment • Damages to lines from fallen trees or broken tree limbs • Damage to poles and other surface equipment from vehicles losing control on icy roads	• Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines • Potential for flashovers • Ice break-up from lines may cause public safety concerns • Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines • Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines • Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines
	Power Distribution: North-South lines and poles	36	48	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Damage from increased weight on overhead lines • Ice falling off of lines • Ice accretion on lines in excess of 12.5 mm (0.5 inches) accompanied by a 90km/h wind could result in structural failure and uneven ice accretion could cause swinging or 'galloping' in the lines • Damage to poles and attached equipment • Damages to lines from fallen trees or broken tree limbs • Damage to poles and other surface equipment from vehicles losing control on icy roads	• Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines • Potential for flashovers • Ice break-up from lines may cause public safety concerns • Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines • Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines

Climate Parameter	System/Component Affected	Risk Rating		Asset Performance Affected	Impacts	Result / Consequence
		Current Climate	Future Climate			
						• Loss of assets • Disruption of service • Difficulty or delays in restoring service due to health and safety concerns for staff, delays in accessing sites, or performing restoration work • Public safety concerns due to downed power lines

6.2 MODERATE RISKS

The moderate current and future climate related risks (risk ratings 12-25) to the infrastructure identified by the assessment team are presented in the Table 13 below. These risks are presented here as a lower priority relative to those that were presented under Section 6.1.

Moderate risks include impacts due to high temperatures on buildings, ice accretion on load break switches, the risk of flashovers and pole fires during fog events, damages to civil structures from increasing freeze-thaw events, and the impacts of mid-level winds on poles and maintenance staff.

Table 13 Moderate Current and Future Climate Related Risks

Climate Parameter	System/Component Affected	Risk Rating		Asset Performance Affected	Impacts	Result / Consequence
		Current Climate	Future Climate			
Daily maximum temp. of 35°C and higher	Administrative and Operational Buildings	12	20	Asset Value - Financial	• Increased cooling demands for the building critical systems (e.g., communication and IT systems).	• Capacity of cooling system may not be adequate to maintain ambient temperature within the design range of equipment affected which can lead to loss of efficiency, functionality or failure
Daily maximum temp. of 40°C and higher	Administrative and Operational Buildings	8	20	Asset Value - Financial	• Increased cooling demands for the building critical systems (e.g., communication and IT systems).	• Capacity of cooling system may not be adequate to maintain ambient temperature within the design range of equipment affected which can lead to loss of efficiency, functionality or failure
	Underground Cables	10	25	Level of Service: Service Quality Asset Value – Financial	• High ambient temperatures in combination with the heating of cables resulting from increasing electrical loading (for example from higher demands from A/C units) may cause an exceedance of the cables' temperature thresholds, particularly in areas were insulating ground cover is limited or non-existent (i.e. civil structures, bridges, etc.).	• Additional strain on, and limits to the underground electrical infrastructure capacity.
Ice accumulation of 40mm (30-year occurrence)	Substations: Station Load Break Switch	18	24	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Ice accretion on load break switches could result in difficulty transferring loads.	• Removal of ice required for the switch to be operable • Delay in restoration
Season with ≥ 50 fog days (Nov.-March)	Power Distribution: East-West Poles	18	24	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Pole fires as a result of salt and other conductive contaminants accumulating onto insulators.	• Risk of electrical arcs, flashovers and pole fires. • Loss of assets • Disruption of service • Public safety concerns
	Power Distribution: North-South Poles	18	24	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Pole fires as a result of salt and other conductive contaminants accumulating onto insulators.	• Risk of electrical arcs, flashovers and pole fires. • Loss of assets • Disruption of service • Public safety concerns
	Power Distribution: North-South - Fused Cut Out	12	16	Level of Service: System Accessibility Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Insulator breakdown on fused cut outs. • Pole fires as a result of salt and other conductive contaminants accumulating onto insulators.	• Risk of electrical arcs, flashovers and pole fires. • Loss of assets • Disruption of service • Public safety concerns
Freeze-thaw cycles – Daily Tmax/Tmin temp. fluctuation of ±4°C around 0°C	Power Distribution: Underground - Civil Structures	16	24	Resource Efficiency Asset Value - Financial	• Water penetration into or around civil structures which freezes causing stress on material	• Deterioration and damage (short- and long-term) to materials. • Uplift of near-surface infrastructure causing higher risks of damage during winter maintenance (e.g., snow removal) operations
Easterly winds of 80 km/hour or higher (cool season [Oct.-March])	Operators Powerline Maintenance Staff	24	24	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Instability of equipment (lift buckets), flying debris, or broken tree limbs hazards	• Health and safety concern for personnel working outdoors
	Power Distribution: East-West Lines and Poles	24	24	Level of Service: Service Quality Resource Efficiency Asset Value - Financial	• Damage to poles and lines from high wind events. • Risk of damages from falling trees, broken tree limbs or flying debris.	• Loss of assets • Disruption of service • Impact on scheduling/productivity/ resources • Difficulty in restoring service due to health and safety concerns for staff • Public safety concerns due to downed power lines

6.3 EXTERNAL RISKS

Through the interview and workshop processes, several external risks were brought to light. These were listed as “Third Party Services and Interactions” in the risk worksheet. External risks identified through this assessment are summarized below:

- Hydro One: power supply, shared infrastructure, attached equipment;
- City of Ottawa: stormwater drainage, winter maintenance;
- Telecommunications: Bell and fibre lines;
- Fuel Supply;
- Hydro Ottawa Subsidiaries: Energy Ottawa, Envari; and,
- Emergency Resources: mutual assistance partners, logistics (food services and lodging).

Managing many of these risks can be a challenge for Hydro Ottawa as in most cases, they have no direct control over the management of these third-party infrastructure elements and services. A discussion on how to address external risks presented in the adaptation report.

7.0 NEXT STEPS

This climate risk and vulnerability assessment represents the first component of a two-part study. The second part of the study will address risk meditation and adaptation recommendations for Hydro Ottawa to help them adapt to future climate risks and facilitate continuous improvement in their electrical distribution and supporting infrastructure.

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Appendix A CLIMATE CHANGE HAZARDS REPORT

RISK SCIENCES INTERNATIONAL

REPORT

Hydro Ottawa Climate Vulnerability Risk Assessment

Prepared for:
Hydro Ottawa

24 May 2019

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1. Climate Data and Analysis

Changes in climate, as reflected in long-term trends and in increases in both frequency and intensity of extreme weather events, are expected to cause a wide range of potentially costly and disruptive impacts to Hydro Ottawa's electrical distribution system, services, and operations. Hydro Ottawa's 1,116 km^2 service area includes both the City of Ottawa and the Village of Casselman (**Figure 1**) and services over 330,000 customers. Hydro Ottawa is the largest local distribution company in eastern Ontario. Having a strong environmental commitment, Hydro Ottawa recognizes the need to lead by example by implementing climate adaptation and resilience into its own assets and operations. In order to assess the resiliency of Hydro Ottawa's electrical distribution system, this project undertakes a distribution system climate vulnerability risk assessment (CVRA). The results of this project will inform the development of a Climate Change Adaptation Plan and help drive continuous improvement to Hydro Ottawa's Asset Management System.

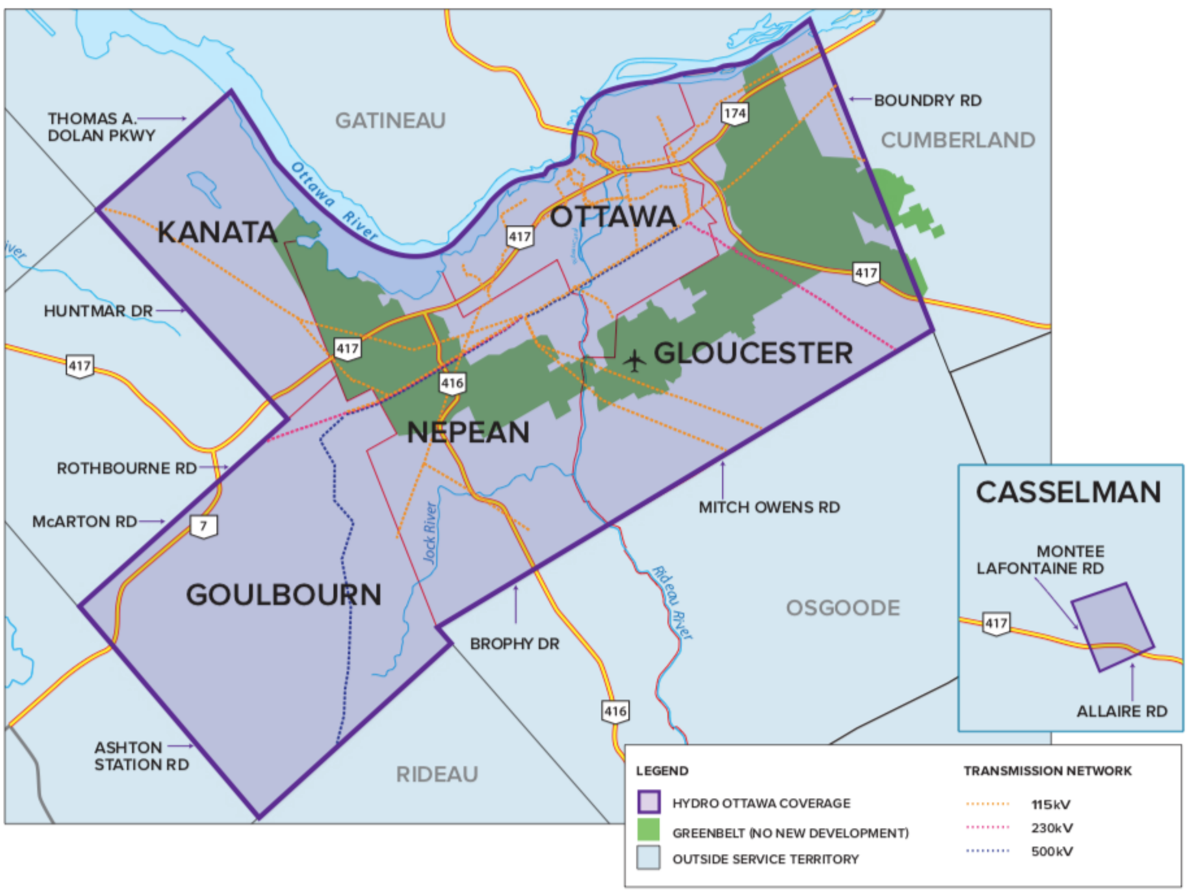

Figure 1: Map of the Hydro Ottawa service area in the City of Ottawa and Village of Casselman regions. Areas shaded in purple represent the Hydro Ottawa service area, while those shaded in blue are outside of its jurisdiction. The Ottawa Macdonald-Cartier International Airport, located in the Gloucester Ward, is also indicated. Figure from Hydro Ottawa, 2018a.

The IPCC defines risk as: "the potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain". Risk is often represented as the probability of occurrence of hazardous events or trends multiplied by the consequences if these events occur (IPCC, 2014a). Risk can be further understood as the interaction between vulnerability, exposure, and hazard (IPCC, 2014b). A hazard is the potential occurrence of an event, trend, or physical impact, which results in damage to something of human value. This could include, but is not limited to, infrastructure, livelihoods, ecosystems, and human health impacts.

Changes in climate translate into direct and indirect impacts to municipal services, critical public infrastructure, spaces and assets/facilities, and community networks. Climate risks and hazards can be associated with two types of climate or weather events analogous to “shock” vs. “stress”: (1) rare, extreme and rapid/sudden-onset extremes or “shock events” and (2) slow onset or “creeping” threats or “stress events”. Extreme events are factored into building codes and practices through the use of extreme value or return period climate probabilities. Alternatively, many of the slow onset or recurring climate events that can be expected to occur several times annually are important when maintaining the service life and durability of structures and are sometimes included in standards. Studies indicate that damages to infrastructure from extreme events tend to increase dramatically above critical climate thresholds, even though the extreme weather events associated with these damages may not be much more severe than the type of storm intensity that occurs regularly each year (Freeman and Warner, 2001; Coleman, 2003; Auld and MacIver, 2007; Auld, 2008). For instance, analyses of insurance loss data and other impact information, together with detailed analyses of extreme winds, indicate that losses to buildings in Southern Ontario are likely highly sensitive to increasing extreme wind speeds above threshold values. A detailed analysis of building damages and insurance claims within the City of Toronto and other Ontario municipalities indicate that damages and losses to buildings begin to increase significantly (nearly exponentially) when wind gusts exceed 90 km/hr (Auld, 2008).

Impacts of climate change on assets can include structural damage, reduced service life for asset components and for assets themselves, and the service life for the asset itself, and increased stress to systems and operations. Subsequent impacts can result in higher repair and maintenance costs, loss of asset value, and interruption of services or production housed by impacted assets, among others.

The development of climate data for this climate vulnerability risk assessment of Hydro Ottawa’s distribution system involved three main activities:

- Identification of climate parameters (e.g. temperature, precipitation, winds) and threshold values at which infrastructure performance would be affected (i.e. climate hazards);
- Projecting the probability of occurrence of climate hazards for future climate (i.e. 2050s); and
- Converting projected probability of occurrence of future climate parameters into the five-point scoring scale used in Hydro Ottawa’s Asset Management System Risk Procedures.

The procedures used to perform this analysis, and the associated analytical results, are detailed in the following subsections, following an overview of the local climate of the Greater Ottawa Region. Additionally, forensic analyses of three high impact events that affected the Hydro Ottawa distribution system in 2018 are provided.

1.1 Climate Data Sources

1.1.1. Baseline Climate: Historical Conditions

The baseline climate refers to the current and historical conditions. Climate data sources for this study include the most recent Environment and Climate Change Canada (ECCC) issued “Climate Normals” for the official averaging period of 1981-2010. In most cases, climatological analyses were completed using data from the ECCC climate data archive from the Ottawa Macdonald-Cartier International Airport meteorological station (**Figure 1**) and the Russell meteorological station. In most cases, the differences between the two stations were such that the Ottawa Airport station was used as the main data source. The Ottawa Airport station provides a long-term uninterrupted set of climate observations with hourly and daily data available to complete the analyses of most climate parameters. Rate-of-rainfall and extreme precipitation analyses are, however, challenged by an out-of-date intensity-duration-frequency (IDF) curve (only updated to 2007) for the Ottawa Airport state. This out-of-date record does not accurately reflect current climate conditions (e.g. missing notable extreme rain events in recent years). Therefore, climate analyses skills and experience are needed for the analyses and careful interpretation of extreme events over the baseline (current and historical) period climate information.

When required, separate datasets and specialised studies were consulted to address localised and high impact events, i.e. parameters which are difficult to observe using standard meteorological instrumentation and methods (e.g. tornadoes and lightning strikes). For instance, the national tornado database (Cheng et al., 2013) and the Canadian lightning detection network (Shephard et al., 2013) were used in the analyses of the tornado and lightning climate parameters, respectively. Specialised datasets and studies were combined with quantitative analyses and expert meteorological judgment to complete evaluation of the baseline conditions of the complex or rare events.

1.1.2. Climate Change Projections

1.1.2.1. CMIP5 Climate Models and the Delta Approach

The most authoritative source of climate change projections is the UN-supported Intergovernmental Panel on Climate Change (IPCC). Climate change projections of temperature- and precipitation-based parameters for this study were derived from an ensemble of 37 Global Climate Models (GCMs) for the most recent IPCC 5th Assessment Report (AR5; IPCC, 2013) (**Table 1**). In this assessment, the 37 GCMs, some with multiple runs per model, resulted in approximately 75 projection estimates from which to calculate possible future conditions. The use of multiple models to generate a ‘best estimate’ of climate change (multi-model ensembles) is preferred over a single or few individual model outcomes since each model can contain inherent biases and weaknesses and constructing multi-model ensembles can reduce and inform on the uncertainties in the climate projections (IPCC-TGICA, 2007; Tebaldi and Knutti, 2007). Maximum, minimum, and mean temperatures are standard output variables from these GCMs, as is mean precipitation.

Table 1. CMIP5 Global Climate Models (GCMs) used in this study.

Model Name (# of runs)	Organization	Country	Organization Details
ACCESS1-0 (1)	CSIRO-BOM	Australia	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
ACCESS1-3 (1)	CSIRO-BOM	Australia	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)
BCC-CSM1-1 (1)	BCC	China	Beijing Climate Center, China Meteorological Administration
BCC-CSM1-1-M (1)	BCC	China	Beijing Climate Center, China Meteorological Administration
BNU-ESM (1)	GCESS	China	College of Global Change and Earth System Science, Beijing Normal University
CanESM2 (5)	CCCma	Canada	Canadian Centre for Climate Modelling and Analysis
CCSM4 (6)	NCAR	US	National Center for Atmospheric Research
CESM1-BGC (1)	NSF-DOE-NCAR	US	National Science Foundation, Department of Energy, National Center for Atmospheric Research
CESM1-CAM5 (3)	NSF-DOE-NCAR	US	National Science Foundation, Department of Energy, National Center for Atmospheric Research
CMCC-CESM (1)	CMCC	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CMCC-CM (1)	CMCC	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CMCC-CMS (1)	CMCC	Italy	Centro Euro-Mediterraneo per I Cambiamenti Climatici
CNRM-CM5 (1)	CNRM-CERFACS	France	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique
CSIRO-Mk3-6-0 (10)	CSIRO-QCCCE	Australia	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence
FGOALS-g2 (1)	LASG-IAP	China	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences
FGOALS-s2 (1)	LASG-IAP	China	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences
FIO-ESM (3)	FIO	China	The First Institute of Oceanography, SOA, China
GFDL-CM3 (1)	NOAA GFDL	US	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2G (1)	NOAA GFDL	US	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2M (1)	NOAA GFDL	US	Geophysical Fluid Dynamics Laboratory
GISS-E2-H (1)	NASA GISS	US	NASA Goddard Institute for Space Studies
GISS-E2-H-CC (1)	NASA GISS	US	NASA Goddard Institute for Space Studies
GISS-E2-R (1)	NASA GISS	US	NASA Goddard Institute for Space Studies

Model Name (# of runs)	Organization	Country	Organization Details
HadGEM2-AO (1)	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2-CC (3)	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
HadGEM2-ES (4)	MOHC	UK	MetOffice Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
INMCM4 (1)	INM	Russia	Institute for Numerical Mathematics
IPSL-CM5A-LR (4)	IPSL	France	Institut Pierre-Simon Laplace
IPSL-CM5A-MR (1)	IPSL	France	Institut Pierre-Simon Laplace
IPSL-CM5B-LR (1)	IPSL	France	Institut Pierre-Simon Laplace
MIROC-ESM (1)	MIROC	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC-ESM-CHEM (1)	MIROC	Japan	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC5 (3)	MIROC	Japan	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MPI-ESM-LR (3)	MPI-M	Germany	Max Planck Institute for Meteorology (MPI-M)
MPI-ESM-MR (1)	MPI-M	Germany	Max Planck Institute for Meteorology (MPI-M)
MRI-CGCM3 (1)	MRI	Japan	Meteorological Research Institute
NorESM1-M (1)	NCC	Norway	Norwegian Climate Centre

Climate analyses in this study use projections for the “business-as-usual” Representative Concentration Pathway emissions scenario – RCP8.5 – and for the 2050s (2041-2700). Current greenhouse gas concentrations correspond to the RCP8.5 projected trajectory (**Figure 2**).

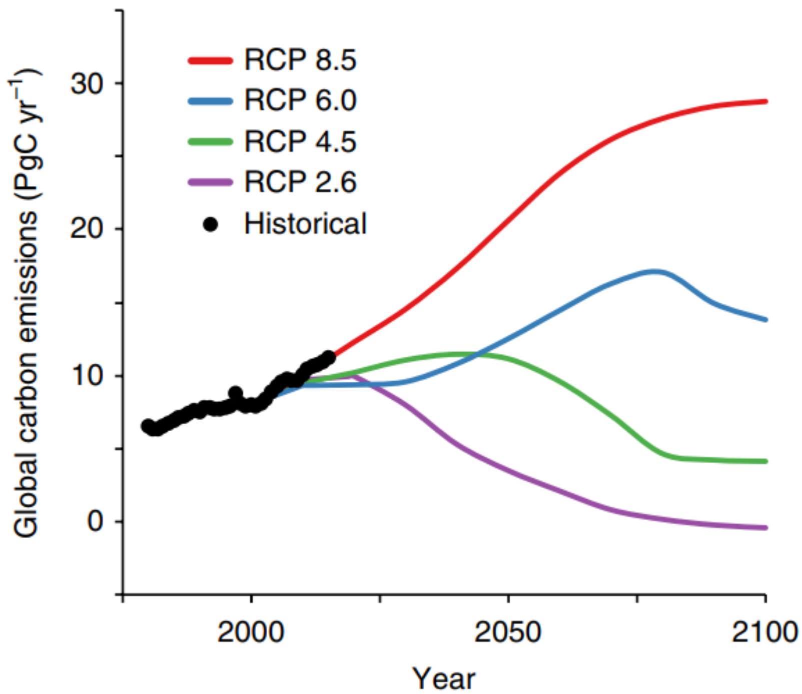

Figure 2. Historical CO2 emissions for 1980-2017 and projected emissions trajectories until 2100 for the four Representative Concentration Pathway (RCP) scenarios. Current global emission trends have very closely followed the "business-as-usual" RCP8.5 scenario trajectory. Figure from Smith and Myers, 2018.

In this study, the "Delta Approach" is used to generate localised climate change projections (IPCC-TGICA, 2007). The Delta Approach method is one of the simplest and most straightforward approaches available for obtaining downscaled projections of future, is easy to understand, and has widespread use in impact and adaptation studies. The Delta Approach consists of applying the average projected difference (the "delta") for a given climate parameter to the historical average or baseline value. The Delta Approach generally provides more useful data when it is coupled with the use of many models (ensembles; e.g. CMIP5 GCMs) to generate projections than when coupled with a single or small set of models, regardless of model spatial and temporal resolution. A detailed description of the Delta Approach and how it is used in this assessment is provided in **Appendix A**.

1.1.2.2. Specialised Studies

Some climate parameters are not well handled by climate modeling at any temporal or spatial resolution (e.g. severe and complex events such as ice storms and tornadoes). For these climate parameters, scientific literature is reviewed for any available guidance on the direction and magnitude of potential changes in these complex variables under a changing climate. The challenges posed in understanding future changes in complex events requires the application of detailed and time-consuming techniques to better reflect the scale and complexity of these hazards, and to increase confidence in analytical results. In these cases, projections were derived from applicable specialised studies available in the published literature, such as research addressing local changes in ice storm activity (Cheng et al., 2011) or high winds in the form of damaging wind gusts (Cheng et al, 2012; Cheng 2014).

In other cases, location-specific studies may not be available, but research into the potential effects of climate change on specific hazards can still provide guidance on future changes which can be applied to the study location. For example, ongoing research is refining our understanding of the links between air temperature and rainfall rates (Westra et al., 2014; Barbero et al., 2017), results which can be used to develop tailored projections for the Greater Ottawa Region. Recent research on trends in tornado activity in the United States (Strader et al., 2017; Gensini and Brooks, 2018) also indicates both recent and future shifts in tornado occurrence which are potentially relevant to the Greater Ottawa Region and surrounding areas. These and other studies are an ongoing area of active investigation and RSI provides insight into these types of phenomena to the best of its ability. Climate hazards where specialized studies are applied in the calculation of future climate projections are identified within each section, and references to literature and studies are provided within the references section of the report.

1.1.2.3. Climate Analogue

Climate projections can also be used to identify a “climate analogue” for the Greater Ottawa Region. Climate analogues are simply geographical locations that currently exhibit *average* climate conditions that are similar to those projected for future time periods in the location of interest. Ideally, climate analogues currently have the same annual average temperature and precipitation values as the future projected climate for the Greater Ottawa Region, and also exhibit similar elevation and topography and exposure to atmospheric circulation patterns (e.g. lake and ocean influences). This method can inform the assessment in many ways, including evaluation of potential viable adaptation options which may be already in place at analogue locations (Ramírez-Villegas et al., 2011). In general, climate analogues can provide potential clues regarding new or emerging hazards which have not yet been experienced in the study location, offering a window into impacts and needed adaptation actions that could reasonably be anticipated under future conditions. They can also provide useful insights into hazards that are not well handled by climate modeling alone, especially when location and hazard specific studies are not readily available in the literature. For this study, a climate analogue location of Pittsburgh, Pennsylvania was identified for the Greater Ottawa Region. Pittsburgh, PA corresponds to the projected future annual average temperatures expected in the Greater Ottawa Region in the 2050s under the RCP8.5 scenario and has roughly similar city and elevation characteristics to those of Ottawa. This climate analogue provides general, “order of magnitude” comparisons which help further determine if climate change projections are in fact realistic and represent potentially “real” climates.

1.1.2.4. Professional Judgment

“Perfect” or “ideal” information and data for given hazard usually do not exist, and assessments always require the application of professional judgment from interdisciplinary teams to make use of the data and information available. While sometimes referred to as a *source* of risk assessment information, professional judgment is better characterised as the process applied to the best available information; i.e., how is all available information weighted, interpreted, and applied within the assessment using the expertise of assessment team members. The PIEVC Protocol, for example, states that “Professional Judgment is the interpretation and synthesis of data, facts and observations collected by the team and the extrapolation of that analysis to provide a judgment of how the infrastructure may respond to a specific set of conditions.” (Engineers Canada, 2016). Within the context of an assessment, this refers to the use of professional judgment to interpret and apply what is often incomplete – but still the best available – data and information. The discussion and decision-making process surrounding the application of professional judgment is also documented in detail for the purposes of traceability, so that future review and application of any analytical results can be understood within the proper context.

1.2 Identification of Climate Parameters and Thresholds

The climate parameters and thresholds established for analysis in this study were assembled and analysed through a combination of the following:

- Climatic design values in engineering codes and standards;
- Practitioner experience (especially in managing past impacts and risks);
- Literature review;
- Forensic investigation of past events; and
- Stantec interviews with Hydro Ottawa personnel.

In some cases, multiple thresholds were developed for the same parameter, either because multiple thresholds held some significance for one or more of the assets in the Hydro Ottawa electrical distribution system, or because the threshold was different for each asset. Climate parameters and thresholds were then verified and refined, as needed, based on the experience and knowledge of Hydro Ottawa personnel at the 12 April 2019 workshop.

Identified climate hazards relevant to Hydro Ottawa's electrical distribution system are outlined below in **Table 2**, ranging from short duration and sudden onset weather events (e.g. tornadoes) to gradual onset climate events (e.g. gradually increasing temperature extremes). Performance considerations and selection rationale are also outlined in **Table 2**.

Table 2: Identified climate parameters and thresholds used in this study, along with an overview of performance considerations and rationale for selection.

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Temperature			
Extreme Heat	$T_{max} \geq 25°C$	**Level of Service** – High heat days; danger to workers on site **Resource Efficiency** – Higher demand on grid for cooling; reduced time for cooling of electrical components	• Tmax ≥ 30°C identified as a personnel issue; • Tmax of 40°C used as a design value; • Higher temperature thresholds lead to extra loading on the system from increased commercial and residential air conditioner use; • Thermal stress can result in cracking and fissuring in materials (e.g. polymer-based materials).
	$T_{max} \geq 30°C$		
	$T_{max} \geq 35°C$		
	$T_{max} \geq 40°C$	**Asset Value** – High temperature operating threshold	
	$T_{mean} \geq 30°C$	**Level of Service** – High heat days; danger to workers on site **Resource Efficiency** – Higher demand on grid; reduced time for cooling of electrical components	
Heat Waves	Consecutive Days with $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$	**Level of Service** – Consecutive high heat days; danger to workers on site **Resource Efficiency** – Prolonged and (very) high demand (near capacity) on grid for cooling (nights not cooling); reduced time for cooling of electrical components	• System overloading common after 3 days of consecutive heat due to high demands on electrical grid (e.g. transformers) by increased air conditioning use; • Equipment unable to cool properly reducing functionality.
	Consecutive Days with $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$		
Extreme Cold	$T_{min} \leq -35°C$	**Level of Service** – Extreme cold days; danger to workers on site **Resource Efficiency** – Higher demand on grid for heating **Asset Value** – Approaching low temperature operating threshold	• Identified as a personnel issue; • Older sections of Ottawa may experience overcapacity due to extensive use of electric baseboard heating;

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
			• Tmin of -40°C used as a design value; • Extreme cold can result in underperformance of vehicles and outdoor infrastructure.
Rain			
Extreme Rain	50 mm in 1 hour	**Level of Service** – Localised flooding; flooding of low-lying areas and subterranean infrastructure (e.g. underground vaults) possible	• Design threshold; • Hydro Ottawa personnel have indicated extreme rainfall has not significantly impact Hydro Ottawa infrastructure, although low-lying equipment, such as vaults, may be more vulnerable (particularly in older neighbourhoods); • Extreme rain can result in reduced accessibility to assets (e.g. flooded roadways).
Freezing Rain & Ice Storms			
Ice Accumulation	25 mm	**Level of Service, Resource Efficiency** – Local to regional power outages	• Design threshold is 25 mm (corresponding to 12.5 mm of radial ice accretion on overhead lines); • Pole fires and flashovers possible during freezing rain events; • Most common damage to infrastructure related to ice accretion and accumulation on
	40+ mm	**Asset Value, Level of Service, Resource Efficiency** – Major and widespread outages possible; prolonged events	

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
			tree branches and resulting breaks; • Combined ice accretion and wind is a concern.
Snow			
Snow Accumulation	Days with ≥ 5 cm	**Level of Service** – Snow clearing begins, could impact poles/infrastructure; salt use	• Equipment issues mostly related to snow plow damage (transformer collars, transformers, and switchgear all potentially impacted); • Issues with access to assets.
	Days with ≥ 10 cm	**Level of Service** – Snow clearing, could impact poles/infrastructure; salt use; access issues	
	Days with ≥ 30 cm	**Level of Service –** Snow clearing, could impact poles/infrastructure; salt use; access to lines and vaults; requires extra clearing	
High Winds			
Seasonal	60+ km/hr gust (Summer)	**Level of Service** – Lower wind speeds required to cause issues when trees have foliage; easterly winds are of particular concern	• Hydro Ottawa personnel have noted wind intensity and frequency has increased in recent years; • North-south power lines identified as vulnerable, particularly to easterly winds (lines are guyed for protection from prevailing westerly winds) (e.g. Greenbank Road, Fisher Avenue, Limebank Road); • Potential damage to infrastructure due to tree and limb falls and wind-swept
	80+ km/hr gust (Winter)	**Level of Service** – Higher wind speeds result in issues when trees are bare; easterly winds are of particular concern	
Annual	90+ km/hr gust	**Asset Value** – Design threshold (corresponds to wind pressure values)	
	120+ km/hr gust	**Asset Value** – Wider spread of damage; straight line wind gusts	

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
			debris and reduced access due to debris deposits
Lightning			
Lightning	Strikes near infrastructure	**Level of Service** – health and safety risk **Resource Efficiency** – direct strike could result in damage and loss of functionality	• Hydro Ottawa personnel have noted thunderstorm duration and frequency are increasing; • Lightning strikes may blow transformers, breakers, fuses, and arrestors (1-2 instances per year noted); • Lightning protection system design frequency of 1 flash/km^2/yr; • Some substations have lightning rods.
Tornadoes			
Tornadoes	EF1+ in Hydro Ottawa service area (City of Ottawa) EF1+ point probability (i.e. tornado striking a specific asset, e.g. a substation, in the City of Ottawa service area)	**Asset Value, Level of Service, Resource Efficiency** – Significant damage and major outages possible; prolonged events	• Rare, but severe impacts to Hydro Ottawa infrastructure (e.g. 2018 tornado outbreak – damage due to tree and limb falls and flying debris, direct hit of Merivale transmission station, disruption of transportation corridors impacted response efforts).

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Invasive Species			
Emerald Ash Borer (EAB)	T_{min} ≤ -30°C	**Asset Value** – Damage to hydro poles and other vulnerable infrastructure	• Hydro Ottawa personnel report increased damage to hydro poles by both EAB and the spike in woodpecker population following the introduction of EAB to the Greater Ottawa Region; • EAB infestation makes trees vulnerable to breakage which can lead to damage to power lines; • Tmin ≤ -30°C is the kill threshold for EAB mature, non-feeding larvae.
Giant Hogweed	3 Days T_{max} ≤ -8°C	**Level of Service** – Significant human health risk upon exposure	• Upon contact, a severe occupational hazard for workers – sap can cause serious skin inflammation on contract, exposure to sunlight results in more serious reaction (e.g. blisters, discolouration, scars), contact with eyes can result in loss of vision, blindness, or damage; • 3 days with Tmax ≤ -8°C required for germination of Giant Hogweed seeds.
Fog			

Climate Parameter	Thresholds	Performance Considerations	Selection Rationale
Fog	Days in Winter (Nov.-March)	**Asset Value –** Damage to hydro poles and other vulnerable infrastructure	• Aerosolizing of salts can cause corrosion and moisture in winter; • Salt spray on insulators and conductors can cause pole fires and flashovers.
Frost			
Freeze-thaw Cycles	Daily T_{max} T_{min} temperature fluctuation around 0°C Daily T_{max} T_{min} temperature fluctuation of ±4°C around 0°C	**Asset Value –** Freeze-thaw cycles can result in weathering and damage to hard infrastructure (minimum of 30 cycles/year required to damage concrete) **Level of Service** – Freeze-thaw cycles can lead to icy conditions which become a health and safety concern	• Hydro Ottawa personnel have noted more mid-winter events, resulting in more pole fires; • Freezing moisture known to cause failure in underground cabling, has increased incidents of pole fires, and limits access by crews; • Associated thermal stresses and frost weathering can result in cracking and fissuring in materials (e.g. polymer-based materials); • Large temperature ranges in freeze-thaw cycles can result in increased weathering and damage.

1.3 Greater Ottawa Region Climate Profile

As with the rest of globe, Canada, and Southern Ontario, the climate of the Greater Ottawa Region has been changing. **Figure 3** presents the annual mean temperature in Ontario over the 1951-1980 and 1981-2010 periods. The change in mean annual temperature can be inferred from comparison of the plots (i.e. the difference in the colouration) with observed increases in temperature throughout the province, Southern Ontario, and in the Greater Ottawa Region. Using data collected at the Ottawa International Airport, observed annual daily mean, maximum, and minimum temperatures have risen over the 1981-2010 time period by 0.9°C, 1.0°C, and 0.8°C, respectively (**Figure 4**). The long observation record at the Ottawa Airport weather station (1939-present) further indicates the overall increase in temperature (OCCIAR, 2011a). Furthermore, this long record highlights that the greatest temperature change has occurred during the winter months with an average mean increase of 2.2°C at the Ottawa Airport (OCCIAR, 2011a) over the 1939-2010 time period. Of the three temperature variables (mean, maximum, and minimum), the greatest changes in a single season have been observed for the average winter minimum temperature over this long record, with an increase of 2.5°C at the Ottawa Airport (OCCIAR, 2011a) during the 1939-2010 time period. The overall annual temperature trend for the Greater Ottawa Region appears to indicate an increase of 1.7°C per century (ECCC, 2016). Previous work in Ontario supports the increasing temperature trends and also suggests that certain areas within Southern Ontario could have summers that are 2-3°C warmer by the mid-century and potentially 4-5°C warmer by as early as 2071 (MNR, 2007).

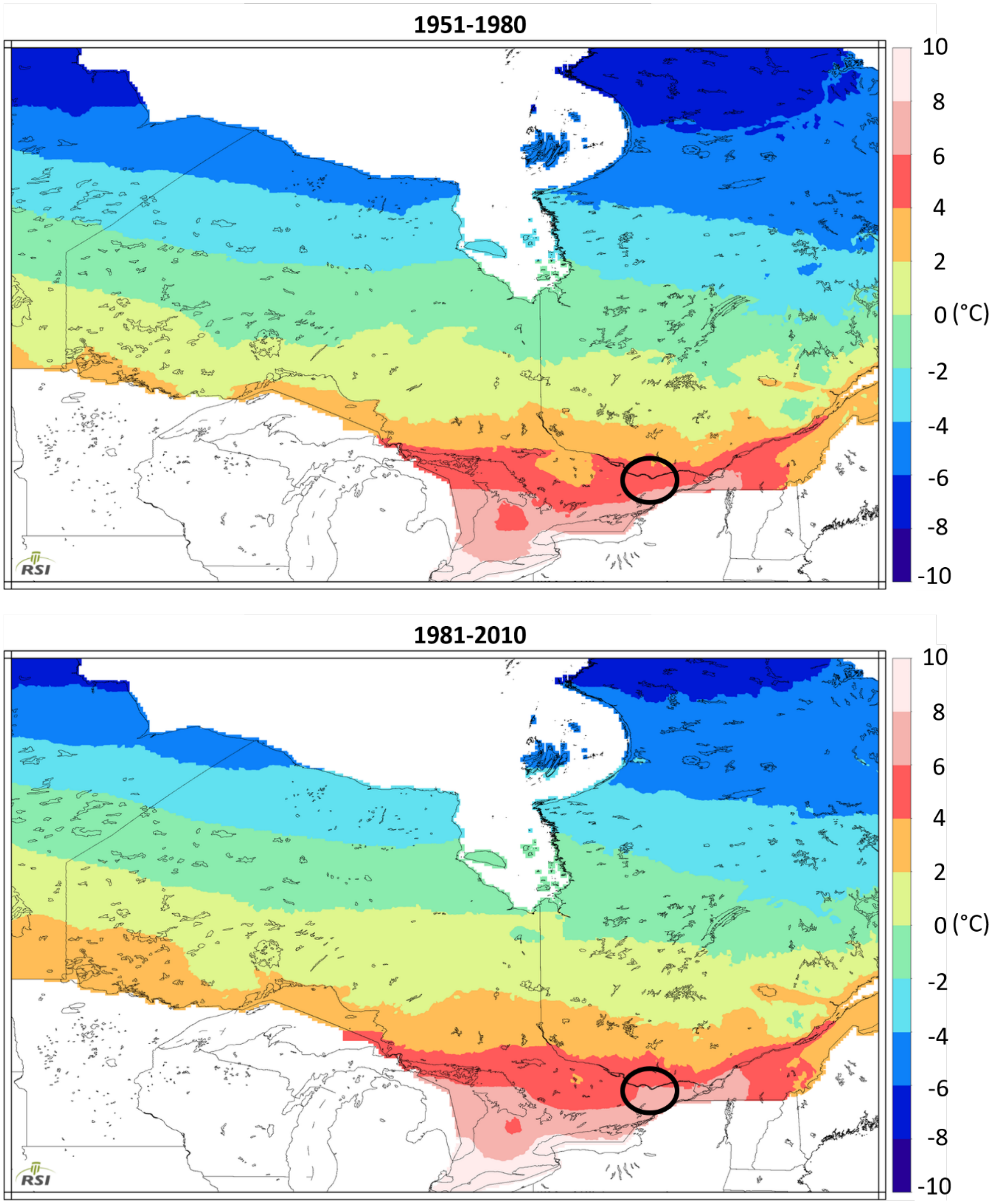

Figure 3. Observed annual mean (2m) air temperature over the 1951-1980 (upper) and 1981-2010 (lower) periods. The change in mean annual temperature can be inferred from comparison of the plots (i.e. the difference in the colouration), with observed increases in temperature throughout Southern Ontario. Annual mean temperatures in the Greater Ottawa Region (located within the black circle) have increased from 4-6°C during the 1951-1980 period to 6-8°C during the 1981-2010 period. (Data from ECCC/NRCan Canadian Gridded Temperature and Precipitation Data [CANGRD], 10 km horizontal resolution, using the ANUSPLIN climate modeling software [McKenney et al., 2011]; plots produced by Risk Sciences International.)

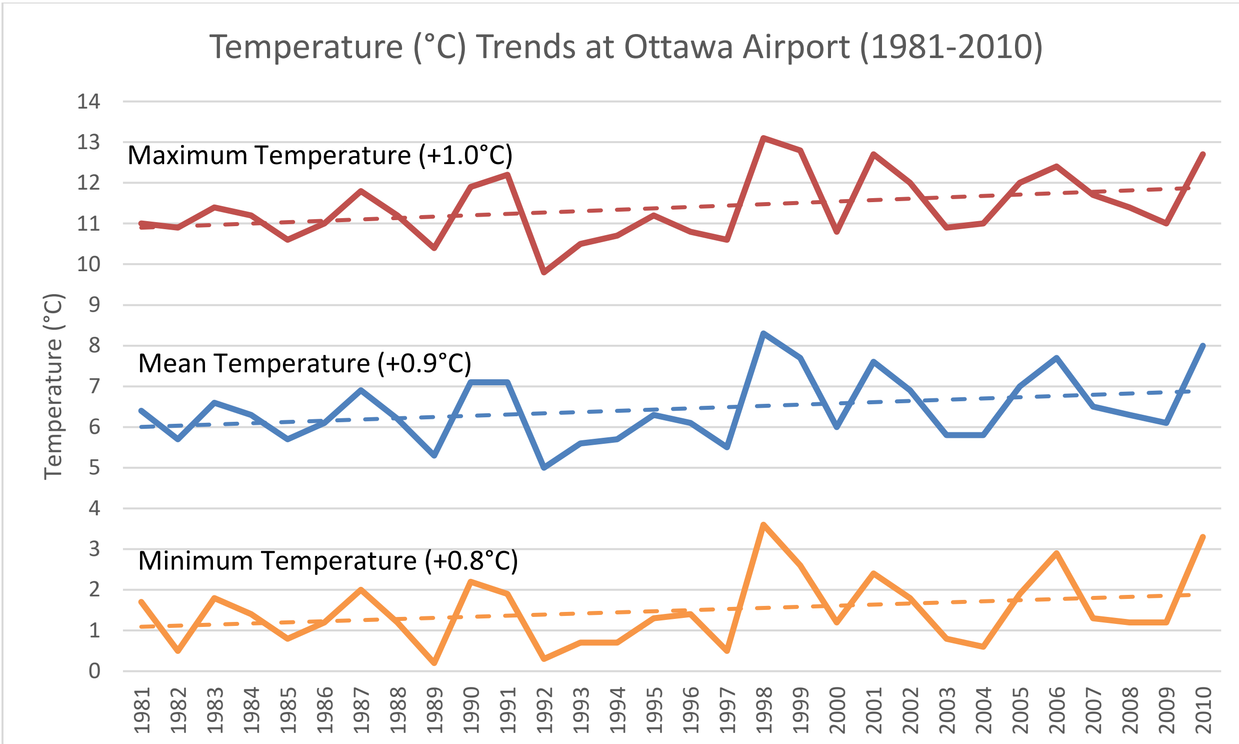

Figure 4. 1981-2010 annual mean, maximum, and minimum temperature data and trends at Ottawa Airport.

The warming of the climate system has also led to important changes in temperature extremes. Since 1950, the number of cold days and nights has decreased while the number of warm days and nights has increased in Canada (Bush et al., 2014). As a result, a decrease in the frequency and intensity of extreme cold events has been observed in the Greater Ottawa Region. Nevertheless, extreme cold events still continue to occur in association with wintertime southward dips in the Polar Vortex, such as those in recent winters (2012-13, 2013-2014, 2017-18, and 2018-19). Alternatively, an increase in the frequency and intensity of extreme heat events has been observed. For instance, at the Ottawa Airport, the average annual number of days with a maximum temperature of 30°C or greater has increased from 13.4 days to 15 days over the 1981-2010 time period. Similarly, an increase in the frequency and duration of heat waves has also been observed in the region.

Precipitation trends in the region also appear to be changing, though less steadily than temperature. The Greater Ottawa Region has experienced an overall increase in observed total annual precipitation, with total precipitation increasing 25.9 mm at the Ottawa Airport during the 1981-2010 time period (**Figure 5**). The long observation record at Ottawa Airport further indicates an overall increase in total annual precipitation (+142 mm over the 1939-2010 time period) (OCCIAR, 2011a). While this long-term increase in total annual precipitation is coupled with a long-term slight decrease in the annual winter precipitation (-9 mm over the 1939-2010 time period) (City of Ottawa, 2011; OCCIAR, 2011a), average December-January-February rainfall total has increased at the Ottawa Airport from 69.1 mm to 80.6 mm during the 1981-2010 time period.

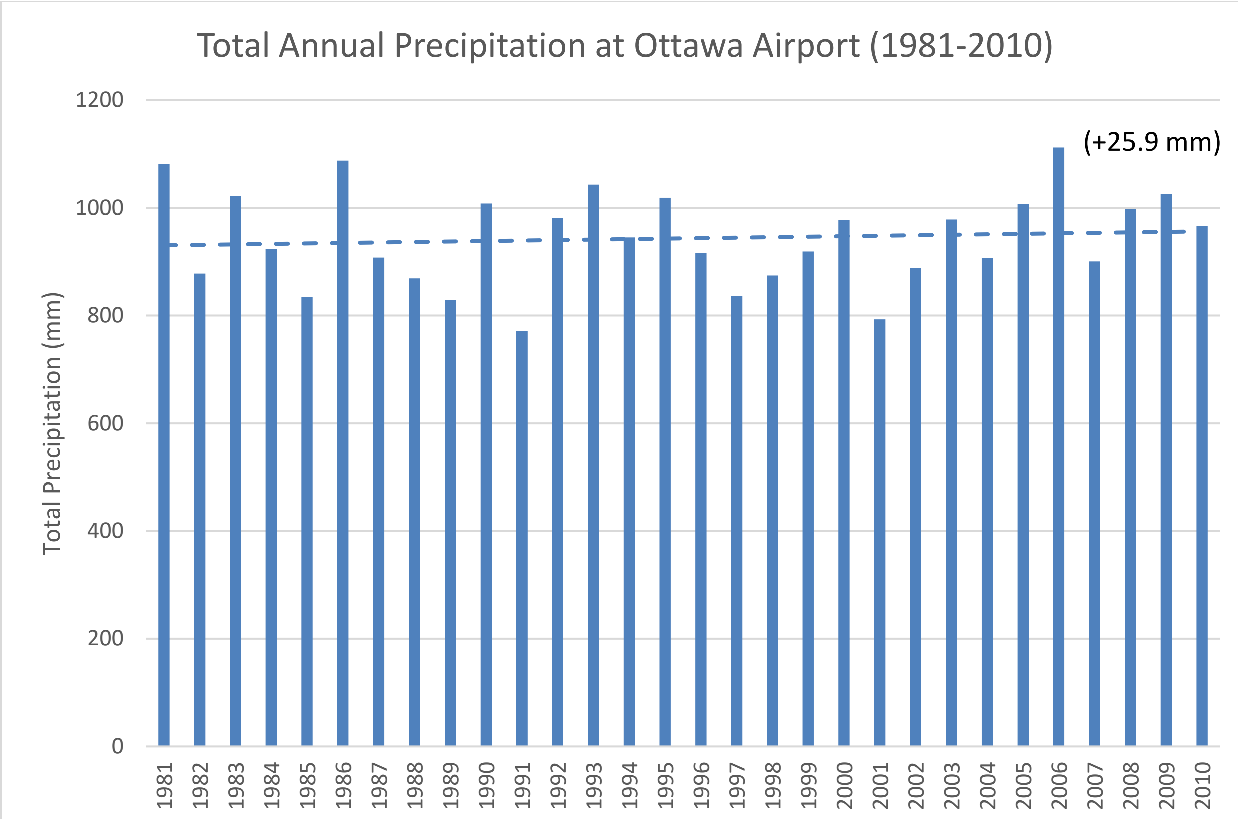

Figure 5. 1981-2010 total annual precipitation data and trend at Ottawa Airport.

Trend analysis of changes in Canadian precipitation and, in particular, extreme precipitation is challenging due in part to the low spatial density of the precipitation data and especially the rate-of-rainfall (tipping bucket rain gauge) station network, with many rate-of-rainfall station records being considerably out-of-date (e.g. by a decade). Subsequently, statistically significant and conclusive evidence on changes in (extreme) precipitation are difficult to obtain from Canadian stations. Nevertheless, an overall increase in total annual rainfall has been observed for Southern Ontario since the 1950s (Mekis and Vincent, 2011; Bush et al., 2014), with more increasing (though often not statistically significant) trends than decreasing trends in extreme rainfall having also been detected (Bush et al., 2014; Shephard et al., 2014; Mekis et al., 2015; Vincent et al., 2018). Regional trend analyses (regionally averaged station data) have been found to detect stronger trends compared to the use of individual station records (Shephard et al., 2014; Soulis et al., 2016). For instance, Soulis et al. (2016) determined that extreme rainfall, averaged for all of Ontario, has increased by 1.8% per decade for 24-hr duration events and by 1.25% per decade for 30-minute duration events during the 1960-2010 period. In contrast to Canadian extreme precipitation research results, U.S. studies have been more conclusive in showing statistically significant increasing regional trends in extremes (e.g. in the US Northeast and Midwest; **Figure 6**) (Walsh et al., 2014; Easterling et al., 2017). In part, these trend differences can be linked to geographical regions and indicators and their threshold levels, although differences in the density of the observing networks may be a main contributor. Many of these increasing trends are being observed in states directly bordering Canada, including Southern Ontario (**Figure 6**), and there is no reason to believe that similar (i.e. increasing) trends to these detected US trends would not also be evident north of the border but are masked by the observation network data itself.

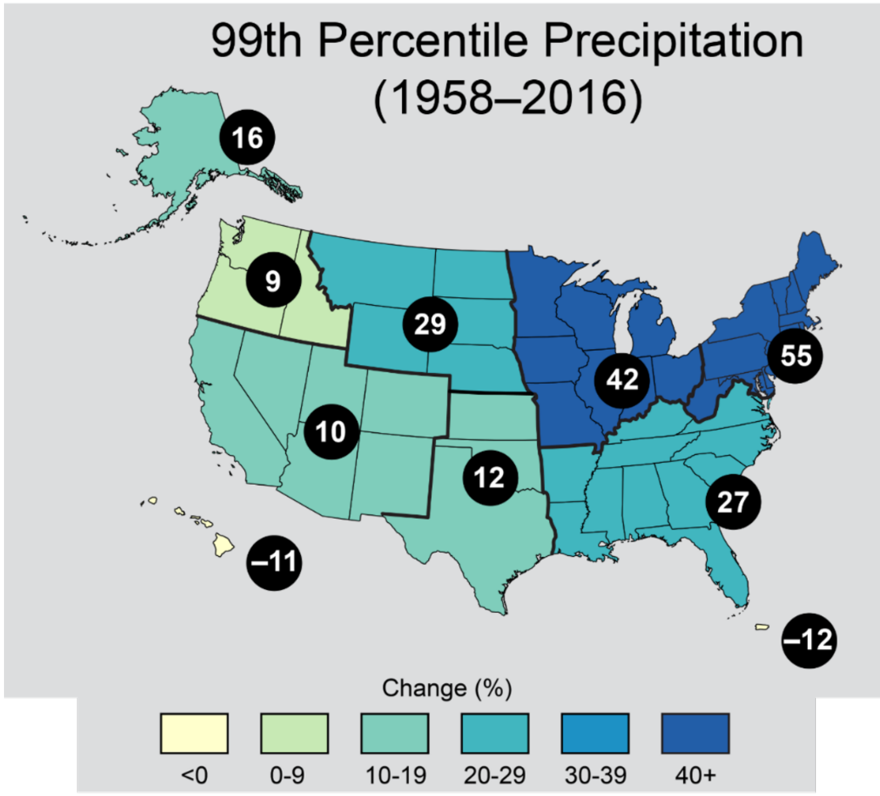

Figure 6. Percent increases in the amount of precipitation falling in daily events that exceed the 99th percentile of all days with precipitation (i.e. the total precipitation falling in the top [heaviest] 1% of daily precipitation events) in the United States, 1958-2012, calculated from daily precipitation total observations. Figure from Easterling et al., 2017.

Severe weather extreme events, such as freezing rain and ice storms, lightning, high winds and tornadoes, can result in significant impact and damage to electrical infrastructure and are influenced by the changing climate. Historical research (Klaassen et al., 2003) was able to confirm four major freezing rain and ice storm events, i.e., those which resulted in long term and widespread power and communication outages, affecting the Greater Ottawa Region since 1940, including the most recent April 2018 event as well as the infamous January 1998 ice storm. Across the Greater Ottawa Region, lightning flash density varies from approximately 1.0 to 1.2 flashes per square kilometer (ECCC National Lightning Database). Eastern Ontario (and Western Quebec) have also historically been subject to periodic significant tornado outbreaks, including the recent September 21, 2018 tornado outbreak which included three significant (EF2 and EF3) tornadoes impacting the Greater Ottawa Region. Gensini and Brooks (2018) also report an observed increase in days with potential for significant tornado develop in northeastern North America over the past ~40 years.

Under climate change, observed trends are projected to continue. **Table 3** outlines general projected changes in climate parameters of interest to Hydro Ottawa's electrical distribution system, services, and operations

Table 3. Summary of potential climatic changes in the Greater Ottawa Region.

Climate Parameter	Projected Changes
Temperature – Extreme Heat	• Increased frequency and intensity • Increased frequency and length of heat waves
Temperature – Extreme Cold	• Decreased frequency and intensity • Occurrence of extreme cold outbreaks ("Polar Vortex" winters) likely to continue
Rain (Short Intensity – High Duration)	• Increased intensity of events • Reduced return periods (e.g. 20-yr return period event becoming a 10-yr return period event)
Freezing Rain & Ice Storms	• Increased frequency • Increased winter season (e.g. January) events
Snow	• Likely decrease in annual total accumulation • Continued occurrence and steady frequency of larger individual events
High Winds	• Slight increase in frequency of high wind events (e.g. 90 km/hr; 120 km/hr)
Lightning	• Increased frequency (by about 12% per degree Celsius of warming) • Increased length of the higher frequency lightning season
Tornadoes	• Increased frequency (25% increase by mid-century) • Increase (near 2x) in number of severe thunderstorm days by mid-century (capable of possibly producing tornadoes, hail, extreme winds, and extreme rainfall events)
Fog	• Likely increase
Frost (Freeze-Thaw Cycles)	• Decrease in annual total number of freeze-thaw days • Increase in monthly totals in the shoulder seasons (e.g. November and March)

1.4 Forensic Analyses of Three High Impact Events

1.4.1. Climate Event Forensic Analysis

Individual high-impact severe weather events can produce disproportionate amounts of damage to electrical distribution systems. These events test the limitations and capacity of response crews, often requiring a "triage process" to prioritize repairs by their criticality to the distribution system, potentially leaving some customers without power for several days. However, by conducting investigations of these events, particularly by combining infrastructure impacts information and weather observations, lessons can be learned and response strategies can be developed to increase the resiliency of the electrical distribution network to help bolster resilience.

Hydro Ottawa identified three high-impact severe weather events as part of the overall scope of the PIEVC assessment:

- April 15-16, 2018 – ice and wind storm;
- May 4, 2018 – wind storm; and,
- September 21, 2018 – tornado outbreak.

The forensic assessment was conducted by combining information on both infrastructure impacts and meteorological data, with the intent of establishing the following:

- **Event Timelines –** Understanding the progression of events leading up to, during, and immediately following major outage events.
- **Meteorological/Climate Diagnosis** – Determine the type, extent, and severity of weather/climate event responsible for outages.
- **Develop Adaptation Recommendations –** Determine actions that can be taken to assist in the preparation and response to similar events in the future.

A summary of each case study is provided below. A much more detailed description of forensic assessment methodology, and case study analyses and results are provided in **Appendix B**. Adaptation recommendations will be the subject of an upcoming portion of the risk assessment project and will therefore be provided at a later date.

1.4.2. 15 - 16 April 2018 Ice and Wind Storm

A combined wind and ice storm resulted in a total of 73,797 customers losing power during this event. Ottawa airport reported a total of 16 hours of freezing precipitation between noon EDT on April 15th and 10 AM EDT April 16th. The freezing rain and drizzle resulted in ice accumulations on overhead electrical infrastructure and adjacent vegetation exceeding 10 mm in total thickness, which was accompanied by strong winds gusting to 67 km/h on April 15 and 74 km/h on April 16. Total estimated ice accumulations by midnight on April 15th were likely around 10 mm, resulting in a small number of scattered power outages. However, between 7 AM and 2 PM on April 16th, the total number of outages increased from approximately 4,000 customers to over 43,000 customers.

Because combined loading from wind and ice are challenging, efforts have been made in other jurisdictions to estimate the potential impacts from various combinations of wind and ice loads. However, the Sperry-Piltz Ice Accumulation (SPIA) Index (Figure 7), a combined ice and wind load scale which is becoming popular among meteorologists and contains 6 categories of increasing severity, ranging from 0-5. However, this event would have been ranked a “4” on the 0-5 scale, corresponding to much more severe impacts than what was observed during this event. This is likely due to the SPIA Index’s development in the central United States (originally the Tulsa, Oklahoma local weather office), and therefore impact statements correspond to infrastructure designed to lower ice and wind combination thresholds.

Main impacts were the result of trees and branches impacting lines; however, several utility poles (33 in total) also suffered structural failures. It is notable that many poles did not fail at the ground line in this case but rather several meters above the ground line. This may be due to significant lateral loading from wind action on ice covered lines, in which case the highest fiber stress within a utility pole can occur above the ground line. We also note that Hydro Ottawa's post storm investigation indicated a small number of the poles were also potentially aged and degraded, which may have further contributed to failures.

The Sperry-Piltz Ice Accumulation Index, or "SPIA Index" – Copyright, February, 2009

ICE DAMAGE INDEX	* AVERAGE NWS ICE AMOUNT (in inches) *Revised-October, 2011	WIND (mph)	DAMAGE AND IMPACT DESCRIPTIONS
0	< 0.25	< 15	Minimal risk of damage to exposed utility systems; no alerts or advisories needed for crews, few outages.
1	0.10 – 0.25	15 - 25	Some isolated or localized utility interruptions are possible, typically lasting only a few hours. Roads and bridges may become slick and hazardous.
	0.25 – 0.50	> 15	
2	0.10 – 0.25	25 - 35	Scattered utility interruptions expected, typically lasting 12 to 24 hours. Roads and travel conditions may be extremely hazardous due to ice accumulation.
	0.25 – 0.50	15 - 25	
	0.50 – 0.75	< 15	
3	0.10 – 0.25	> = 35	Numerous utility interruptions with some damage to main feeder lines and equipment expected. Tree limb damage is excessive. Outages lasting 1 – 5 days.
	0.25 – 0.50	25 - 35	
	0.50 – 0.75	15 - 25	
	0.75 – 1.00	< 15	
4	0.25 – 0.50	> = 35	Prolonged & widespread utility interruptions with extensive damage to main distribution feeder lines & some high voltage transmission lines/structures. Outages lasting 5 – 10 days.
	0.50 – 0.75	25 - 35	
	0.75 – 1.00	15 - 25	
	1.00 – 1.50	< 15	
5	0.50 – 0.75	> = 35	Catastrophic damage to entire exposed utility systems, including both distribution and transmission networks. Outages could last several weeks in some areas. Shelters needed.
	0.75 – 1.00	> = 25	
	1.00 – 1.50	> = 15	
	> 1.50	Any	

Figure 7. SPIA Index (Sperry, 2009) describing combination of wind and ice loading and expected impacts. Note that the scale currently over-estimates the severity of associated impacts to the Hydro Ottawa system and would require further tailoring for use in eastern Canada.

1.4.3. 4 May 2018 High Wind Event

An intense low-pressure system tracked across a large portion of southern Ontario through to southern Quebec and adjacent areas of the United States, resulting in power outages for approximately 45,000 Hydro Ottawa customers. Damage reports, mainly consisting of large branches and individual trees being uprooted, was first reported in eastern Michigan in the Detroit area at 1:09 PM EDT. As the storm moved across southern Ontario, wind gusts approaching or exceeding 120 km/h were recorded at several locations. Widespread wind damage was reported across the Kitchener-Waterloo and Golden Horseshoe regions beginning after 3 pm EDT, including three fatalities attributed to the storm, as well as damage consisting of large branches and/or large trees snapped or uprooted, shingles and portions of roofs removed from homes and commercial buildings, and tens of thousands of electrical distribution customers in multiple jurisdictions losing power.

High winds and associated customer outages occurred in two distinct “waves” which were associated with different portions of the weather system (Figure 8). Several locations southwest of the City of Ottawa first reported wind related power outages after 7 PM EDT, with a total of 11,000 customers losing power in Kanata, Stittsville, Richmond and Munster by 7:48 PM. This first wave of high winds continued east-northeast, triggering similar outages in the Finlay Creek area by 8:50 PM. The second period of high winds, which also appeared to be more severe than the first, began in in the late evening, with most damage occurring roughly between 10 and 11:30 PM EDT. By 11:40 PM EDT, Hydro Ottawa reported that in excess of 30,000 customers had lost power. The worst affected areas in the City of Ottawa following the second, late evening period of high winds required more than a day of repair work to fully restore power.

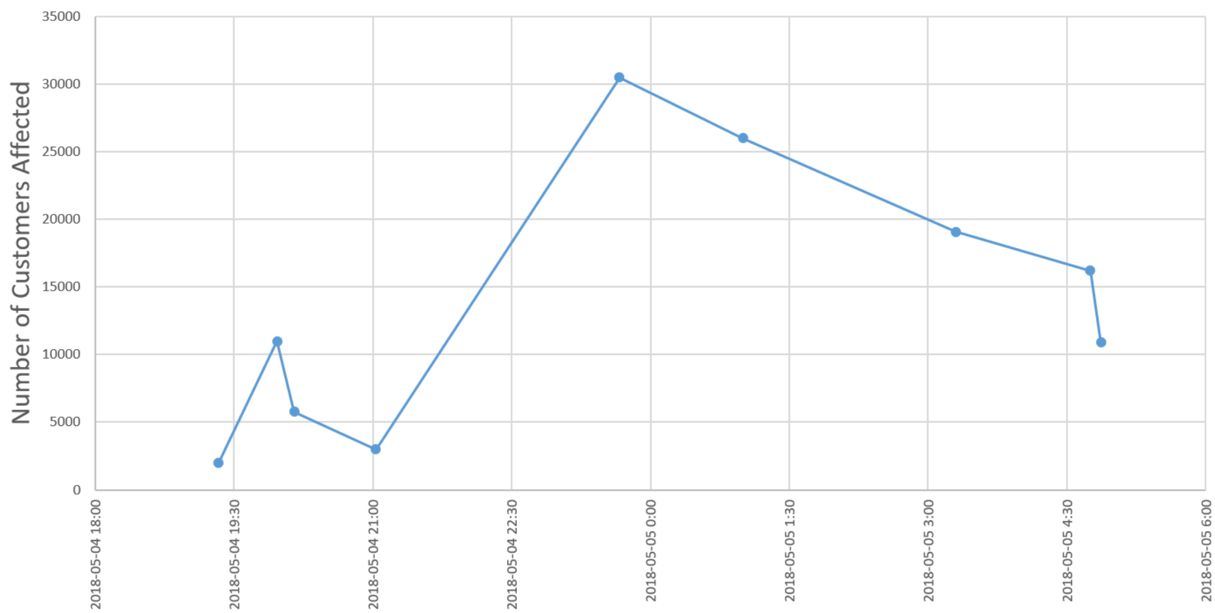

Figure 8. Timeline describing number of customers affected during May 4, 2018 wind storm. Note small peak of ~11,000 between 7:30 and 8:00 PM EDT, followed by much larger peak of >30,000 later in the evening. Total number of customers affected based on outages reported by Hydro Ottawa's Twitter account.

With such a large-scale wind event, the potential existed for understanding potential impacts to Hydro Ottawa’s electrical system by monitoring upstream utilities and meteorological data. In addition to high winds reported at various airports across southern Ontario, local utilities suffered widespread outages several hours prior to Hydro Ottawa, including utilities in the Kitchener-Waterloo region (~35,000 customers) Toronto Hydro (over 30,000), and Hydro One’s rural distribution network (over 126,000 customers affected). Damage reported by media and Hydro Ottawa staff also suggest that winds were likely stronger in some parts of the City of Ottawa than those measured at the airport. A peak gust of 96 km/h was recorded in the late evening, but cladding and shingle damage to homes, as well as some more intense damage to trees and branches in some areas, suggest winds exceeded 105 km/h in some isolated locations within the service area.

1.4.4. 21 September 2018 Tornado Outbreak

The September 21, 2018 tornado outbreak consisted of at least 7 separate tornadoes, with Hydro Ottawa's service area suffering impacts from the two strongest confirmed tornadoes within the outbreak, the long-tracked Kinburn-Dunrobin-Gatineau tornado, rated EF3 on the 0 to 5 EF-scale of tornado intensity, and the Nepean-South Ottawa tornado, rated EF2. The Kinburn-Dunrobin-Gatineau tornado formed at approximately 4:32 PM EDT, tracking roughly northeast until crossing the Ottawa River at approximately 4:52 PM EDT. Approximately one hour later, at 5:51 PM EDT, the Nepean tornado formed in association with a second line of storms. This tornado impacted the Merivale Transmission Station (TS) at almost exactly 6:00 PM EDT, resulting in a significant proportion of outages triggered in this event, and dissipated shortly after at approximately 6:09 PM EDT. All damage associated with these tornadoes, resulting in over 207,000 customers being affected, occurred in a time span of approximately 38 minutes (Figure 9).

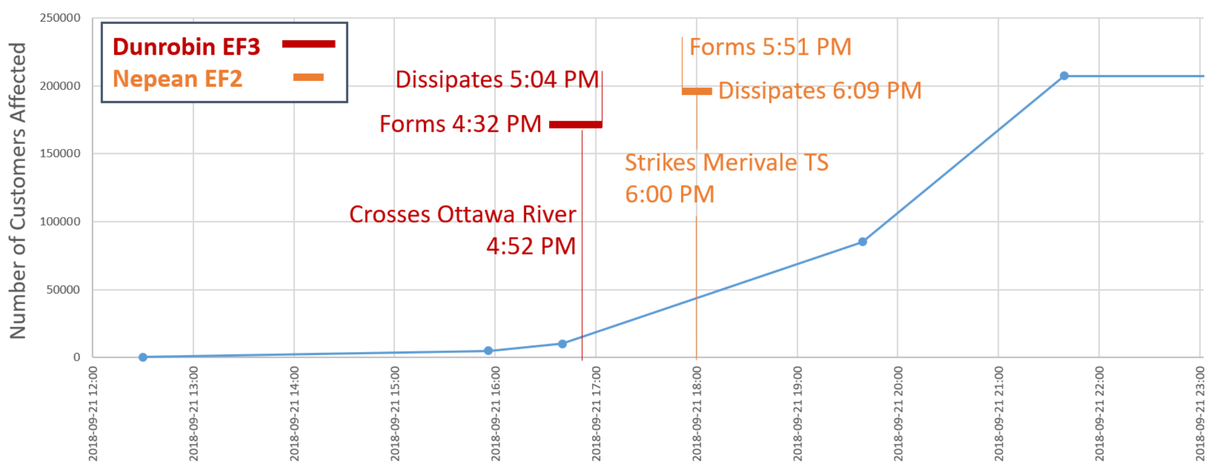

Figure 9. Timeline comparing the total number of reported customers affected versus the occurrence of the Kinburn-Dunrobin-Gatineau tornado (red) and the Nepean-South Ottawa tornado (orange). Outage totals are based on those reported by Hydro Ottawa's Twitter account and the final total based on post-event reports.

Based on a review of historical events, this appears to be the first day in recent history in which two significant (i.e., EF2 or stronger) tornadoes affected Hydro Ottawa's service area on the same day. Damage surveys conducted by teams from Environment and Climate Change Canada (ECCC) and the University of Western Ontario (UWO) wind engineering group helped better clarify what occurred at Merivale TS. In spite of the widespread impacts of this direct strike on the station, the tornado was likely at EF1 intensity when these impacts occurred, suggesting maximum winds of around 170 km/h.

1.4.5. Case Study Based Recommendations

Details and elaboration regarding the case study based recommendations can be found in the detailed report on forensic analyses in **Appendix B**. We note that Hydro Ottawa after action reports also provide a number of recommendations for improving response and system resilience, those are not repeated here and can be found in Hydro Ottawa's after action reports relating to each of these events.

Operations, Maintenance and Monitoring

- ***Use of social media to enhance situational awareness before and during severe weather events:*** Many of Canada's leading weather forecasters, as well as its large and medium sized electrical utilities, maintain a social media presence, particularly on the Twitter platform. These accounts can be monitored to provide additional details on weather conditions as well as recent or ongoing impacts, which that can provide additional data and interpretation of weather information beyond standard publicly available weather forecasts, watches and warnings.
- ***Additional monitoring of key meteorological parameters within Hydro Ottawa's service area:*** Since many of the meteorological measures critical to impacts on electrical systems – particularly wind gust speeds and freezing precipitation ice accretion amounts – are not well monitored, Hydro Ottawa could enhance such monitoring through the installation of additional weather monitoring stations.
- ***Monitoring weather conditions and electrical distribution and transmission outages for locations "up-stream" of Hydro Ottawa's service area:*** Particularly for large scale, cool season weather events, up-stream utilities may be affected by the same weather system several hours prior to Hydro Ottawa's network being affected. Monitoring weather observations and local utilities in up-stream jurisdictions can help to provide early warning of incoming impacts, as well as providing some indication of the potential severity and duration of these impacts.
- ***Improved outage reporting systems:*** To further improve understanding of the sensitivity and resilience of the distribution system, and perhaps to better target and prioritise response during events, improvements to the outage reporting system could be investigated. Such improvements should aim to automatically report and record the exact timing, location, and number of affected customers for individual outage events.

Planning and Training

- ***Basic severe weather forecasting and awareness training for staff:*** Additional training and education of Hydro Ottawa staff would allow for better use of available weather observation information and forecast products. Such training can assist with better anticipation of the extent, type and severity of weather events and can also be leveraged to target portions of the system for response operations during and immediately following severe weather events, particularly during warm season events which tend to result in more localised and concentrated impacts on distribution networks.

System Management, Repair and Upgrades

- ***Review of/increased emphasis on tree trimming operations:*** A majority of impacts resulting from severe weather are due to tree contacts, and an emphasis on tree trimming can significantly reduce these impacts, particularly for events which would otherwise be well within the design load limits of overhead systems.
- ***Strategic equipment upgrades:*** As individual components are replaced due to age, damage, or critical vulnerability, they can be replaced with more robust and/or more easily repaired components. Over time, these strategic upgrades can increase the overall resiliency of the network.
    - ***Break-away connectors and other sacrificial components:*** These are one example of the type of component which can be used as a replacement for legacy equipment. These are specifically indicated in cases where widespread damage occurs to individual

customer connections, which tended to result in the longest outages for individuals affected by severe weather related power interruptions.

Event Specific Recommendations

- ***Development of tailored combined ice and wind impact scale for eastern Canada:*** Indices used to help forecast potential severe weather impacts – in this case, the SPIA Index for combined wind and ice loading – are currently being developed and refined but may require further tailoring to take into account differences in climate conditions and infrastructure design loading for different regions within North America. However, results of development and testing indicate that such scales can be very consistent in their ability to predict impacts for a series of wind and ice load combinations, and would be of great utility for impacts forecasting and event response.

1.5 Climate Probability Scoring for Risk Ranking

Statistical information for both historical (1981-2010) and projected (2050s) event frequencies of the identified climate parameters and the five-point scoring scale applied in Hydro Ottawa's Asset Management System Risk Procedures (**Table 4**) were used to develop probability scores for this study. A score of 1 refers to a climate event that is "rare" and has a very low likelihood of occurring during the time period of interest, while a score of 5 refers to an event that is "almost certain" and highly likely to occur in the period.

Table 4: Probability scoring scale used in Hydro Ottawa's Asset Management System Risk Procedures.

Probability Score	Descriptor	Detailed Description	Probability (p) Range
1	Rare	May only occur in time period under exceptional circumstances	$p \leq 5\%$
2	Unlikely	Could occur in time period	$5\% < p \leq 35\%$
3	Possible	Might occur in time period	$35\% < p \leq 65\%$
4	Likely	Will probably occur in time period	$65\% < p \leq 95\%$
5	Almost Certain	Is expected to occur	$95\% < p$

In this study evaluates the probability of an event directly impacting the Hydro Ottawa service area with both the annual probability and probability over a 30-year period calculated. The annual probability of an event occurring provides insight for functional and operational (O&M) impacts while the probability over a 30-year period provides insight for structural impacts.

1.6 Climate Thresholds and Analytical Results

Historical baseline (1981-2010) and projected climate change (2050s) information under the RCP8.5 scenario for the identified climate parameters is presented. **Table 5** provides a summary table of the analytical results (annual and 30-year probabilities and scores). Included in **Table 5** are the relevant thresholds for each climate parameter, historical and projected annual frequency and probabilities, study period (30-year) probabilities, and the corresponding probability scores. Annual averages (frequencies) for each parameter are provided in terms of events per year (yr^{-1}). Probability values (%) are calculated based on the probability of an event directly impacting the Hydro Ottawa service area. The probability scores, ranked from 1 to 5 (**Table 4**), are used to calculate risk values and will appear in the risk matrix summarizing the overall results of the risk assessment. Detailed discussions for each climate parameter are provided in **Appendix C**.

Table 5: Annual and 30-year probabilities and scores for the historical baseline (1981-2010) and future climate (2050s) under the RCP8.5 scenario.

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)			
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score
Temperature – Extreme Heat								
Daily maximum temp. of 25°C and higher	100% (~62-63 yr^{-1})	5	100%	5	100% (~99 yr^{-1})	5	100%	5
Daily maximum temp. of 30°C and higher	100% (~14-15 yr^{-1})	5	100%	5	100% (~42 yr^{-1})	5	100%	5
Daily maximum temp. of 35°C and higher	50% (< 1 yr^{-1})	3	>99%	5	100% (~6 yr^{-1})	5	100%	5
Daily maximum temp. of 40°C and higher	6% (< 1 yr^{-1})	2	84%	4	100% (~1-2 yr^{-1})	5	100%	5
Daily average temp. of 30°C and higher	3% (< 1 yr^{-1})	1	60%	3	100% (~1-2 yr^{-1})	5	100%	5
Heat wave: Consecutive days with $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$	7% (< 1 yr^{-1})	2	89%	4	100% (~2 yr^{-1})	5	100%	5
Heat wave: Consecutive days with $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$	0% (0 yr^{-1})	1	0%	1	37% (<1 yr^{-1})	3	>99%	5
Temperature – Extreme Cold								
Daily minimum temp. of -35°C and colder	3% (< 1 yr^{-1})	1	60%	3	0.1% (Rare)	1	3%	1
Rain								
50 mm of rainfall in 1 hour	1% (< 1 yr^{-1})	1	~25%	2	4.5% (< 1 yr^{-1})	1	75%	4
Freezing Rain & Ice Storms								

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)			
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score
Ice accumulation of 25 mm	5% (< 1 yr^{-1})	1	79%	4	6% (< 1 yr^{-1})	2	84%	4
Ice accumulation of 40 mm	2.5% (< 1 yr^{-1})	1	>50%	3	3.8% (< 1 yr^{-1})	1	~70%	4
Snow								
Days with 5 cm or more of snowfall	100% (~15 yr^{-1})	5	100%	5	100% (~15 yr^{-1})	5	100%	5
Days with 10 cm or more of snowfall	100% (~5-6 yr^{-1})	5	100%	5	100% (~5 yr^{-1})	5	100%	5
Days with 30 cm or more of snowfall	13% (< 1 yr^{-1})	2	98%	5	10% (< 1 yr^{-1})	2	>95%	5
High Winds								
Annual wind speeds of 60 km/hr or higher	100% (~14-15 yr^{-1})	5	100%	5	100% (~16 yr^{-1})	5	100%	5
Easterly winds of 60 km/hr or higher (warm season [April -Sept.])	28.9% (< 1 yr^{-1})	2	100%	5	32.4% (< 1 yr^{-1})	2	>99%	5
Easterly winds of 60 km/hr or higher (summer [June-Aug.])	2.6% (< 1 yr^{-1})	1	55%	3	2.9% (< 1 yr^{-1})	1	~60%	3
Annual wind speeds of 80 km/hr winds or higher	100% (~1-2 yr^{-1})	5	100%	5	100% (~1-2 yr^{-1})	5	100%	5
Easterly winds of 80 km/hr or higher (cool season [Oct.-March])	5.3% (< 1 yr^{-1})	2	80%	4	6.3% (< 1 yr^{-1})	2	85%	4

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)			
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score
Easterly winds of 80 km/hr or higher (winter [Dec.-Feb.])	2.6% (< 1 yr^{-1})	1	55%	3	3.2% (< 1 yr^{-1})	1	>60%	3
Annual wind speeds of 90 km/hr or higher	23% (< 1 yr^{-1})	2	>99%	5	29% (< 1 yr^{-1})	2	>99%	5
Annual wind speeds of 120 km/hr or higher	2.5% (< 1 yr^{-1})	1	53%	3	3.1% (< 1 yr^{-1})	1	61%	3
Lightning								
Strikes near infrastructure (flashes/ km^2/ year)	1.1% (< 1 yr^{-1})	1	28%	2	1.5% (< 1 yr^{-1})	1	36%	3
Tornadoes								
EF1+ in Hydro Ottawa service area (City of Ottawa)	14.6% (< 1 yr^{-1})	2	>99%	5	18.2% (< 1 yr^{-1})	2	>99%	5
EF1+ point probability (i.e. striking a specific asset in City of Ottawa service area)	0.018% (Rare)	1	0.6%	1	0.023% (Rare)	1	0.7%	1
Invasive Species								
Emerald Ash Borer (Daily min. temp. of -30°C or colder [kill temp.])	53% (< 1 yr^{-1})	3	>99%	5	3% (< 1 yr^{-1})	1	60%	3

Climate Thresholds	Baseline Probabilities				2050s Probabilities (RCP8.5)			
	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score	Annual Probability	Annual Probability Score	30-Year Probability	30-Year Probability Score
Giant Hogweed (3 consecutive days of -8°C or colder [gemination requirement])	100% ($25\ yr^{-1}$)	5	100%	5	100% ($17\ yr^{-1}$)	5	100%	5
Fog								
Season with ≥ 50 fog days (Nov.-March)	37%	3	100%	5	*Likely increase*	3-4	100%	5
Frost								
Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation around 0°C	100% ($\sim 2\text{-}3\ yr^{-1}$)	5	100%	5	100% ($\sim 2\ yr^{-1}$)	5	100%	5
Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C	30% ($< 1\ yr^{-1}$)	2	>99%	5	38% ($< 1\ yr^{-1}$)	3	>99%	5

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Appendix A: Delta Approach

The following presents the 5 steps of the Delta Approach and how it is used in this project. The Delta Approach is applied to temperature (maximum, minimum, and mean) and precipitation data.

Step 1 is completed using observational data (i.e. from the Ottawa International Airport weather station).

1. Obtain the baseline condition (or 'average' climate) for each climate variable at each of the chosen observation stations.
    - Climate conditions for the 1981-2010 (30-year) time period are used as the "Climate Normals", or baseline, for this project. This 30-year period is the current official "Climate Normals" period considered by ECCC.

The following three steps (Steps 2 to 4) are then completed for each individual CMIP5 model (i.e. the 'delta' is calculated for each individual model) using monthly data. For some of the 37 GCMs included, multiple projections have been produced and all available outputs (model runs) are considered. When a model has multiple runs, the individual model mean delta is calculated (i.e. deltas from all runs for the individual model are averaged) and is used when calculating the CMIP5 ensemble mean delta value (completed prior to Step 5).

2. Obtain the model average climate for the 1981-2010 time period for the observation station location.

3. Obtain the future climate projections for the observation station location, for the required future time period (i.e. 2050s), and the RCP emission pathway to be evaluated (i.e. RCP8.5). These projections will provide an overview of the average future conditions as projected by CMIP5 GCMs for the time period of interest.

4. The difference (or 'delta') between the modeled baseline (obtained is Step 2) and respective modeled future time period (obtained in Step 3) will then be calculated, representing the change in the specified climate conditions (the 'climate change signal'). Climate deltas will be produced for each modelled variable, relative to the 30-year baseline (1981-2010).

Once all individual CMIP5 model deltas have been calculated, the individual model deltas are averaged to obtain the overall CMIP5 ensemble mean value for the station location and is utilized in Step 5. Prior to calculating the CMIP5 ensemble mean, the individual model outputs are re-gridded to a common resolution since different modelling centres use different grid alignments and dimensions. This re-gridding uses a scale representative of the resolution of the GCMs (in this case approximately 200 km by 200 km) in order to match to the grid dimensions of the popular NCEP (National Centres for Environmental Prediction) reanalysis, and a resolution intermediate of all models. This is done using a process of linear interpolation to obtain the re-gridded datasets.

5. The final step is to apply the CMIP5 ensemble mean delta value calculated to the observed station data 1981-2010 baseline period value (i.e. the CMIP5 ensemble delta for the month is applied to the daily observational data accordingly). This has the effect of correcting for any difference (or

bias) between the true measured baseline climate and the CMIP5 projected baseline climate. By applying the delta to the true measured baseline, localized climate projections are generated for the future period and variables which can be directly compared against the observed 1981-2010 baseline data, along with information on the ‘spread’ (or range) of the model projections. Uncertainty can be approximated by considering the spread of the projections, with smaller ranges suggesting more confidence in the projected value(s) than a wide projection range. This approach also accommodates use of finer scale baseline climate information.

Once the Delta Approach has been completed, projected changes in the climate parameters are calculated by applying the chosen threshold(s) and using the CMIP5 ensemble-based climate projections generated in Step 5 and the observed 1981-2010 baseline.

Appendix B: Detailed Forensic Analyses of High Impact Weather Events

High Impact Event Forensics

Individual high-impact severe weather events can produce disproportionate amounts of damage to electrical distribution systems, with tens to hundreds of thousands of customers losing electrical power. These can result in in dozens of individual locations within the distribution network suffering damage in rapid succession, testing the limitations and capacity of response crews, often necessitating prioritization of repairs and leaving some customers without power for one or more days. However, by conducting investigations of these events, response strategies can be developed to increase the resiliency of the electrical distribution network and to reduce impacts in subsequent storms.

We note that Hydro Ottawa already conducts post-event forensic analyses of events, which is rare among utilities in Canada. These investigations have resulted in the development of a number of key recommendations for improved response and disaster planning, particularly regarding operations and response during and immediately following events. These are already available in detailed reports (Hydro Ottawa 2018b, 2018c and 2018d) and will not be repeated here.

The value added for the analysis conducted in conjunction with the PIEVC assessment includes the application of an understanding of atmospheric dynamics and physics related to severe weather events and associated processes. These are combined with investigations already conducted by Hydro Ottawa staff to provide an atmospheric science-based perspective on how to further analyse these high impact events with the ultimate goal of developing recommended action items, such as improved monitoring, identifying response strategies and improving overall resilience to severe climatic events.

Identification of Key Events

Hydro Ottawa pre-defined three high-impact severe weather events for investigative focus as part of the overall scope of the PIEVC assessment:

- April 15-16, 2018 combined ice and wind storm;
- May 4, 2018 wind storm; and,
- September 21, 2018 tornado outbreak.

The forensic assessment was conducted by combining and comparing information regarding both infrastructure impacts and meteorological data. The objective of the forensic analyses were to develop, for each event:

- **Occurrence Timelines –** Determine which impacts occurred when to understand the progression of events leading up to, during, and immediately following major storms resulting in widespread service outages.
- **Meteorological/Climate Hazard Diagnosis** – Determine the type, extent, and severity of weather/climate phenomenon responsible for outages. This includes the assessment of the relative contributions of weather and infrastructure characteristics to damage and failures, as well as a comparison to both historical cases and future climate change projections to better understand the true frequency and overall risk posed by these hazards.

- **Develop Adaptation Response Recommendations –** Develop recommendations for consideration in improving overall resilience and response to similar events.

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Methodology

Several sources of information were consulted for this analysis, including:

- News Media sources (e.g. Ottawa Citizen, CBC, CTV)
- Hydro Ottawa social media, specifically Twitter and news media press releases
- Hydro Ottawa post-event reports
- Meteorological observations (e.g. weather station data, weather radar)
- Historical climate data, including specialised data sets for extremes (i.e., ice storms, tornadoes)
- Relevant literature and design information (e.g. climatic loads from CSA standards)

These various sources of data and information are then combined to establish facts and hypotheses regarding the event under investigation.

April 15-16, 2018 Combined Ice & Wind Event

A combined wind and ice storm, which began in Ottawa around midday on April 15 and intermittently continued until midday April 16, resulted in a total of 73,797 Hydro Ottawa customers losing power. Leading up to this event, Environment and Climate Change Canada (ECCC) issued freezing rain warnings on April 14 for a large swath of southern Ontario, with up to 40 mm of freezing rain ice accretion possible between Windsor, the Muskokas, and east through to the Ottawa area, including the Greater Toronto and Hamilton areas (National Post, 2018). Ice accretion impacts were felt across southern Ontario and began a full day prior to the start of the event affecting Hydro Ottawa.

Ottawa airport reported a total of 16 hours of freezing precipitation between 12 PM EDT on April 15 and 10 AM April 16. The freezing rain and drizzle resulted in ice accumulations on overhead electrical infrastructure and adjacent vegetation and was accompanied by strong winds gusting to 67 km/h on April 15 and up to 74 km/h on April 16. Total estimated ice accumulations for April 15 were likely around 10 mm, which resulted in a small number of scattered outages within the service area. However, ice continued to accumulate overnight and into mid-morning. Between 7 AM and 2 PM on April 16, the total number of Hydro Ottawa service area outages (as reported via Hydro Ottawa's Twitter account) increased from approximately 4,000 customers to over 43,000 customers. Conditions were significant enough to down large trees by 10 AM, and entire line segments, consisting of rows of snapped utility poles carrying multiple circuits, were down by 11:30 AM.

In addition to trees and branches impacting lines, a total of 33 poles were snapped across the City during the event, including 16 in a north-south oriented segment along Limebank Road. The majority of affected customers had service restored by the afternoon of April 16, but a small number of customers who had suffered damage to individual grid connections remained out for much longer, with "less than 50" remaining out by 7 AM EDT on April 18.

April 2018 Event – Analytical Results

As with the May 4, 2018 wind storm (described below), significant damage occurred to utilities up-stream of Hydro Ottawa's network well ahead of any local outages. In this case, they began approximately one day prior to the event affecting Ottawa's distribution system. By April 15, the day ice accretion in the Ottawa area began and prior to major, city-wide damage to the system, Hydro One had already experienced damage across multiple regions within its rural electrical distribution network. An April 15 press release, with data up to 6:30 PM EDT, indicated 34,000 customers without power, as well ongoing damage associated with the eastward progression of the storm. Another 89,000 customers had already lost power and been subsequently restored. Impacts were reported in Algoma district, north of Lake Huron, as well as several in Hydro One service regions along a swath from southern Lake Huron to the north shore of Lake Erie and Golden Horseshoe Region (Hydro One Press Release, April 15, 2018). By April 16th, Hydro One reported that more than 200 poles, along with countless overhead wires, had been downed across the province, with many more customers affected in eastern Ontario's "cottage country" (i.e., Peterborough and Fenelon Falls) to the east of the Ottawa River Valley, as well as parts of southeastern Ontario south of Ottawa (Vankleek Hill and Winchester areas) (Hydro One Press Release, April 16, 2018).

Toronto Hydro suffered similar damage to Hydro Ottawa's network, reporting a total of over 44,000 customers affected (Toronto Hydro Press Release, April 16 12:35 EDT). Damage occurred over a span of 5 hours, beginning late in the evening of April 15th, with most outages occurring by 3 am on April 16, effectively lagging impacts to Hydro Ottawa's system by approximately 6-10 hours. Combined wind and ice loading was also indicated in the Toronto area (Toronto Hydro Press Release, April 16 12:35 EDT), including similar winds as were reported in the Ottawa area, gusting to 74 km/h and 69 km/h on April 15 and 16, with higher winds reported near the Lake Ontario shoreline, e.g., City Centre Airport reported a maximum gust of 100 km/h on April 15. At least a dozen more local electrical distribution utilities also suffered impacts in southern and eastern Ontario. This provides a basis for better anticipating impacts to Hydro Ottawa's system by monitoring the nature, rate of progression and severity of impacts to up-stream utilities.

The best estimates of total ice accretion indicate total ice accumulations were likely in the 10-15 mm range. Hydro Ottawa's incident reports (Hydro Ottawa, 2018b) suggest ice accretion formed a roughly 6 mm thick layer of ice on conductors, which corresponds to total ice accretion thickness of about 12 mm. Observational data from Ottawa International Airport, although not reporting freezing rain ice accumulation explicitly, suggest a similar amount. A rainfall total of 11.4 mm from April 15 likely represents a total ice accretion amount of approximately 11 mm, since temperatures remained below freezing and observations indicate no liquid precipitation on this date. Between midnight and 10 AM EDT on April 16, another 6 hours of freezing rain was observed. This was followed by a change to temperatures above freezing, with a report of an air temperature of 0.2°C and liquid rain at 10 AM EDT, signaling an end to ice accretion conditions. The majority of electrical outages, seen as an order of magnitude increase in the total number of customers being affected, were triggered by these final few hours of ice accretion, in combination with high winds, in the early to mid-morning of April 16. It is likely that the morning ice accretion only represented a few additional millimeters of ice, since the total precipitation of 23.2 mm reported for April 16 includes both 6 hours of freezing rain, 1 hour of snowfall, and 12 hours of liquid rainfall.

A review of high impact historical freezing rain events, listed in Klaassen et al. (2003), found a total of 3 other freezing rain storms of similar or greater intensity impacting the Ottawa region since 1940; March 15-16, 1943, December 24-25, 1986, and of course January 4-9, 1998. In contrast to the April 2018 event, all of these cases featured much higher ice accretion totals in the Ottawa area. The events in 1943 and 1998 were far more significant, with ice accretion maxima of ~50 mm and up to 80 mm (slightly less in the City of Ottawa proper), respectively.

The main impacts from the storm were due to tree and branch contacts on lines, emphasising the importance of tree clearing programs. However, a total of 33 utility poles were broken as well. It is notable that poles did not fail at the ground line in most cases but rather a few meters above the ground line. This may be due to significant lateral loading from wind action on ice covered lines, particularly on trunk lines carrying multiple circuits. With increasing lateral loading near the top of the pole, the highest fiber stress within the utility pole begins to shift above the ground line (e.g. Vaughan and Eng, 2008). This results in peak wood fiber stresses occurring in a more tapered portion of the pole with a smaller cross-sectional area, potentially resulting in premature failure. However, we also note that Hydro Ottawa's post storm investigation (Hydro Ottawa, 2018b) indicated that many of the poles were also aged and potentially degraded, including visible rot in some of the broken sections.

Because predicting and even characterising combined loads from wind and ice are challenging, efforts have been made in other jurisdictions to estimate or otherwise categorise potential ice storm impacts from various combinations of wind and ice loads. However, the Sperry-Piltz Ice Accumulation (SPIA) Index (e.g. McManus et al., 2008; SPIA Index, 2009), a combined ice and wind load impacts scale which is becoming popular among meteorologists, may require further tailoring to be applicable to ice storm events in eastern Canada. The index is a 6-point scale, with ranks ranging from 0-5, which provides several wind-ice combinations for each tier which are expected to result in gradually increasing severity of impact. However, for a best estimate of 12 mm of ice accretion and peak winds of 74 km/h, the index indicates the April 15-16, 2018 event would have ranked as a "4" on SPIA Index scale, corresponding to "Prolonged and widespread utility interruptions, extensive damage to main distribution feeder lines, and some high voltage transmission, **5-10 day outage**" [emphasis added]. These impacts are much more severe than what was observed during the April 2019 event and the discrepancy is likely due to the scale's development in the central United States, originating from the Tulsa, Oklahoma National Weather Service office, and therefore corresponds to infrastructure designed to lower ice and wind combination thresholds. However, impacts in Ottawa from the April 2018 do appear to better correlate with an SPIA Index value of "3", "Numerous utility interruptions with some damage to main feeder lines and equipment expected. Tree limb damage is excessive. Outages lasting 1-3 days". This suggests that a tailored version for eastern Canada could be developed with modifications allowing for consideration of more robust design requirements and other local conditions. Such an index is indeed needed, since winds required to significantly exacerbate ice loading can be well below ECCC weather warning criteria for high winds (i.e., gusts to 90 km/h or sustained winds of 70 km/h) and still contribute to impacts. In other words, winds which are capable of triggering damage to overhead systems, when combined with ice loading, may not trigger a wind warning.

May 4, 2018 Wind Storm

An intense low-pressure system tracked across a large portion of southern and central Ontario through to southern Quebec, as well adjacent areas of the United States south of the Great Lakes. The storm resulted in power outages for approximately 45,000 Hydro Ottawa customers. Wind gusts approaching or exceeding 120 km/h were recorded at several locations, including Kitchener-Waterloo Region International Airport (122 km/h), Hamilton's John C. Munro Airport (126 km/h) and Toronto's Pearson International Airport (119 km/h). Widespread wind damage was reported in all of these regions, including three fatalities attributed to the storm, as well as widespread damage consisting of large branches and/or entire trees snapped or uprooted, shingles and portions of roofs removed from homes and commercial buildings, as well as hundreds of thousands of electrical distribution customers in multiple jurisdictions losing power.

Damage reports, mainly consisting of large branches and individual trees being uprooted, began in states along the international border, stretching in a swath from eastern Michigan and northwestern Ohio, northeast through to the Vermont/Maine border. Damage in eastern Michigan, just north of the City of Detroit and approximately 25 km west of the Ontario border, was first reported at 1:09 PM EDT (SPC, 2018). In the following hours, significant impacts began across southern Ontario's major metropolitan centers of Kitchener-Waterloo and the Greater Toronto-Hamilton Area (GTHA) beginning after 3 pm EDT and continued well into the evening.

High winds occurred in two distinct "waves" which were associated with different portions of the weather system (**Figure B - 1**). This phenomenon was first noted in the GTHA (Weatherlogics, 2018) and was again seen in the Ottawa region several hours later. These winds also impacted two different areas within Hydro Ottawa's service area, with additional evidence that the two periods of high winds also differed in severity and extent. Several locations southwest of the City of Ottawa first reported wind related power outages after 7 PM EDT, with a total of 11,000 customers losing power in Kanata, Stittsville, Richmond and Munster by 7:48 PM. However, many of these customers were very quickly restored, with approximately half of affected customers reported back online by 8:09 PM. This first wave of high winds continued east-northeast, triggering similar outages in the Finlay Creek area, southeast of the more heavily populated portions of the City of Ottawa, by 8:50 PM.

The second period of high winds, which also appeared to be more severe than the first, began in in the late evening, with most damage occurring roughly between 10:00 and 11:30 PM EDT. By 11:40 PM EDT, Hydro Ottawa reported that in excess of 30,000 customers had lost power. In contrast to rapid restoration times for customers in the Kanata and surrounding areas from the first period of high winds, where many customers were restored within approximately one hour, the worst affected areas in the City of Ottawa following the late evening second period of high winds required more than a day to fully restore power.

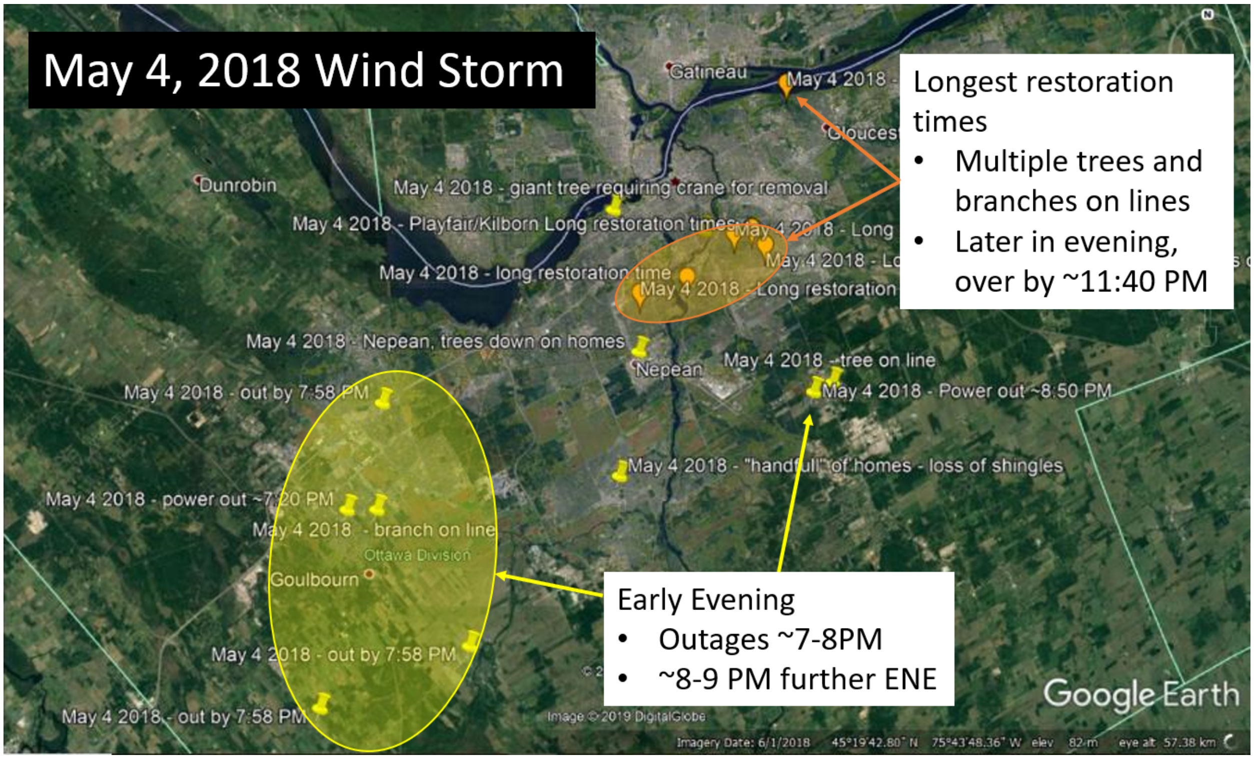

Figure B - 1. Map of damage and outage locations indicating timing and progression of events. Early evening outages SW of the City are circled in yellow, while late evening and long lasting outages are shown in orange.

May 4, 2018 Event – Analytical Results

With such a large-scale wind event, and as with the April 2018 freezing rain storm described above, the potential existed for monitoring incoming impacts and weather conditions for Hydro Ottawa's electrical system by monitoring upstream utilities and meteorological data. In addition to high winds reported at various airports across southern Ontario, approximately 35,000 local electrical distribution customers were reported affected at the height of the storm in the Kitchener-Waterloo region, Toronto Hydro reported over 68,000 customers affected (Toronto Hydro Press Release, May 15, 2018), and Hydro One's rural distribution service reported more than 540,000 customers affected (Hydro One Press Release, May 6, 2018). Hydro One also reported that more than 480 poles were destroyed by the storm, "The damage to our system is so extensive that in some areas we are essentially rebuilding the system." Greg Kiraly, Chief Operating Officer, Hydro One (Hydro One Press Release, May 6, 2018).

In the GTHA, this first period of high winds was associated with thunderstorm activity (Weatherlogics 2018); however, a review of weather radar data and observations at Ottawa's International Airport indicate that thunderstorms were *not* present when the first wave of high winds affected Hydro Ottawa's infrastructure. The lack of thunderstorm activity, which acts to enhance wind gusts, may have been a factor in the less severe damage and lower winds associated with the first period of high winds in the Ottawa area.

Damage reported by media and Hydro Ottawa staff also suggest that winds were likely stronger in some parts of the City of Ottawa than those measured at the airport (**Figure B - 2**). The highest winds reported at Ottawa International were gusts to 96 km/h which occurred during the second period of high winds in the late evening. However, a few locations reported impacts such as the removal of cladding and large sections of roof shingles from homes, as well as multiple large trees being either completely uprooted or being snapped off at the trunk. These types of impacts are usually associated with winds in excess of 105 km/h (ECCC, 2014). Furthermore, a portion of south Ottawa, stretching from the Carlton Heights neighbourhood east-northeast to Alta Vista, were subject to the longest restoration times (> 24 hours), reportedly due to *multiple* trees and branches on lines. Damage to multiple large branches and trees, as opposed to reports of isolated trees and branches, is indicative of winds likely in excess of 100 km/h. This result indicates the need for better monitoring of important climate parameters, since even for large scale storms affecting multiple provinces and states, measurements taken at a single point may not be fully representative of conditions responsible for the most severe impacts.

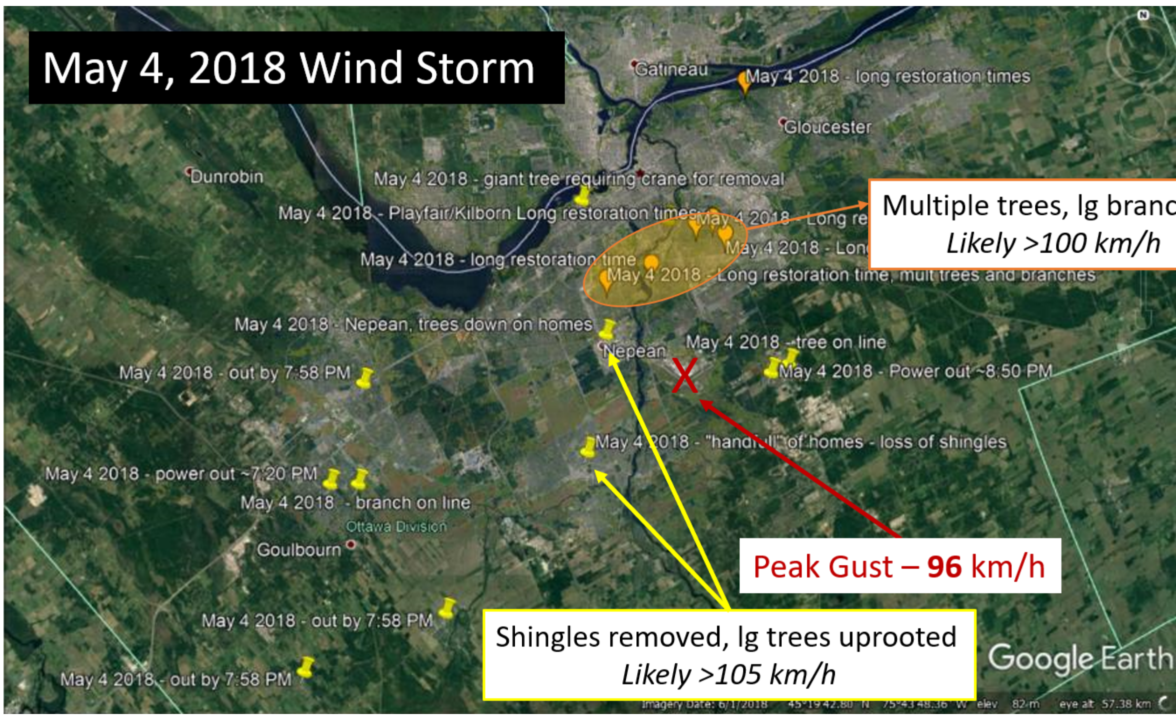

Figure B - 2. Map comparing peak gust value measured at Ottawa International Airport with areas reporting damage suggesting higher wind speed values.

Finally, we address the mechanisms responsible for producing high winds. These findings may explain the differences in damage severity and could also assist with future anticipation of and response to similar events. The first period of high winds was associated with a portion of the weather system called a "low-level jet", a stream of high-speed air present in low-pressure systems located approximately 1.5 km above the surface ahead of the surface cold front. The momentum from this stream of fast-moving air can be transported to the surface though a number of mechanisms, including embedded thunderstorm or rainfall activity, with the falling precipitation acting to "carry" momentum from winds aloft down to the surface. Winds within the low-level jet were around 120 km/h, which correspond very well with maximum wind gusts reported in the GTHA and Kitchener-Waterloo area in the early afternoon in association with thunderstorm activity (Weatherlogics, 2018). However, no thunderstorm activity was present in Ottawa when this portion of the weather system reached the area, meaning elevated streams of high winds were less directly able to affect the surface. However, the second period of high winds, which occurred in colder air behind the cold front and located just south of the center of the low pressure system, were far more intense and damaging. Given the location and intensity of these winds, they were possibly associated with a phenomenon referred to as a "sting-jet" (e.g. Browning 2004). This is a separate stream of high winds that requires specific conditions to form and result in a swath of extremely high winds generally located to the immediate south of the track of the center of low pressure. These events occur more frequently in areas prone to more intense low pressure systems such as northern Europe, and can produce wind gusts in excess of 200 km/h in severe cases.

September 21, 2018 Tornado Outbreak

The September 21, 2018 tornado outbreak consisted of at least 7 separate tornadoes (Sills et al. 2018), from as far south as Sharbot Lake, Ontario, to as far north as the Baskatong Reservoir in western Quebec, approximately 140 kilometers north of Ottawa. Public weather forecasts for the day indicated the potential for severe thunderstorms and high winds, but the potential for significant (EF2 or stronger) tornadoes was not discussed. Severe winds associated with the strong low-pressure system began to trigger power outages before the tornadoes formed, with Hydro Ottawa reporting "multiple outages" across their network by 3:56 PM EDT via Twitter. Given the vague nature of forecast and warnings and the lack of a tornado watch being in place, this wind damage may have confused response crews into assuming the "main event" had already begun.

Hydro Ottawa's service area was impacted by the two strongest confirmed tornadoes within the outbreak, the long-tracked Kinburn-Dunrobin-Gatineau tornado, rated EF3 with estimated winds of up to 265 km/h, and the Nepean-South Ottawa tornado, rated EF2 with maximum estimated winds of around 220 km/h. The Kinburn-Dunrobin-Gatineau tornado first formed near Kinburn at approximately 4:32 PM EDT. It was already the second tornado of the day, produced by a storm cell that had just impacted the Calabogie area. Tornadoes on this day were also characterised by extremely rapid forward motion. The Kinburn-Dunrobin-Gatineau tornado crossed the Ottawa River at approximately 4:52 PM EDT, having travelled nearly 30 km in 20 minutes. It produced damage of up to EF3 intensity both in Dunrobin and later in Gatineau, Quebec, and reached a maximum width of over 1.3 km in the Dunrobin area.

Approximately one hour after the Kinburn-Dunrobin-Gatineau tornado crossed the Ottawa River, at 5:51 PM EDT, the Nepean-South Ottawa tornado formed in association with a second line of storms approaching Ottawa from the west. The tornado produced minor damage to homes in the eastern portions of the Glen Cairn neighbourhood of Kanata before tracking to the northeast, rapidly widening and intensifying. The most severe damage occurred in the Arlington Woods and Craig Henry neighbourhoods of Nepean, reaching a maximum intensity of EF2 and a maximum path width of over 750 meters. After exiting the Craig Henry neighbourhood, the tornado weakened and narrows but remained on the ground for several more minutes, impacting the Merivale Transmission station at almost exactly 6:00 PM EDT, as well as downing medium voltage trunk lines after crossing the Rideau River. The tornado dissipated shortly after at approximately 6:09 PM EDT, immediately south of the Ramsayville industrial park.

September 21, 2018 Event – Analytical Results

Although other multi-tornado events have affected the Ottawa River Valley and surrounding areas in the past (**Figure B - 3**), this appears to be the first event in recent history – and since higher quality tornado records have been kept – in that two significant (i.e. EF2 or stronger) tornadoes affected Hydro Ottawa's service area on the same day. The two tornadoes affected the Hydro Ottawa service area for a total of approximately 38 minutes, meaning that the vast majority of the damage that resulted in over 207 thousand customers occurred in less than ¾ of an hour.

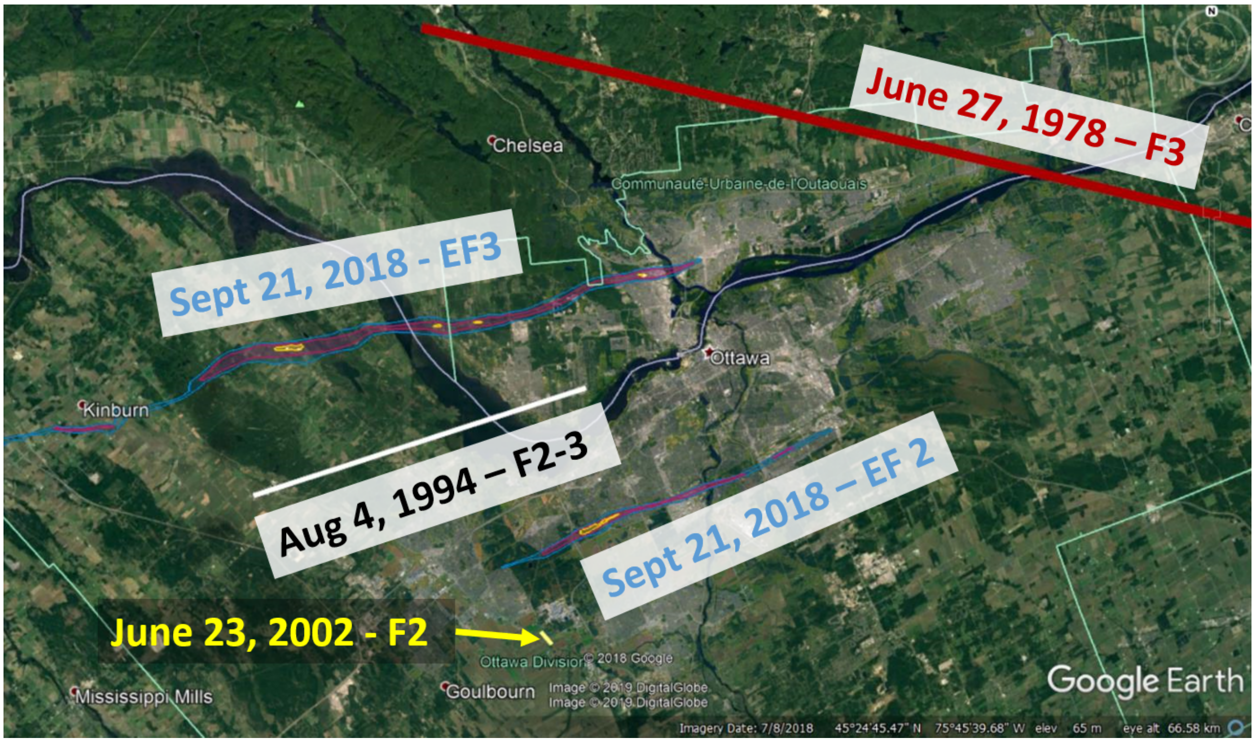

Figure B - 3. Map of all confirmed significant (F2+/EF2+) tornadoes in the Ottawa area for the period 1970 to 2018. Detailed track maps for the Sept 21, 2019 event courtesy of Sills et al. (2018), track data for historical events from Sills et al. (2012).

One of the key concerns expressed by Hydro Ottawa staff were that the gravity of the situation, and the potential for strong tornadoes, was not clear from readily available severe weather watch and warning statements. On August 1, 2018, only seven weeks prior to this event, another series of storms affected the City of Ottawa and surrounding area, triggering tornado warnings. However, no damage was reported, and the event resulted in a false alarm. This led to a reduced level of concern from staff when tornado warnings were issued again on September 21. Outreach and additional severe weather education may have assisted in better interpretation of warning messages, since only a portion of tornado warnings result in confirmed tornado activity. Access to additional weather information and messaging could have assisted in better framing events on the two different days, since the risk and potential impacts from tornadoes were much greater on September 21 than on August 1. This difference was reflected in discussions from several meteorologists active on social media during the September 21 event, information which did not reach Hydro Ottawa response crews.

Damage surveys conducted by joint teams from Environment and Climate Change Canada (ECCC) and the University of Western Ontario (UWO) wind engineering group were shared with the assessment team (Sills et al., 2018). These helped better clarify what occurred at various points along the damage tracks, including impacts to Merivale TS, critical medium voltage trunk lines, and the Arlington Woods and Craig Henry neighbourhoods. Maps of tornado damage tracks indicated that Merivale TS suffered a direct strike from the Nepean tornado, and that the tornado was likely at EF1 intensity when impacts occurred, suggesting maximum winds of up 170 km/h, but of lesser intensity than large portions of the first part of the tornado track, and certainly of much lesser intensity than what was experienced in portions of the Dunrobin-Gatineau EF3 tornado damage area. Similarly, a maximum intensity of EF1 damage was also indicated along many of the trunk lines carrying multiple circuits. Finally, the severe overhead system damage in south Nepean, which was characterised by severe damage to individual customer connections to the system and resulting in extended restoration times, was associated with EF2 damage to homes and trees, suggesting winds in the 180 to 220 km/h range. When events of such intensity occur, all overhead systems within the area of most extreme winds are damaged or destroyed, significantly increasing restoration times due to the need for repairing and replacing each individual customer connection.

Forensic Case Study Based Recommendations

Detailed recommendations stemming from the case studies are provided below, including a description of recommended actions and associated reasoning.

Operations, Maintenance and Monitoring

Use of social media to enhance situational awareness before and during severe weather events:

Social media, which is currently being used very effectively by Hydro Ottawa to communicate and interact with customers, can also be used to keep Hydro Ottawa informed of the potential development of severe weather events. Many of Canada's most highly skilled meteorologists are also active on social media – particularly Twitter – and their accounts can be monitored to help refine understanding of both the potential hazard or hazards for a given day, as well as provide more clarity and detail during an event. Specific applications include:

- Monitoring of Twitter accounts from meteorologists responsible for forecasting in Canada, Ontario and Quebec:
    - Suggested Twitter accounts include: Dr. David Sills (@dave_sills), Executive Director, Northern Tornadoes Project, University of Western Ontario; Mark Robinson (@StormhunterTWN), Jaclyn Whittal (@jwhittalTWN) and Brad Rousseau (@bradrousseau), meteorologists and storm chasers at The Weather Network; Antoine Petit (@MeteoAntoine), Monica Vaswani (@monhyp88) and Robert Kuhn (@KuhnyRob), meteorologists/weather forecasters at Environment and Climate Change Canada, responsible for forecasting in Ontario and southern Quebec.
- Monitoring of Twitter accounts from upstream utilities: Depending on the scale of the severe weather event, important information can be gleaned from monitoring weather impacts reported by utilities in geographical regions affected by weather systems prior to Hydro Ottawa

being affected (e.g., the May 4, 2018 wind storm produced impacts in the Kitchener-Waterloo and Greater Toronto Areas several hours before affecting the City of Ottawa). Representative locations will depend on the conditions of the day of the event, since weather systems

Additional monitoring of key meteorological parameters within Hydro Ottawa's service area:

Many of the weather and climate parameters that are important for impacts to utilities are not well monitored and/or data is not immediately available in real-time. In particular, gaps are noted in recording of:

- Freezing precipitation ice accretion thickness; and,
- Wind speeds, both sustained and gusts.

Additional data on these key parameters would provide more representative for comparison to resulting infrastructure damages, as well as real-time monitoring for operations and response activities, including the potential for developing tailored, real-time warning systems specific to Hydro Ottawa's network. Long term monitoring will also provide better information regarding any differences in climate conditions throughout the service area, addressing questions such as if wind loads are indeed less significant for areas outside of Ottawa's core (e.g., Casselman). New monitoring sites should be distributed throughout the service area and would also require installation of data archiving and storage systems.

Monitoring weather conditions and electrical distribution and transmission outages for locations "up-stream" of Hydro Ottawa's service area:

For larger scale weather systems typical of late-fall, winter and early to mid-spring, meteorological conditions such as wind gust speeds and precipitation amounts, as well as reports of associated impacts such as power outages and/or tree and structural damage, could be monitored to help anticipate impacts upwards of several hours in advance of Hydro Ottawa's service area suffering impacts. These can also provide some indication of the expected nature and severity of approaching severe weather, which can be taken into account for operational and response measures. Determination of representative "up-stream" locations and conditions depend on conditions on the day of the event, but typically weather events approach from the west. However, interpretation of available information would be significantly improved when combined with additional weather awareness and forecast training for staff.

Key "up-stream" utilities identified in the forensic case studies include Hydro One (particularly its rural distribution network), Toronto Hydro, Alectra Utilities (now servicing large portion of the GTHA), as well as multiple smaller utility companies.

Planning and Training

Basic severe weather forecasting and awareness training for staff:

A multitude of weather forecasting and monitoring products are readily available but require additional education and training for proper interpretation and use. These include weather radar – particularly useful during severe thunderstorm events such as tornado and large hail events – satellite imagery, lightning network observations, as well as a multitude numerical weather forecast products. Hydro Ottawa staff could make use of these tools if provided with sufficient training. With such training, staff would be much better able to interpret available weather information, including understanding the meaning and importance of weather watches and warning, and possibly being able to target particular locations within the service area which may have suffered impacts during an event (e.g. tracking specific storm cells to understand possible tornado track locations in real-time). Training could include so-called “weather map typing”, which uses weather patterns identified in past severe weather events to help forecast weather event types and severity. Such weather maps are already available for ice storm events and could assist with anticipating particularly severe events and impacts.

System Management, Repair and Upgrades

Review of/increased emphasis on tree trimming operations:

The majority of damage to overhead systems result from tree contacts. More aggressive tree trimming practices, or greater operational investment in tree trimming and maintenance, can significantly reduce the number of outage events resulting from conditions that otherwise would not be capable of causing direct damage to the infrastructure itself. This has been successfully implemented by Toronto Hydro following their PIEVC risk assessment (R. McKeown, pers. comm.).

Improved outage reporting systems:

To best correlate impacts to electrical infrastructure with weather observations, an automated outage reporting system which indicates the exact time and location (as close as possible) that outages are triggered, as well as which components failed and the number of customers affected, would be of considerable assistance to both operations and response, as well as post-event investigations. Automated digital recording and archiving of failures would assist in more quickly locating outages, as well as in prioritising outages when multiple outages occur in rapid succession.

Strategic equipment upgrades:

As systems age and regular upgrades are executed, or when structural failures occur and broken components require immediate replacement, individual components can be replaced with more robust or resilient components. For example, this can include replacing broken poles with higher class poles, particularly for infrastructure in locations which have demonstrated or have been assessed to have greater vulnerability. Strategic upgrades can significantly increase system resilience, particularly if done in a sustained, targeted, and prioritised fashion.

Break-away connectors and other sacrificial components:

Break-away and other controlled failure components speed up restoration times and reduce or prevent damage to adjacent components in the event of a failure. This is particularly true of severe weather events in which damage to individual customer grid connections occur, as was observed in the more intense areas of residential damage during the September 21st tornadoes, and was reported in the 1998 ice storm.

Improved disaster response, including operations and training, for extreme events:

For particularly severe events, such as the January 1998 ice storm and September 2018 tornadoes, the cost of designing infrastructure to *prevent* failures is prohibitive. Hence, long-duration power outages and severe damage to portions of the distribution system are expected during these events, and response to these particularly severe cases requires disaster response rather than structural hardening or other adaptations. Improved disaster response includes incorporating lessons learned from historical events, as well as improved situational awareness and staff training. This includes the execution of realistic disaster scenario excercises, to understand what types of disasters are possible, how likely they are to occur, and most importantly to know when they are occurring (e.g., what conditions and signs are available to differentiate a severe thunderstorm event that occurs every few years versus a day which could result in large, intense tornadoes affecting the service area). Pre-planning and pre-defining strategies can be critical to reducing impacts and improving response times during major events.

Event Specific Recommendations

April 15-16 Ice and Wind Event:

- Develop locally relevant/tailored version of SPIA Index to allow for better characterisation of potential impacts and expected recovery times for combined wind and ice loading events;
- Review medium voltage trunk corridors to identify any other locations which may be lacking in storm guys or other key structural components leading to greater vulnerability.

Appendix C: Detailed Discussion of Analytical Results

Temperature – Extreme Heat

Thresholds:

T_{max} ≥ 25°C; 30°C; 35°C; 40°C

T_{mean} ≥ 30°C

Extreme heat was evaluated by calculating the number of days per year with the respective temperature parameter exceeding the selected threshold. Historical baselines of extreme heat climate parameters were established using data from the Ottawa Airport meteorological station and projections were generated using CMIP5 ensemble projections and the Delta Approach.

All extreme heat parameters are projected to increase in frequency under climate change. Increased frequencies of the number of days per year with T_{max} ≥ 25°C and T_{max} ≥ 30°C have been observed during the 1981-2010 baseline, with continued notable increases in frequency by the 2050s: Baseline mean of ~62-63 time per year increasing to ~99 times per year in the 2050s for T_{max} ≥ 25°C and baseline mean of ~14-15 times per year increasing to ~42 times per year in the 2050s for T_{max} ≥ 30°C (**Figure C - 1** and **Figure C - 2**, respectively). During the 1981-2010 time period, T_{max} ≥ 35°C is observed 0-3 times per year, with an annual probability of 50%, and is projected to increase to ~6 time per year in the 2050s (**Figure C - 3**). Historically, T_{max} ≥ 40°C and T_{mean} ≥ 30°C have not be observed at the Ottawa Airport, however, under climate change it is expected to see these temperature thresholds exceeded ~1-2 times per year and ~4 times per year, respectively, during the 2050s.

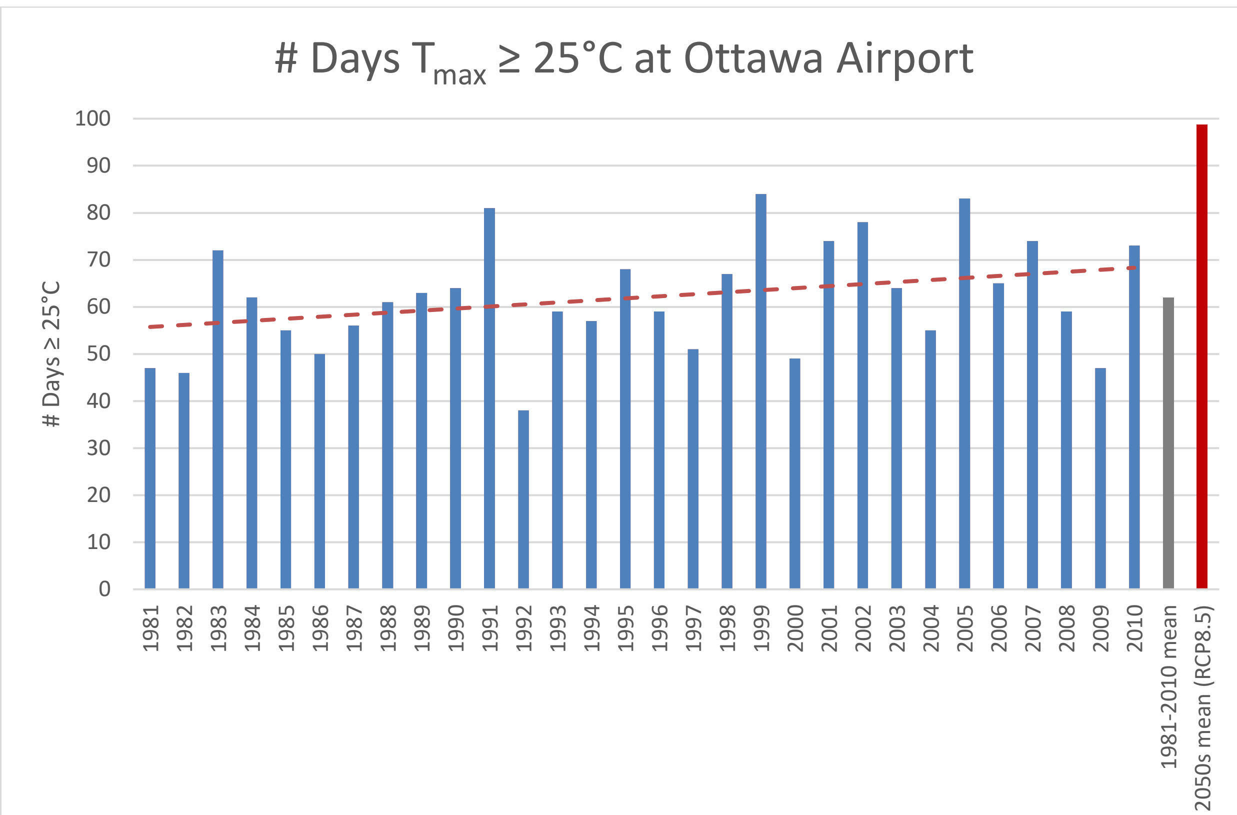

Figure C - 1. Number of days per year with the maximum temperature ≥ 25°C during the 1981-2010 time period at Ottawa Airport. The annual mean for the 1981-2010 baseline and projected for the 2050s under the RCP8.5 scenario is also presented.

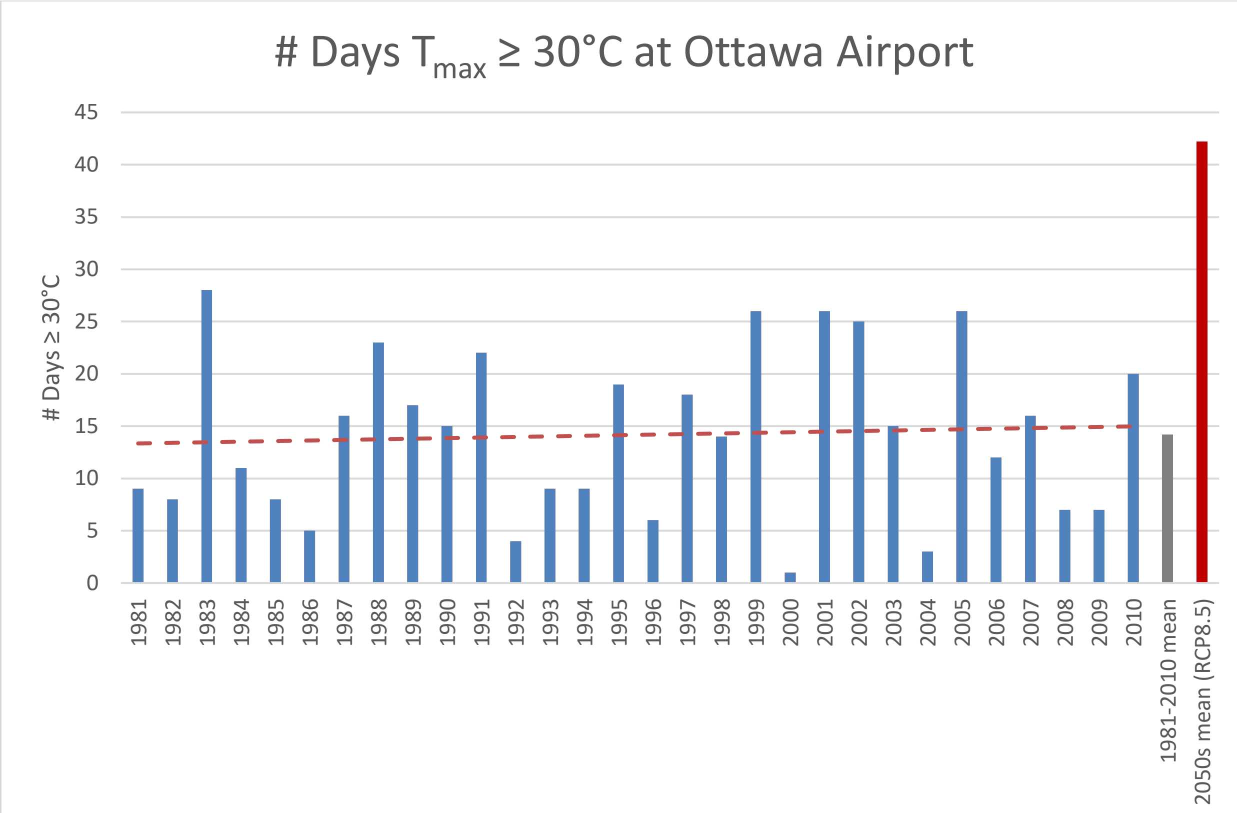

Figure C - 2. Number of days per year with the maximum temperature ≥ 30°C during the 1981-2010 time period at Ottawa Airport. The annual mean for the 1981-2010 baseline and projected for the 2050s under the RCP8.5 scenario is also presented.

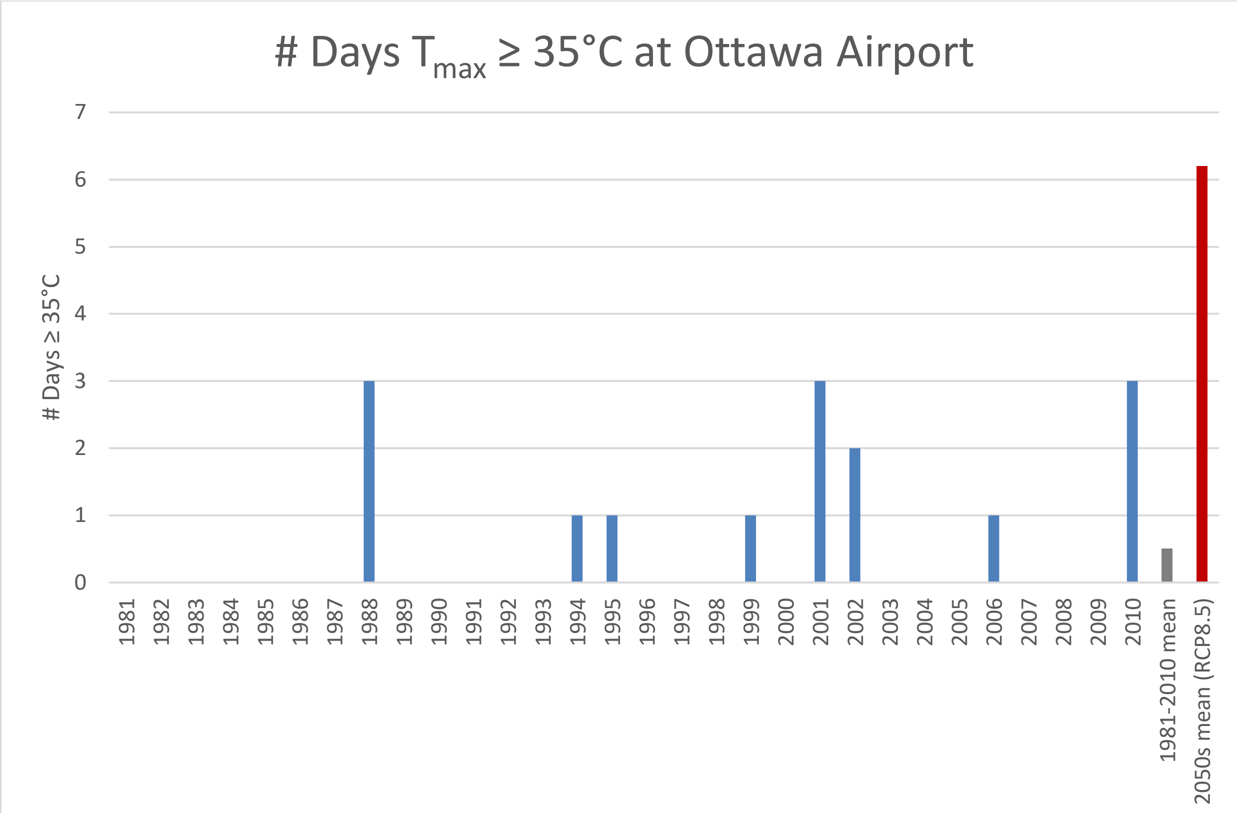

Figure C - 3. Number of days per year with the maximum temperature ≥ 35°C during the 1981-2010 time period at Ottawa Airport. The annual mean for the 1981-2010 baseline and projected for the 2050s under the RCP8.5 scenario is also presented.

Heat Waves

Thresholds:
Consecutive Days with $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$;
Consecutive Days with $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$

Heat waves were evaluated by calculating the number of events per year corresponding to the selected threshold. Historical baselines for the frequency of heat waves were established using data from the Ottawa Airport meteorological station and projections were generated using CMIP5 ensemble projections and the Delta Approach.

The frequency of heat waves is projected to increase under climate change. During the 1981-2010 time period, the Greater Ottawa Region has experienced two heat waves of consecutive days with $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$, with the heat waves lasting 2 days, resulting in an annual probability of 7%. Under climate change, these $T_{max} \geq 30°C$ and $T_{min} \geq 23°C$ heat waves are projected to increase in frequency, averaging ~2 heat waves per year, and length (average length of 2.4 days and an average maximum length of 5 days) during the 2050s under the RCP8.5 scenario. During the 1981-2010 time period, the Greater Ottawa Region has not experienced a heat wave of consecutive days with $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$. Under climate change, however, these $T_{max} \geq 30°C$ and $T_{min} \geq 25°C$ heat waves are projected to occur with an annual probability of 37% (and a 30-yr probability of >99%) and with an average length of 2.5 days (and average maximum length of 4 days) during the 2050s under the RCP8.5 scenario.

Temperature – Extreme Cold

Threshold:
T_{min} ≤ -35°C

Extreme cold was evaluated by calculating the number of days per year with the minimum temperature exceeding the selected threshold. The historical baseline was established using data from the Ottawa Airport meteorological station and the 2050s projection was generated using CMIP5 ensemble projections and the Delta Approach.

Extreme cold events with T_{min} ≤ -35°C at the Ottawa Airport are historically rare (3% annual probability), with a minimum temperature of -35°C or below being observed only one day during the 1981-2010 baseline period (in 1981). Under climate change, the frequency of extreme cold events is projected to further decrease, with a 0.1% annual probability projected for the 2050s under the RCP8.5 scenario.

Nevertheless, while the number of days with T_{min} ≤ -35°C is projected to be rare under climate change, the occurrence of extreme cold events is not expected to vanish completely. The amplified warming in the Arctic under climate change has been linked to a more unstable Polar Vortex and the occurrence of extreme weather in the mid-latitudes (30 – 60°N) (Francis and Vavrus, 2012; Coghlan, 2014; Kretschmer et al., 2018). Subsequent wintertime southward dips in the Polar Vortex over Southern Ontario have the potential to result in extreme cold events such as those in recent winters (2012-13, 2013-14, 2017-18, and 2018-19) and could impact the Greater Ottawa Region. Furthermore, the effects of Polar Vortex events under climate change (Mitchell et al., 2012) are not well captured by climate models, meaning that the future frequency of extreme cold events may be somewhat underestimated.

Rain

Threshold:
50 mm of rainfall in 1 hour

Short duration-high intensity (SDHI) rainfall was evaluated using Intensity-Duration-Frequency (IDF) rainfall data and calculating the probability of occurrence of a rainfall of 50 mm in 1 hour. Historical IDF station data is available from the Ottawa Airport meteorological station (1967-2007, not inclusive of all years with data missing for 2001 and 2005). 2050s projections were generated using specialised literature and expert climatological interpretation.

Currently, the occurrence of SDHI rainfalls of 50 mm in 1 hour is rare, with an annual probability of 1% during the 1981-2010 baseline. While the frequency of these events is projected to increase under climate change, rainfalls of these magnitude will continue to be rare, with an annual probability of 4.5% during the 2050s under the RCP8.5 scenario. Nevertheless, a notable increase in the 30-year probability from 25% during the baseline to 75% during the 2050s is projected.

The projected general trends of increasing rainfall are expected to be expressed in higher rainfall rates for individual events. SDHI rainfall (e.g. convective thunderstorm rainfall) has been shown to be particularly sensitive to increases in air temperature and atmospheric moisture, increasing at a rate proportional to the Clausius-Clapeyron (CC) rate. This CC relation (based on atmospheric thermodynamics) is founded on an empirical relationship between air temperature and the amount of water the air could potentially hold, increasing as air temperature also increases. Therefore, warmer air temperatures have the potential to provide increasingly greater amounts of moisture, producing more intense extreme rainfall events as a consequence. Accordingly, low to moderate increases in rainfall amounts are expected with individual events, while very large increases in rainfall rates may occur with the most extreme storms resulting in increased frequency of SDHI events, such as 50 mm rainfalls in 1 hour.

Freezing Rain & Ice Storms

Thresholds:

Ice accumulation of

25 mm; 40 mm

Freezing rain and ice storms were evaluated by calculating the number of events per year where ice accumulation exceeded the selected threshold. Historical baselines were established using historical incident data in Klaassen et al. (2003), as well as ice accretion design data provided in the CSA design standard for overhead electrical transmission systems (CSA, 2010). This specialised data set and design criteria were used instead of climate station data because ice accretion information is not regularly reported at climate stations. Theses data sources were further supplemented by media reports for the most recent (April 2018) high impact ice storm in the Greater Ottawa Region. Projections were generated through literature review and expert climatological interpretation. Cheng et al. (2011) produced downscaled estimates of future ice storm activity, including a breakdown of monthly and seasonal changes, which were used here to estimate future activity in the Greater Ottawa Region.

Several high impact ice storms have affected the Greater Ottawa Region, with the first major ice storm affecting the Ottawa River Valley listed by Klaassen et al. (2003) as having occurred in November of 1909, although earlier less well documented events may have occurred. Historical research was able to confirm four major events, i.e., those which resulted in long term and widespread power and communication outages, affecting the region since 1940, including the most recent April 2018 event as well as the infamous January 1998 ice storm. As such, larger magnitude freezing rain and ice storm events of 25 mm and 40 mm of ice accumulation are relatively rare, with annual probabilities of 5% and 2.5% observed during the 1981-2010 baseline, respectively. While the frequency of these events is projected to increase under climate change, these large magnitude events will continue to be relatively rare, with annual probabilities of 6% (ice accumulation ≥ 25 mm) and 3.8% (ice accumulation ≥ 40 mm) during the 2050s under the RCP8.5 scenario. Nevertheless, the 30-year probabilities of an event with 25 mm ice accumulation is notable, with a baseline 30-year probability of 79% and projected to increase to 84% in the 2050s. Similarly, for an event with 40 mm ice accumulation, the 30-yr probability is projected to increase from >50% during the baseline to ~70% during the 2050s.

Furthermore Cheng et al. (2011) note that while future warming may result in a slight decrease of 10% or less in shoulder season ice storm activity (i.e., November and April), a consistent and significant increase in freezing precipitation was indicated for the cooler period, particularly in January which may see future changes of 75% to 80%, or nearly doubling the occurrence of mid-winter ice storm events.

Snow

Thresholds:
Snow accumulation
≥ 5 cm; 10 cm; 30 cm

Snow was evaluated by calculating the number of events per year exceeding the selected threshold. Historical baselines were established using data from the Ottawa Airport meteorological station. Projections were generated using literature review, climate analogues, and expert climatological interpretation.

The number of snow events per year is projected to remain roughly steady for all three magnitude snow events – snow accumulations ≥ 5 cm, ≥ 10 cm, and ≥ 30 cm. While the total amount of snowfall in a given season is projected to decrease under climate change, it is likely that the frequency of moderate to heavy snowfall events will remain nearly constant. It may seem counter-intuitive to expect steady trends in the frequency of moderate to heavy snowstorms during warming winters, however, meteorological principles dictate that warmer temperatures allow for more moisture to be contained within an air mass, and that if the mean temperature remains below freezing, this precipitation would continue to fall as a frozen precipitation type such as snow, freezing rain, or sleet. The Greater Ottawa Region also has the particular climatological condition of being subject to the western edge of deepening Atlantic storms and is also situated in a valley where colder temperatures predominate for longer periods of time. Larger snowfall events still will remain likely in warmer climate scenarios, even with a decreasing total overall snowfall for a season, as extreme cold outbreaks (so-called “Polar Vortex” winters) are likely to continue occurring in response to arctic amplification (Zhang et al., 2016; Overland, 2016) and stuck weather patterns. Furthermore, studies in parts of the United States have indicated that severe snowstorms (i.e. blizzards) do occur in otherwise warmer and shortened winter seasons, as storms require only a brief period of anomalously cold temperatures (along with the right combination of moisture and atmospheric dynamics) to produce them (Lawrimore et al, 2014; Melillo et al., 2014). It is therefore likely that the frequency of moderate to heavy snowfall events will remain constant through the mid-century (i.e. 2050s).

While small increases in the frequency of lower magnitude snow events – snow accumulations ≥ 5 cm and ≥ 10 cm – have been observed during the 1981-2010 baseline, the frequency of these events is projected to remain steady under climate change. Events with snow accumulation ≥ 5 cm is projected to remain steady with ~15 events per year observed during the baseline and projected for the 2050s under the RCP8.5 scenario (**Figure C - 4**). Similarly, the frequency of events with snow accumulation ≥ 10 cm are observed ~5-6 times per year during the baseline and have a projected occurrence of ~5 time per year in the 2050s under the RCP8.5 scenario (**Figure C - 5**).

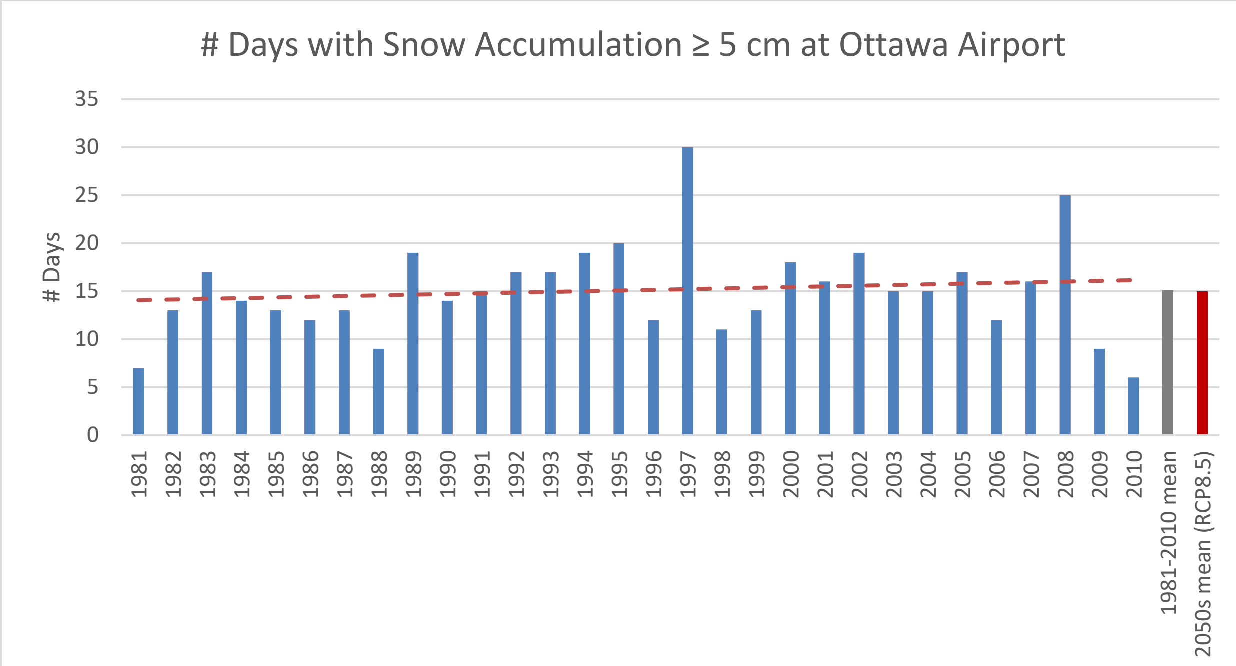

Figure C - 4. Number of events per year with a snowfall accumulation ≥ 5 cm at the Ottawa Airport during the 1981-2010 time period. The annual mean for the 1981-2010 baseline and projected for the 2050s under the RCP8.5 scenario is also presented.

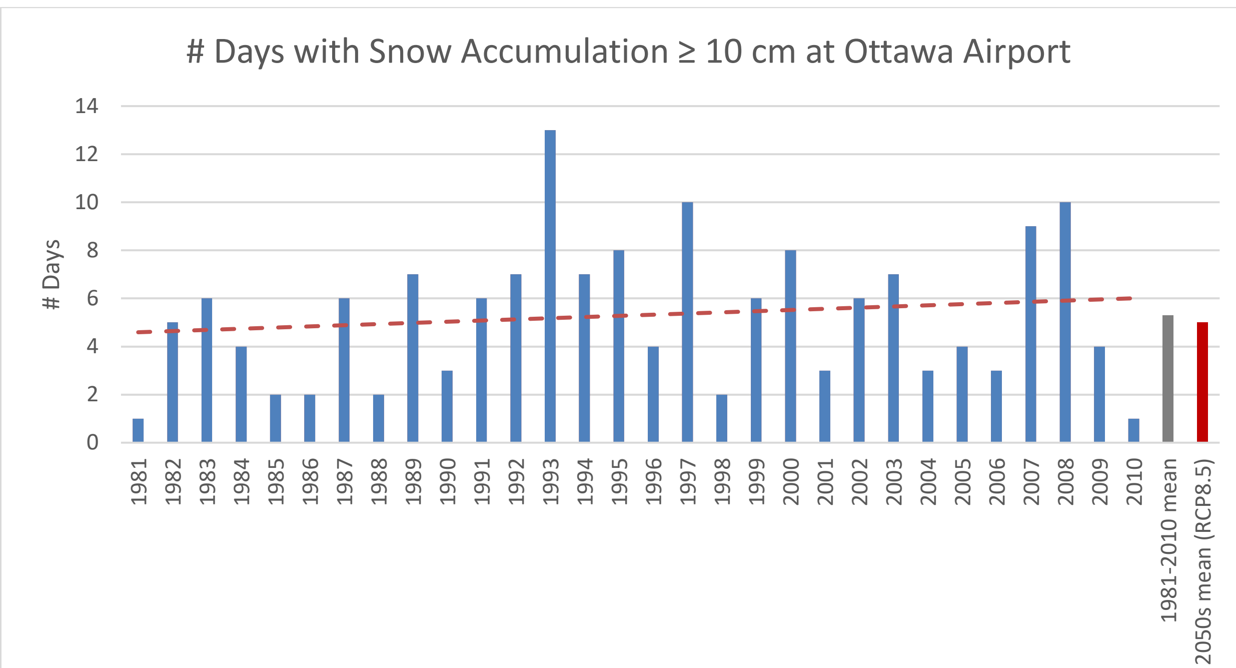

Figure C - 5. Number of events per year with a snowfall accumulation ≥ 10 cm at the Ottawa Airport during the 1981-2010 time period. The annual mean for the 1981-2010 baseline and projected for the 2050s under the RCP8.5 scenario is also presented.

Larger magnitude snow events – snow accumulations ≥ 30 cm – are relatively rare. During the 1981-2010 baseline, events with snow accumulations ≥ 30 cm have been observed 4 times (1984, 1993, 2007, and 2008), with an annual probability of 13%. These larger magnitude events are projected to decrease slightly under climate change, with an annual probability of 10% projected for the 2050s under the RCP8.5

scenario. Nevertheless, the 30-year probabilities of these events are notable, with a 30-year probability of 98% during the baseline and >95% projected during the 2050s.

High Winds

Thresholds:
Wind gusts ≥ 60 km/hr;
80 km/hr; 90 km/hr; 120 km/hr

High winds were evaluated by calculating the number of days per year exceeding the selected threshold. Annual frequency of events exceeding the selected gust thresholds were evaluations. In addition to annual frequency evaluations, easterly wind events with gusts of 60+ km/hr during the warm season (April-Sept.) and summer (June-Aug.) and events with easterly wind events with gusts of 80+ km/hr during the cool season (Oct.-March) and winter (Dec.-Feb.) were evaluated. These lower speed but easterly wind events are of particular interest to Hydro Ottawa as North-South lines are more vulnerable and are guyed on the westside against the prevailing winds. Historical baselines were established using data from the Ottawa Airport meteorological station. Projections were generated using literature review, specialised studies, and climatological interpretation. Currently, the only available downscaled climate change projection studies of damaging wind gusts available for eastern Canada are those produced by Cheng (2014), employing a suite of previous generation (IPCC 4th Assessment Report) climate models. As with other extreme events, specialised studies are needed for such localised and relatively rare extreme events. Cheng (2014) grouped locations into different regions with similar wind gust climates, which also allowed for the comparison of the Greater Ottawa Region's wind climate to other similar stations.

The frequency of events with wind gusts ≥ 60 km/hr is projected to increase slightly under climate change. Annually, the frequency of events with wind gusts ≥ 60 km/hr from any direction is currently ~14-15 times per year during the 1981-2010 baseline and is projected to increase to ~16 time per year in the 2050s under the RCP8.5 scenario. Events with easterly wind gusts ≥ 60 km/hr are less common, with annual probabilities for the baseline of 28.9% during the warm season (April-Sept.) and 2.6% during meteorological summer (June-Aug.). Under climate change the annual probabilities are projected to increase to 32.4% (warm season) and 2.9% (summer) during the 2050s under the RCP8.5 scenario. While the annual probabilities of these easterly wind gust events are lower, the 30-year probabilities are notable, especially for warm season events, with 30-year probabilities of ~100% for warm season events and 55%-60% for summer events (baseline and projected).

The annual frequency of events with wind gusts ≥ 80 km/hr is projected to remain steady under climate change while the cool season and winter frequency of events with easterly wind gusts ≥ 80 km/hr is projected to increase slightly. Annual, the frequency of events with wind gusts ≥ 80 km/hr from any direction is projected to remain steady with ~1-2 times per year observed during the 1981-2010 baseline and projected for the 2050s under the RCP8.5 scenario. Events with easterly wind gust ≥ 80 km/hr are less common, with annual probabilities for the baseline of 5.3% during the cool season (Oct.-March) and 2.6% during meteorological winter (Dec.-Feb.). Under climate change the annual probabilities are projected to increase to 6.3% (cool season) and 3.2% (winter) during the 2050s under the RCP8.5 scenario. While the annual probabilities of these easterly wind gusts are lower, the 30-year probabilities are still notable, especially for cool season events, with 30-year probabilities of 80%-85% for cool season events and ~55%-60% for winter events (baseline and projected).

The frequency of higher magnitude wind events – wind gusts ≥ 90 km/hr and ≥ 120 km/hr (any wind direction) – are also projected to increase under climate change. During the 1981-2010 baseline, events with wind gusts ≥ 90 km/hr have an annual probability of 23%, which is projected to increase to 29% in the 2050s under the RCP8.5 scenario. Although events with wind gusts ≥ 90 km/hr are less common, during both the baseline and 2050s time periods, there's a 30-year probability of >99% of this event occurring. Events with wind gusts ≥ 120 km/hr are relatively rare, with an annual probability of 2.5% observed during the 1981-2010 baseline. The frequency of these high magnitude wind events are projected to increase slightly to 3.1% annual probability during the 2050 under the RCP8.5 scenario. During the baseline and 2050s time periods, there's a 30-year probability of an event with wind gusts ≥ 120 km/hr occurring of 53% and 61%, respectively.

Lightning

Threshold:
Strikes near infrastructure
(flashes/km^2/year)

Lightning was evaluated using lightning flash density (flashes/km^2). A historical baseline (1998-2018) was established using the Environment and Climate Change Canada (ECCC) Canadian Lightning Detection Network. Projections were generated using literature review, specialised studies, and expert climatological interpretation.

Flash density varies across the Greater Ottawa Region (**Figure C - 6**), differing from approximately 1.0 to 1.2 lightning flashes per square kilometer. A flash density of 1.13 per square kilometer per year was therefore selected as a representative value for assets within the Ottawa urbanised areas. Note that resulting probability values used are based on further analyses which take into account the probability of a strike on a specific individual asset, which resulted in annual probabilities of ~1-1.5% for a specific asset being impacted under current and future climate regimes.

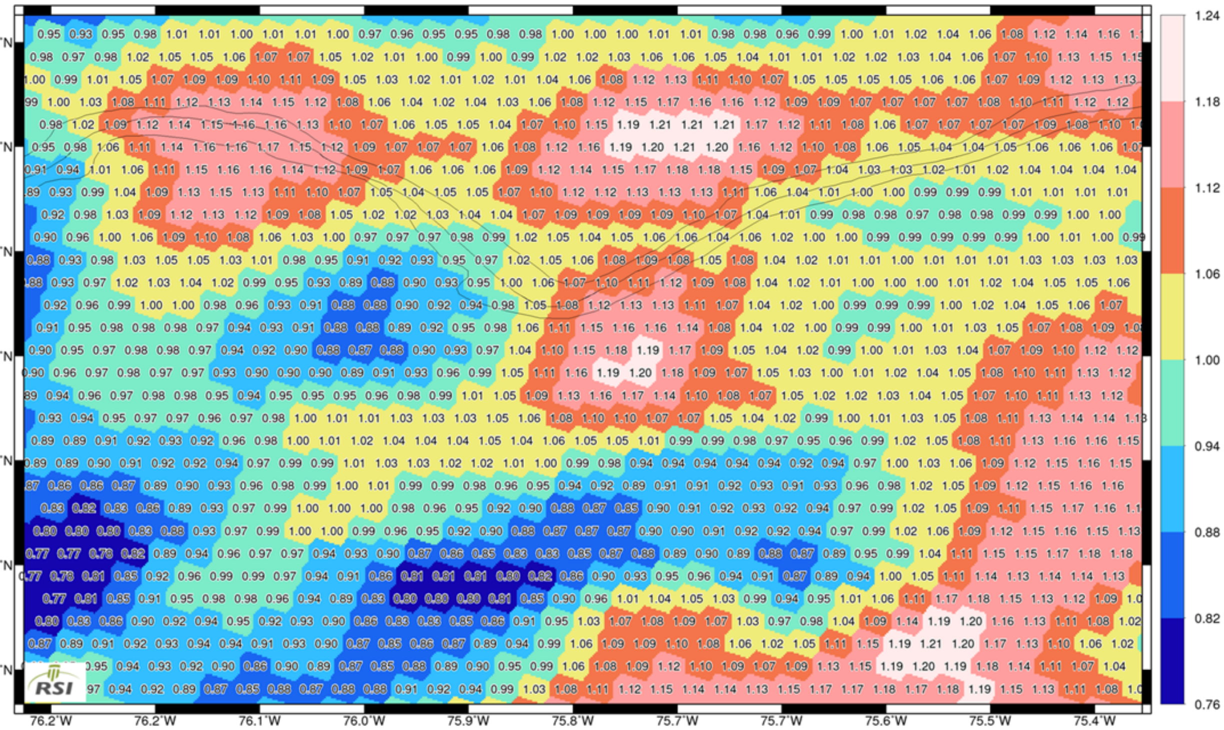

Figure C - 6. Map indicating the lightning flash density in lightning flashes per square kilometre per year for the Greater Ottawa Region and surrounding areas. (Data from the ECCC National Lightning Database; plot produced by Risk Sciences International.)

Climate change studies attempting to quantify future differences in lightning activity have varied by nearly an order of magnitude in projected change values depending on the methodology and associated assumptions used. Greater increases for the North American continent are reported for more robust, meteorological process-based estimates of future lightning activity (e.g. Romps et al., 2014). This is in contrast to global studies which indicate an overall potential *decrease* in the number of lightning strikes on a global scale under a warming climate (Finney et al., 2018), but these changes in global average are mainly driven by decreases in lightning activity in the tropics and are not applicable to mid-latitude countries such as Canada and the United States.

Rough estimates of increases in lightning frequency for the Greater Ottawa Region, based on a study from the U.S. (Romps, 2014), indicated that lightning activity could be expected to increase by about 12 percent per degree Celsius of warming, with about a 50 percent rise over the 21st century. Therefore, it is projected that flash density in the Greater Ottawa Region will increase in annual frequency from 1.1% in the 1998-2018 time period to 1.5% in the 2050s under the RCP8.5 scenario. Furthermore, the length of the higher frequency lightning season is also expected to increase with warming under climate change.

Tornadoes

Thresholds:

EF1+ in Hydro Ottawa service area (City of Ottawa);

EF1+ point probability (i.e. striking a specific asset in the City of Ottawa service area)

Tornadoes were evaluated for the number of F1+ (historical) and EF1+ (since 2013) rated tornadic events per year[1]. A historical baseline was established using the Canadian Tornado Database (1981-2009; Cheng et al., 2013), Ontario historical tornado listing (1892-2009), and media sources (for more recent events). Projections were generated through literature review, specialised studies, and using expert climatological interpretation.

Eastern Ontario and Western Quebec have historically been subject to periodic significant tornado outbreaks, including the recent September 21, 2018 tornado outbreak and a similar outbreak that occurred in the region on June 26, 1978. The June 1978 outbreak included a tornado affecting Masson-Angers, QC of very similar intensity, size and track length to the Dunrobin-Gatineau tornado of September 2018.

Due to the extremely complex nature of tornadoes and other severe thunderstorm hazards, understanding the effects of climate change on their behaviour has been challenging. Unlike other hazards, tornadoes are the result of a combination and balance of a set of meteorological conditions, which also helps to explain their rarity compared to other atmospheric hazards. Only relatively recently have detailed studies of climate change effects on severe thunderstorm activity been able to provide some indication of the potential effects of climate change over the North American continent.

Trapp et al. (2007) assessed the potential effects of climate change on severe thunderstorm activity by looking at two key ingredients, the potential energy available for producing thunderstorms and the atmospheric wind shear – defined as a change in wind speed and/or direction with height. Previous studies looking at overall average conditions suggested that energy will increase but wind shear will decrease under a changing climate, suggesting a possible "break even" condition in that no significant change will occur. However, by looking at the combination of these conditions rather than looking at their average individual change, Trapp et al. (2007) indicated the potential for an overall increase of up to a doubling of severe thunderstorm potential in some parts of North America. Diffenbaugh et al. (2013) further expanded upon this by investigating the change in conditions on individual days rather than longer term averages, finding that the average decrease in wind shear was mainly driven by changes on days *without* significant thunderstorm potential. The result was in fact an overall *increase* in the number of days with combination of high values of both potential energy and wind shear, especially for days with strong wind shear in the lowest portions of the atmosphere, which is particularly relevant for tornado production (Diffenbaugh et al. 2013). Furthermore, these changes were sensitive enough to climate warming that they occur by mid-century and/or under moderate warming (e.g. RCP4.5), and do not require an extreme warming scenario to develop (Diffenbaugh et al. 2013). These studies are further

[1] ECCC adopted the updated "Enhanced Fujita" or EF-Scale in April 2013 (ECCC, 2018) for the purposes of rating the intensity of severe thunderstorm winds and tornadoes based on their resulting damage. However, the historical dataset under the old "F-Scale" was maintained, and modern intensity ratings have been scaled to be roughly equivalent to historical events of similar intensity.

supported by the finding of Gensini and Brooks (2018) who report an observed increase in days with the potential for significant tornado development in the northeastern USA during the 1979-2017 time period.

As such, a conservative estimate of a 25% increase by mid-century (2050s) was applied to EF1+ tornado values for the future, with the annual probability of an EF1+ tornado impacting the Hydro Ottawa service area (City of Ottawa) increasing from an extended 48-year baseline value of 14.6% to a projected 18.2% in the 2050s under climate change. This projected increase in tornadic activity is consistent with other studies looking at future risks of EF2+ tornadoes (Strader et al. 2017) and considers some of the uncertainty associated with climate change projections of severe thunderstorm activity. Additionally, the results of Diffenbaugh et al. (2013) apply not only to tornadoes, but also to other severe thunderstorm hazards including extreme winds from thunderstorms (e.g. downbursts and “derechoes”), large and damaging hail, and even cases of extreme localised rainfall. This means that tornado events only represent a portion of the increase in projected severe weather days.

The point probability of an EF1+ tornado striking a specific Hydro Ottawa asset was also evaluated. Although the probability of a direct strike to a specific piece of infrastructure is very low, the annual point probability is also projected to increase under climate change with the baseline value of 0.018% projected to increase to 0.023% in the 2050s. Nevertheless, while the point probabilities are very low, a direct strike of a EF1+ tornado to infrastructure can result in considerable damage as was observed during the September 2018 outbreak and the direct strike of the Merivale station.

Invasive Species

Thresholds:

Emerald Ash Borer – $T_{min} \leq -30°C$ (kill temp.);

Giant Hogweed – 3 consecutive days with $T_{max} \leq -8°C$ (germination requirement)

Two invasive species of interest to Hydro Ottawa were evaluated in this study – Emerald Ash Borer and Giant Hogweed. Emerald Ash Borer (EAB) was highlighted by Hydro Ottawa due to the direct and indirect impacts on wood poles. EAB can potentially infest (and therefore weaken) poles and the introduction of EAB to the region has resulted in an increase in the woodpecker population, which is in turn damaging poles searching for the EAB. Giant Hogweed was highlighted by Hydro Ottawa as an occupational hazard to personnel due to the serious and potentially damaging impact the plant’s sap can cause to skin and eyes. In this study, relevant temperature thresholds were evaluated corresponding to the invasive species (kill temperature for EAB mature, non-feeding larvae and temperature requirement for germination of Giant Hogweed seeds). As such, historical temperature baselines were established using data from the Ottawa Airport meteorological station and projections were generated using CMIP5 ensemble projections and the Delta Approach.

$T_{min} \leq -30°C$ represents the temperature at which EAB mature, non-feeding larvae will die. During the 1981-2010 baseline, an average of 0.5 days per year (annual probability of 53%) with $T_{min} \leq -30°C$ has been observed at the Ottawa Airport (**Figure C - 7**). In most years, $T_{min} \leq -30°C$ has been observed 0-1 days per year, with the exception of 2003 (2 days) and 1993 (6 days). Under climate change, the frequency of cold days is projected to decrease with $T_{min} \leq -30°C$ becoming a rare event (2050s projected annual probability of 3%). While the occurrence of $T_{min} \leq -30°C$ days are not expected to vanish completely due to the amplified warming in the Arctic under climate change and the more unstable Polar Vortex, the probability of reaching the EAB larvae kill temperature is very low. Subsequently, the warmer winter temperatures will promote the survive of the EAB larvae. A recent study of underbark temperatures and emerald ash borer prepupae mortality has suggested that a reduction in the probability of prepupae mortality in Southern Ontario and the NCA has already occurred in response to warming winter temperatures (Cuddington et al., 2018).

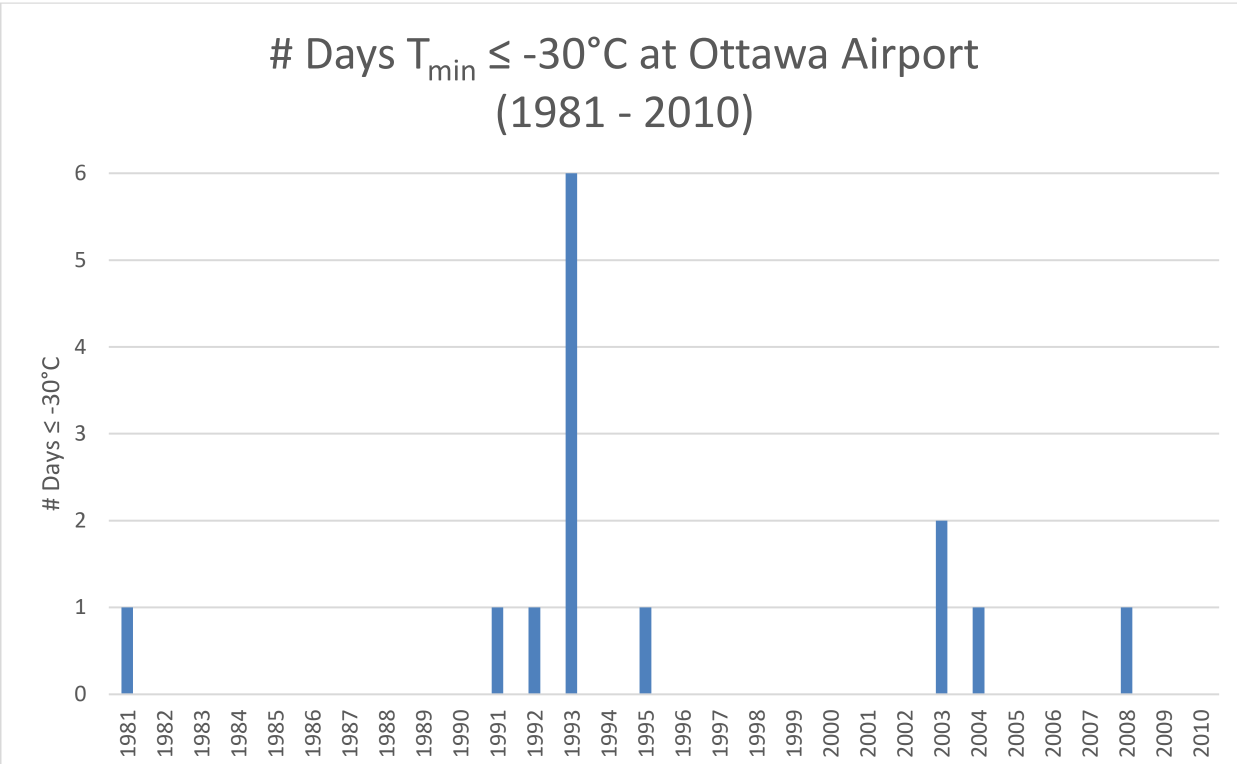

Figure C - 7. Number of days per year with the minimum temperature ≤ -30°C during the 1981-2010 time period at Ottawa Airport.

3 consecutive days with T_{max} ≤ -8°C represents the temperature requirement for germination of Giant Hogweed seeds. During the 1981-2010 baseline, 3 consecutive days with T_{max} ≤ -8°C has occurred on an average of 25 times per year at the Ottawa Airport. Under climate change, the frequency of these events is projected to decrease to an average of 17 times per year in the 2050s under the RCP8.5 scenario. Despite the projected decrease in frequency, the 3 consecutive days with T_{max} ≤ -8°C germination requirement will still be reached multiple times annually allowing continued spread and growth of Giant Hogweed in the Greater Ottawa Region.

Fog

Threshold:
Season with ≥ 50 fog days (Nov.-March)

Fog was evaluated for the winter months (November-March) by calculating the number of days per year with fog reported. Annual probability was evaluated for winters with 50 or more fog days, representing winters with fog observed 1/3 or more of the November-March season. Fog in the winter months promotes aerosolizing of salts (e.g. road salt) which can cause corrosion to infrastructure and salt spray on insulators and conductors can cause pole fires and flashovers. A historical baseline for fog days was established using hourly data from the Ottawa Airport meteorological station and projections were generated using literature review and expert climatological judgment.

During the 1981-2010 baseline, winter fog has been observed an average of 49 days per year and with a decreasing frequency over the 30-year period (**Figure C - 8**). During this baseline, there is an annual probability of 37% for a winter with 50 or more fog days. Days with winter fog is likely to increase under climate change as winter temperatures warm, increasing moisture availability and promoting more evaporation in the region.

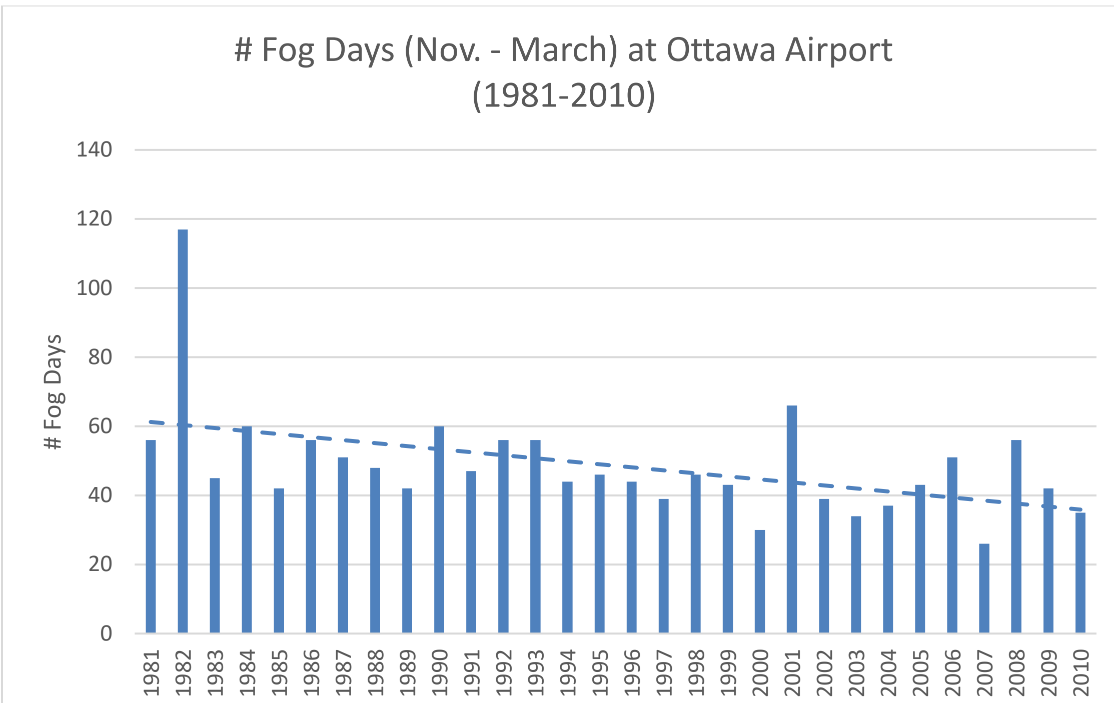

Figure C - 8. Number of days per year with winter (Nov.-March) fog reported at the Ottawa Airport during the 1981-2010 time period.

Frost

> **Thresholds:**
>
> Freeze-thaw cycles – Daily T_{max} T_{min} fluctuation around 0°C;
>
> Hard Freeze-thaw cycles – Daily T_{max} T_{min} fluctuation of ±4°C around 0°C

Freeze-thaw cycles represent days (24-hr periods) where the maximum daily temperature (T_{max}) is greater than 0°C and the minimum daily temperature (T_{min}) is less than 0°C. Therefore, freeze-thaw cycles were evaluated by calculating the number of days meeting this criterion. Additionally, “hard” freeze-thaw cycles with a larger temperature fluctuation – $T_{max} \geq 4$°C and $T_{min} \leq -4$°C – were also evaluated. Larger temperature ranges in the freeze-thaw cycle can further promote the presence of moisture, which is required to cause damage to exposed infrastructure. Freeze-thaw probabilities presented represent the frequency of damaging cycles. Laboratory tests of un-reinforced concrete samples under combined structural loading and freeze-thaw cycling found damage begins in the 20-40 freeze-thaw cycle range (Sun et al., 1999), indicating the selection of 30 freeze-thaw cycles as a lower bound. Therefore, the number of annual freeze-thaw cycles were divided by 30 for probabilities representative of damaging freeze-thaw cycles. Historical baselines were established using data from the Ottawa Airport meteorological station and projections were generated using CMIP5 ensemble projections and the Delta Approach.

The annual number of freeze-thaw cycles (T_{max} and T_{min} fluctuation around 0°C) is projected to decrease under climate change, from a baseline (1981-2010) mean of ~76 cycles per year to 59-60 cycles per year in the 2050s (**Figure C - 9**). Subsequently, the annual frequency of damaging freeze-thaw cycles (i.e. total number of cycles divided by 30) is projected to decrease from the baseline mean of ~2-3 times per year to ~2 times per year in the 2050s. Evaluating the monthly distribution of the number of freeze-thaw cycles reveals that the number of cycles per month during the 1981-2010 time period is greatest during the 'shoulder season' months (e.g. November and March) during the fall and spring seasons (**Figure C - 9**). While the number of freeze-thaw cycles is projected to decrease in many months under climate change, increases are projected for the months of December, January, and February, during which freeze-thaw cycles can be particularly damaging.

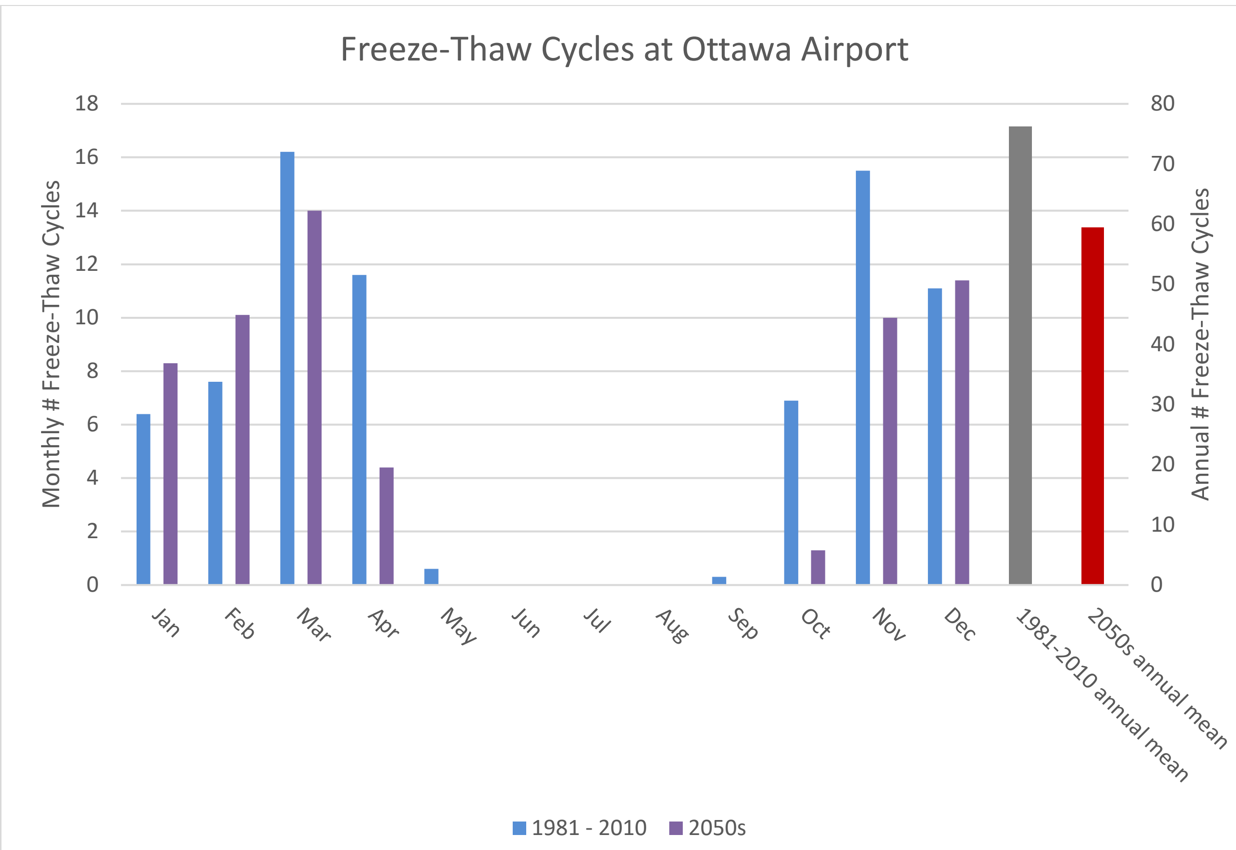

Figure C - 9. Monthly distribution and total annual number of freeze-thaw cycle at the Ottawa Airport during the 1981-2010 time period and projected for the 2050s under the RCP8.5 scenario.

The annual number of hard freeze-thaw cycles (T_{max} T_{min} fluctuation of ±4°C around 0°C) is projected to increase under climate change, from a baseline (1981-2010) mean of ~9 cycles per year to 11-12 cycles per year in the 2050s (**Figure C - 10**). Subsequently, the annual probability of damaging freeze-thaw cycles (i.e. total number of cycles divided by 30) is projected to increase from a baseline of 30% to 38% in the 2050s. Evaluating the monthly distribution of the number of freeze-thaw cycles reveals that the number of cycles per month during the 1981-2010 time period is greatest during the month of March (**Figure C - 10**). Under climate change, the number of freeze-thaw cycles is projected to increase for the months of December, January, February, and March, during which freeze-thaw cycles can be particularly damaging.

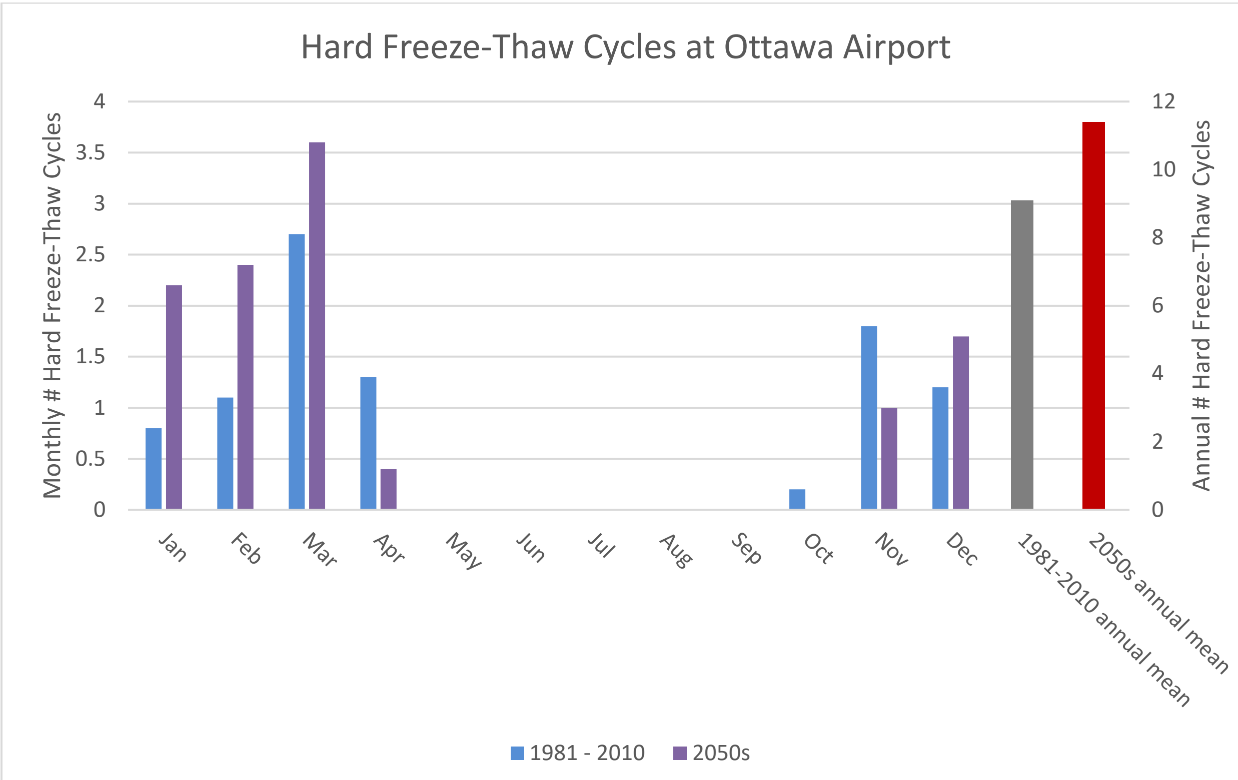

Figure C - 10. Monthly distribution and total annual number of hard freeze-thaw cycle at the Ottawa Airport during the 1981-2010 time period and projected for the 2050s under the RCP8.5 scenario. Hard freeze-thaw cycles are freeze-thaw cycles with a larger temperature fluctuation around 0°C, defined in this study a temperature fluctuation with T_{max} ≥ 4°C and T_{min} ≤ -4°C.

Appendix B SUMMARY OF NOTES FROM INTERVIEWS

To:	Matthew McGrath (Hydro Ottawa),	From:	Riley Morris (Stantec), Guy Felio (Stantec)
Cc:	Nicole Flanagan (Stantec), Eric Lafleur (Stantec), Norman Shippee (RSI), Katie Pingree-Shippee (RSI), Simon Eng (RSI), Heather Auld (RSI)		
File:	Hydro Ottawa Climate Risk Assessment and Adaptation Plan – Interview Results Summary	Date:	November 11, 2019

PREAMBLE

Hydro Ottawa has retained Stantec Consulting Ltd. to conduct a climate change risk assessment and provide recommendations for adaptation and risk mitigation within their operation, design, and business functions to help protect their infrastructure, service delivery and occupational health and safety. A series of interviews with Hydro Ottawa staff within their Operations, Engineering and Design, and Emergency Planning and Response divisions was completed to provide detailed information to inform the climate risk assessment. Three 1.5-hour interviews took place on March 7th and 8th, 2019 and each included 3-4 participants from Hydro Ottawa. A full list of interview participants is provided in **Table 1**. Discussion during these interviews was guided by a prepared list of questions but was encouraged to wander when relevant points arose. The information provided during these interviews will help to identify the climate risks that Hydro Ottawa are exposed to and to gain an appreciation for the challenges and vulnerabilities that could potentially be mitigated through changes in their operations, design, and response policy and practices. A summary of the discussion that took place during these interview sessions is provided herein.

PARTICIPANTS

The following participants attended the interview sessions that took place on March 7-8, 2019.

Table 1 List of Interview Participants and their Roles

Participant	Role
Guy Felio	Interviewer (Stantec)
Riley Morris	Interviewer (Stantec)
Matthew McGrath	Project Manager (Hydro Ottawa)
Operations Staff – March 7, 2019	
Greg Bell	Manager, Distribution Operations (Underground)
Brent Fletcher	Manager, Program Management and Business Performance
Jeff Bracken	Manager, Distribution Operations (Overhead)
Engineering and Design Staff – March 7, 2019	
Margret Flores	Supervisor, Asset Planning
Jenna Gillis	Manager, Asset Planning
Tony Stinziano	Manager, Distribution Design
Ben Hazlett	Manager, Distribution Policies and Standards
Emergency Planning and Response – March 8, 2019	
Doug Boldock	Manager, System Operations
Brian Kuhn	Manager, Distribution Operations (Overhead)
Adam MacGillivray	Business Continuity Management Specialist

CLIMATE PARAMETERS

Wind Events

All participants agree that the intensity and frequency of wind storms has increased in recent years. Wind damage is more prevalent in the north end of Ottawa. The typical path of wind storms is from Kanata towards Crystal Bay and then along the river.

- Wind storms that affect Ottawa do not seem to affect Casselman.
- Sustained winds and gusts were noted to be an issue.
- Wind speed that causes damage to trees depends on the period of the year, i.e., if trees have foliage or not. It was mentioned that with foliage, branches can occur at winds of 60 km/h; with no foliage, winds of more than 80 km/h.
- East-West power lines generally have little impact.
- North-South power lines are vulnerable.
  - North-south power lines are guyed for protection from prevailing winds (from the West).
  - Most intense storms that cause damage come from the East, staff feel that guying should be done from both directions.

- Particularly vulnerable lines include rural lines; for example, Greenbank Road, Fisher Avenue, Limebank Road.

Microbursts

Note: Environment Canada defines a Microburst as "a downburst (strong convective downdraft resulting in an outward burst of often damaging winds at or near the surface) less than 4 km in horizontal dimension. Microbursts tend to have a shorter lifetime and be more intense than larger downbursts and can result in damage intensity similar to that associated with a strong tornado."

- Damaging, especially if coming from the East (poles are guyed from the West).
- Noticed that they occur more often than in the past.
- Knock down older – more vulnerable poles, trees and cause damages to surface infrastructure.

Tornados

- "Can't really do anything except pick up the wires afterwards".
- Areas of improvement include better forecasting to alert employees and contractors, and to mobilize crisis management team.

Specific Instances

- High sustained winds (April 28, 2012) – Lost 3-4 poles, delayed restoration, took hours to recover.
- Remnants of Hurricane Sandy (November 2012) – Cold wind, bucket swaying during maintenance, safety concerns.
- Microburst in Gloucester at Blair and Ogilvie (early-mid 1990s, summer) – Lost a lot of poles.
- Microburst in Lincoln Fields area.
- Tornados of 2018.

Freezing Rain

- Pole fires are common during freezing rain events (electrical current travelling via moisture/dust/salt on conductors/insulators to the pole, which heats up and catches fire). Occurs near 0°C as temperatures are rising + precipitation.
- Flashovers possible.
- To avoid pole fires and flashovers, Hydro Ottawa may sometimes wash porcelain insulators.
- Freezing rain conditions can limit operators/maintenance teams' ability to access impacted areas.
- The weight of ice accretion could cause structural issues or lines to sag. This is not too significant unless there is also wind. The combined effect can cause problems at 1/2 inch of ice accretion + 90km/h winds.
- Ice accretion on switchgear could cause difficulties in switching, each equipment has its own operable limits for ice cover (on the order of 10mm). Near 0°C, it is usually easy to remove accumulated ice off of switch.

- Damages to distribution network are often tree-related (broken limbs, etc.) – severity depends on level of foliage and whether leaf-out has occurred. A lot of damage from tall trees that have limbs that hang above power lines.
- Freezing rain of any quantity is concerning, however, a quantity of 10mm was identified as a possible threshold where Hydro Ottawa starts closer monitoring of the system.
- The impacts of freezing rain are not as severe when it turns into rainfall.

Specific Instances

- The 1998 ice storm was a major issue for Hydro Ottawa.
- Freezing rain storm on April 16, 2018 was memorable for emergency planning team.

Lightning (Atmospheric discharges)

- Not a significant issue.
- May blow transformers, breakers, fuses under direct strike (1-2 instances per year).
- Noticed that thunderstorms recently last longer and that they typically occur more frequently.
- Lightning damage is more prominent in southern Ottawa.
- Lightning protection system design frequency: 1 flash/km^2/year.
- Arrestors aren't actively maintained. Arrestors blow when lightning strikes a pole and can handle a few nearby strikes. Once every 3 years an arrestor replacement program is done.
- Placement of lightning arrestors is much better than in the past
- There are lightning rods at some substations
- Lightning may be a concern if it increases in the future

Heavy Rainfall and Flooding

Rainfall

- No real issues directly caused by rainfall itself.

Flooding

- Electrical equipment in low-lying areas are vulnerable. For example: ponding around vaults, underground equipment, or low pad-mounted/backyard transformers/switchgear is of concern. Transformer will fail if transformer box fills with water. Flow into civil structures or chambers from ponding is an issue.
- Ponding issues are less worrisome in the summer, however during winter melt or rainfall events, frozen ground, ice damming, and iced-over grates exacerbate flooding potential and problems.
- Issues from flooding/ponding are common during spring ice melt.
- Older neighborhoods did not sufficiently plan for flooding and are more vulnerable. Drainage design in new subdivisions is likely to reduce flooding problems.
- Hydro Ottawa can provide input during drainage design stages for subdivision planning.
- Hydro Ottawa relies of the City of Ottawa storm water management system.

Specific Instances

- Flooding event in 2017 – Vaults on Riverside Drive were flooded

Humidity

- Under high humidity, “air gear” (a component of the switchgear) rusts out prematurely from condensation and pooling of water when improperly vegetated. They’ve found that it is cheaper to replace more often than to heat or ventilate to relive moisture n switching centers.

Extreme Temperatures

- Equipment/infrastructure specifications typically has a design temperature range of -40°C to +40°C (ambient).

Extreme Heat

- Heat is not so much an issue for infrastructure.
- Issue in terms of heat advisories are primarily for personnel.
- Extra loading on system (from A/C use) could cause system crashes – load distribution may be required.
- Conductors expand, and lines may sag in the heat – this is not seen as a major issue. The system and components are designed for up to+40°C ambient temperature.
- Most devices are passively cooled.

Prolonged Heat (heat waves)

- After more than three days of heat (mid-30°s) loading capacity issues in the system arise.
- System overloading is common due to extensive A/C use throughout the city. When trying to switch overcapacity loads, breakers often trip. To avoid this, it is often more favorable to overload the equipment (which have short-term overload capabilities) instead of switching. Doing this, however, the equipment needs time to intermittently cool down, if heat continues through the night, it does not get this cool-down time.
- Frequent equipment tripping reduces its life span.

Extreme Cold

- Similar to extreme heat, extreme cold temperature is not viewed as a major issue (equipment design to -40°C ambient temperature), but cold advisories for personnel is required.
- Electric baseboard heating is more common in older areas of Ottawa; these sections can be overcapacity under extreme cold events.
- In extreme cold, switchgear is tight and brittle and very difficult to operate when Hydro Ottawa needs to manually switch loads.

Specific Instances

- Heat waves in 2009 and 2010.

Snowfall

- Concerns about snow events relate to snowplows that damage on-grade infrastructure (ex: transformer collars, transformers, switchgear).
- Access issues can also occur if on-grade equipment and infrastructure are covered in snow.

Freeze-Thaw

- Flooding can result from winter melt or rainfall events, frozen ground, ice damming, and iced-over grates and can impact underground or grade-level infrastructure.
- Freezing moisture can cause failure in underground cabling. If ducts are frozen, crews cannot access to do work.
- There have been more mid-winter freeze-thaw events recently and therefore more pole fires.
- Impacts from the amount of calcium spread during freeze-up events: increased calcium spread results in salt spray onto insulators and conductors which can cause flashovers and pole fires

Wild (forest, grass) Fires

- Grass fires can sometimes turn into forest fires, rural infrastructure can be at risk.
- Even if Hydro Ottawa is not directly at risk, their suppliers' risk (e.g., Hydro One) may be transferred to Hydro Ottawa if their supply lines are affected.

Insect Infestations/Invasive Species

- Increased woodpecker damage to hydro poles (introduction of emerald ash borer caused a spike in the woodpecker population).
- Ticks and giant hogweed are an occupational hazard now for operation/maintenance personnel.
- Shift in vegetation species may impact vegetation management program (growth time, methods, etc.).

GENERAL NOTES

General Comments

- All participants agree that although storm frequency is fairly consistent, storms are getting increasingly more severe; more extreme events are occurring.
- It was noted that there has been a shift in electricity demand peaks in recent years. In the past, winter was a peak demand period for heating; however, customers are converting to gas as heating fuel, and becoming more energy conscious. A/C is becoming standard in houses/offices where it once was a "luxury"; this now results in summer-peaking demand. Because of reduced demand peaks and generally high system performance, Hydro Ottawa has seen fewer system overloading in recent years.
- Major insurance repercussions (in the millions of dollars) if Mutual Assistance Groups are not contacted during an emergency event.
- Casselman does not appear to be impacted as much as Ottawa: this may be a result of storms generally tracking closer to the river and typically not reaching Casselman, or possibly because the electrical system is more robust. Nonetheless, there are less emergencies in Casselman.
- Forecasting: Environment Canada, DTN, The Weather Network - forecasting services getting more expensive for Hydro Ottawa.
- More investment in infrastructure and programs increase rates, which displease the public; however, major event days and the rapid response and restoration of service reminds the customers of the need for robust infrastructure.
- Climate change (e.g. increase in extreme events, higher summer temperatures, lower winter temperatures) will likely cause a shift in their service peaks.
- Hydro Ottawa has never closed their offices due to weather events; however, they have asked people to work from home under extreme conditions (e.g., tornados). Hydro Ottawa recently procured a new intra-company alert system (for all hazards, not just weather).

Event Response

- Hydro Ottawa averages two "Major Event Days" per year; operations believe that this will increase over time.
- Definition of Major Event Day: statistical calculation based on the SAIDI measure exceeding a threshold of 5.5 (IEEE Standard 1366). SAIDI: System Average Interruption Duration Index – The average outage duration for each customer serviced
- Challenges depend on when (time of day) the event occurs, and at times to coordinate staff and their work/sleep schedules can be difficult, particularly during a major event day.
- On a typical day, operators work during the day with a group on call at night
- On a major event day, all available staff work during the day and all staff sleep at night to be ready to start in full force at 6am the next morning with the exception of a small crew who remain at night to manage and operate the systems/communication/monitoring. This is a new practice that is thought to be more efficient and safer for the field crews.
- Hydro Ottawa receives tailored alerts from forecasters. Based on these, forecast and experience, a judgement call is made on how to manage staff
- Emergency planning team feels that they are getting better at responding

Third Party Risks

- Pole availability issues: forest fires in BC have made sourcing wooden poles difficult.
- What telecommunications companies manage with their assets can affect Hydro Ottawa. For example, communications towers lost power during the September 2018 tornados. Hydro Ottawa lost radio, email, and phone capabilities. Because of a critical asset agreement with Bell, they were able to get Bell crews to restore communications within an hour.

Plans, Programs, and Tools

- Storm Hardening Plan
  - Plan was a reaction to 2013 Toronto ice storm.
  - Vegetation Management Plan (VPM): Began quality control program as part of new VMP. Identification of tree species and removing those that are likely to cause issues or rather cutting them back further than the standard 10' radius from lines. Also removing diseased or vulnerable trees, including those that have shallow root systems that could fall onto lines. This plan also includes an education component, for example, telling the city where to plant trees that won't affect their infrastructure.
- Mutual Assistance Groups in which Hydro Ottawa participates
  - Canadian Mutual Assistance Group (CANMAG)
  - North Atlantic Mutual Assistance Group (NAMAG)
  - Quebec Regional Assistance Group (QRAG)
  - Hydro One and Hydro Ottawa will help each other when in need

- Business Continuity Plan
  - Business Impact Analysis on mission critical processes
  - Enterprise Risk Management Group looked at risk identification
  - Emergency Response Plan
  - Crisis Management Plan
  - Incident Management Tool: itemized tool of instructions so that in an emergency, anyone can perform system operation procedures. Each mission critical process has a manual work around.

Areas in which Hydro Ottawa shows Innovation

- Hydro Ottawa currently building new headquarters, which will bring more connectivity among staff and resources, more technology, new SCADA more data for tracking and alerts. New work from home policy (incl. all employees to have laptops) will improve business continuity.
- New equipment, for example, backyard bucket to access backyards and limited access areas including off-road.
- Transition from overhead to underground services has reduced environmental exposure
  - New subdivisions are underground
  - New trunk feeds are underground
- Hydro Ottawa has requested Public Safety Canada to list it as critical infrastructure, which they are currently not. This, for example, would give Hydro Ottawa access to critical radio services.

Areas in which Hydro Ottawa improve

- Hydro Ottawa could have a better alert system. For example, there was not adequate warning for the September 2018 tornados to properly activate the Crisis Management Plan which would have strengthened communication among different response groups, gathered external resources, and would have allowed Hydro Ottawa to contact Mutual Assistance Groups (MAGs) with more notice. In this case, by the time the MAG aid arrived, little assistance was needed.
- To protect North-South power lines, staff feel that poles should be guyed from both the West (where prevailing winds come from) and the East (where intense storms come from), instead of just the West. Alternatively, it was suggested installing a concrete pole every 5-10 poles as anchor poles so the whole line doesn't fail in a storm.
- More intensive vegetation management would reduce impacts. Currently limited to a 10' radius around the powerlines.
- In general, there is interest within the company to adapt to climate change (particularly in the last 1-2 years), but there is no clarity on how to do so.

Benefits of extreme weather events and climate change

- Extreme events can point to the vulnerabilities in the system and help strengthen weak and vulnerable assets.
- Shorter winter seasons may result in a longer construction season
- Improvements to response and preparedness with each event.
- Potential increase in sales of electricity due to increased summer demand

Appendix C SUMMARY OF NOTES FROM WORKSHOP

Notes from Hydro Ottawa 12 April 2019 Workshop

FEEDBACK ON CLIMATE PARAMETERS AND THRESHOLDS

Tmean ≥ 30°C:

- Hydro Ottawa has noticed sensitivity of their equipment to this climate parameter/threshold
- However, it's more of an issue when there's a heat wave….
  - Loading on transformer after the third day becomes the big issue, equipment is unable to cool down properly
- Implications for health and safety of staff working outdoors (can postpone regular maintenance, but at some cost, but not repair responses)
- Consider use of critical limits for CDD, as per note on additional parameters.

Extreme Minimum Temperatures:

- Hydraulics on trucks – may be sensitive to temperatures ~-35°C and colder
- Slower crew responses. Also, crew equipment (e.g. safety gloves) may not respond well (e.g. require bare hand work).

Heat Waves:

- The warm Tmin associated with heat waves is more representation of when Hydro Ottawa system is impacted than the Tmax
- Tmax ≥ 30°C impacts the personnel while the warm Tmin results in increased stress on the electrical system (e.g. loading and transfer of loads to different circuits, equipment unable to cool down properly)
- Tmin of 23°C and 25°C were mentioned (25°C seemed to be mentioned more)
- Therefore, they would be interested in Tmax ≥ 30°C + Tmin ≥ 25°C (or 23°C) for heat wave definition

Extreme Rainfall:

- Hydro Ottawa confirmed no vault flooding due to extreme rainfall
- Any flooding issues were due to riverine flooding (spring, +snowmelt-driven flooding) – 1 Riverside vault has been flooded due to the Rideau River flooding with a ~30-yr frequency (once in the Spring of 1986 or 87 and again in the Spring of 2017)
- Hydro Ottawa noted that buried equipment is submersible and equip to deal with water/flooding
- For health and safety reasons, repair crews may not be able to go aloft in trucks for extreme SDHI events, leading to longer period of power outage before repairs.

Freezing Rain and Ice Storms:

- Freeze thaw and the accumulation of ice speeds up wear and tear
- Freezing rain/ice accretion + wind is the big issue
- Uneven ice accumulation can lead to "galloping" of the lines at wind speeds lower than 90 km/hr
- Design load: ½ inch ice + 90 km/hr wind

- May pose restrictions on times for repair crew responses due to health and safety risks i.e. longer to reach sites, fallen tree branches on roads, slip and fall risks, and use of truck buckets.
- Could add – failure of communications infrastructure will impact responses and their coordination.

High Winds:

- High gust events are an issue because they create spot events (e.g. broken pole)
- Larger spatial scale sustained wind events are also an issue and make life more complicated because, while the individual issues are smaller, it means the crews are deployed over a larger area
- Wind thresholds for restrictions on operation of truck buckets not clear (also issues for falling tree branches). For power outages, this would affect the ability to respond to outages and duration of outages. Question - if a crew member works in high wind or other risky situation and the bucket truck tips or boom drops, who would be blamed? Likely the crews.
  In UK, booms designed up to **35 mph**, after which the boom can collapse. Also, boom could be deflected into distribution infrastructure, with risks if system is wet. Buckettrucks.org website claims "Do not operate the boom **if wind gusts exceed 30 mph** or there is a threat of an **electrical storm**". So, 30 mph = **48 kph**. Suspect that workers do not adhere to this limit.
- Issues associated with flying debris, particularly for exposed sub-station equipment (i.e. higher severity than for a building, for example) – wind thresholds for flying debris likely around 60 kph? City of Calgary's criteria for flying construction debris: 41 - 50 km/h raises sheet metal, aluminum, 20 gauge; half-inch plywood sheet; steel stud, half-inch diameter plastic pipe; Winds 75 - 89 km/h raise half-inch nut, scaffolding, five-eighth-inch drywall sheet, plastic pipe/conduit, four-inch diameter
- Flying debris also poses a staff (repair crew) safety issue
- Note than Casselman station may have issues with flying debris (exposed substation(s), lumberyard across road, abandoned McDonalds adjacent)

Winter Fog, Light Drizzle:

- Hydro Ottawa has a washing program for insulators: twice a year (fall and spring) every year. This is preventative action against seasonal salt buildup on lines, other equipment that can result in fires, outages.
  - Spring washing occurs in mid-March or early April (essentially as soon as the temperature warms up) since winter build-up of salt + warm-up can cause pole fires.

Additional Parameters:

- During the workshop Heather and I got wondering if it's worth adding HDD/CDD and smog/AQ days (didn't discuss with Hydro Ottawa people, just wrote down the thoughts). CDD and HDD threshold would relate to the first severity score for System Accessibility, Sa, where load demand could exceed planning limits. Need some means to relate CDD and HDD to these planning limits.
- Under more extreme weather events, there will likely be a call for mutual aid and need for lodging, food, coordination. The severity of the weather hazard will impact these responses.

Snow Events

- Not much insight provided on different types of snow events other than access issues.

Lightning Events

- Again, not much discussed here.
- Health and safety issue? Crew in buckets repairing systems in an intense lightning storm?
- Cascading Impacts and severity were often mentioned e.g. several of the severity scores interact, as in extreme event triggers widespread power outages which in turn impact ability to respond quickly, efficiency of access and of equipment used to restore system, health and safety of employees, etc. As well, wind on ice or wet snow and directionality can greatly exacerbate impacts.

FEEDBACK ON (ADDITIONS TO) INFRASTRUCTURE LIST

- Hydro fibre
- Residential metering
- Overhead load break switches
- Underground urban infrastructure (e.g. vaults in the downtown core)
- Food services (3rd party) as part of emergency supplies
- Lodging (3rd party) during emergency response

MISCELLANEOUS INFORMATION GATHERED DURING WORKSHOP

- Hydro Ottawa indicated that they discuss the level of risk they are willing to accept and that helps to inform the severity rating for the matrix
- At Casselman:
  - There is no substation building, all equipment is “outdoors” and in cabinets as necessary
  - Cabinets have a heating component but no AC (only fans to ventilate/circulate the air through the cabinet)
  - Casselman station is a ‘two-legged station’ with build-in redundancy
  - Casselman station is across the street from a lumberyard and next to an old McDonald’s Golden Arches (McDonalds moved ~15 years ago so arches have not been maintained)
  - Hydro Ottawa has people on contract in Casselman who can deal with immediate issues. If Hydro Ottawa has to go on-site to fix an issue, it currently takes them up to 1.5 hours to get there (will be ~45 minutes once they move to their new location)
  - There are 3,400 customers in Casselman (residential and businesses)
  - Village of Casselman provides road and storm sewer maintenance
  - Hydro One provides power to Casselman station
  - Bell and Rogers provided telecommunications (copper and fibre)
- Temp < -40°C: metres work (in heated cabinets) but communication system may not
- Transformers are susceptible to windblown debris
- Ground grid is buried 12-18 inches deep; the tails/whips are the exposed and therefore concerning part of the equipment

- There was various discussion on the minimum wind speed that prevents employees going aloft in the bucket trucks (30 km/hr was indicated but there was no definitive speed determined, sounds like it depends on the individual crews deployed) – see above under winds
- “Service equipment” (under “Service and Personnel” on the matrix) was defined as field equipment/tools necessary to complete the job, including portable generators, hot sticks, Class 4 high voltage gloves
- Crews don’t work in extreme rainfall due to Health and Safety reasons – see above under rainfalls
- Freeze-thaw cycles can lead to ice build-up which becomes a Health and Safety concern e.g. breaking hands
- Hydro Ottawa gets fuel from the City of Ottawa and the City gets fuel delivered in – multiply days of heavy snow is needed before the fuel reserve would become an issue

Appendix D RISK WORKSHEET (CURRENT AND FUTURE)

Asset/Infrastructure Element	Performance Considerations				Maximum Temperature – Climate 1									Maximum Temperature – Climate 2									Minimum Temperature – Climate 3								
Current Climate	Level of Service: System Accessibility	Level of Service: Service Quality	Resource Efficiency	Asset Value - Financial	Daily maximum temp. of 35°C and higher									Daily maximum temp. of 40°C and higher									Daily minimum temp. of -35°C and colder								
					Probability = 3									Probability = 2									Probability = 1								
					Final									Final									Final								
	Sa	Sq	Se	Sf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																															
a) General System-Wide Assets																															
Buildings																															
Administrative and Operational Buildings					Y				4				12	Y				4				8									
Roof (Sloped)																															
Roof (Flat)																															
Envelope																															
Structure																															
Foundation																															
Gas																															
Attached Equipment																															
Substation Buildings					Y				4				12	Y				4				8									
Roof														Y				1				2									
Envelope																															
Structure																															
Foundation																															
Gas														Y				1				2									
Attached Equipment																															
Substations																															
Buildings and Structural Components																							Y				1				1
P&C Buildings																															
Switchgear Buildings																															
Equipment Support Structures																															
Station Yard																															
Station Load Break Switch																							Y		1		1		1		1
Station Capacitor Voltage Transformers																															
Station Circuit Breakers																							Y		1				1		
Indoor Breakers																															
Outdoor Breakers (Metalclad)																							y		1		1		1		1
Station Power Transformers																															
Surge Arrestors																															
Bushings																															
Radiators																															
Fans																															
Control Cabinet																															
Tap Changer																															
Bushing Enclosure																															
Conservator																															
Monitoring and Protection Systems																															
Online Dissolved Gas Analyzer																							Y				1				1
Core, Windings, Oil														Y		1				2											
Station Metering																															
spaces)																															
Batteries (INDOOR - ok; OUTDOOR…)																							Y		1				1		
Battery Charger																															
Protection Relays																															
Instrument transformer																															
Electro-Mechanical Relays																															
Microprocessor Relays																															
Station Grounding and Ground Grid																															
Equipment																															
Station Miscellaneous Equipment																															
Busbar																															
Station Post Insulator																															
Lightning Rods and Arrestors																															
LV Power Transformers														Y				1				2									
Cable Trenches																															
Cable Trays																															
Cables														Y				1				2									
Station Lighting																															
Service and Personnel																															
Service Vehicles																															
Service Equipment																							Y	1	4	4	1	1	4	4	1
Staff and Occupational Health and Safety																															
Operators														Y			9	4			18	8	Y			1				1	
Powerline Maintenance Staff														Y			9	4			18	8	Y			1				1	
Support Staff																															
Communications, Smart Grid and Metering																															
Hydro fiber																															
Residential Metering																															
Third Party Services and Interactions																															
Hydro One																															
Power Supply														Y		1				2											
Shared Infrastructure																															
Attached Equipment																															
City of Ottawa																															
Drainage																															
Winter Maintenance																															
Telecommunications																															
Bell & Fibre Lines																															
Fuel Supply																															
Hydro Ottawa Subsidiaries																															
Energy Ottawa																															
Envari																															
Emergency Resources																															
Logistics (Food Services, Lodging)																															
b) Old Subdivisions, Rural and Transmission																															
Power Distribution - Overhead (East-West Orientation)																															
Distribution Lines														Y		1				2											
Primary Overhead Conductor																															
Secondary Overhead Conductors																															
Ground Conductors																															
Third Party Equipment																															
Poles																															
Pole (Wood)																															
Pole (Concrete, Composite, Metal)																															
Cross Arms																															
Guy Wires and Anchors																															
Insulators																															
Surge Arrestors																															
Overhead Transformer														Y		1		1		2		2									
Enclosure																															
Primary Bushing																															
Secondary Bushing																															
Tap Changer																															
Hanging Lugs																															
Overhead Load Breaker Switch																															
Ground Connection																															
Surge Arrestors																															
Fused Cut Out																															
Power Distribution - Overhead (North-South Orientation)																															
Distribution Lines														Y		1				2											
Primary Overhead Conductor																															
Secondary Overhead Conductors																															
Ground Conductors																															
Third Party Equipment																															
Poles																															
Pole (Wood)																															
Pole (Concrete, Composite, Metal)																															
Cross Arms																															
Guy Wires and Anchors																															
Insulators																															
Surge Arrestors																															

Asset/Infrastructure Element	Heat Wave – Climate 4									Extreme Rainfall – Climate 5									Freezing Rain/Ice Storm – Climate 6									Freezing Rain/Ice Storm – Climate 7								
Current Climate	Heat wave: Consecutive days with Tmax ≥ 30°C and Tmin ≥ 25°C									50 mm of rainfall in 1 hour									Ice accumulation of 25 mm									Ice Accumulation of 40mm (30-year occurrence)								
	Probability = 1									Probability = 1									Probability = 1									Probability = 3								
	Final									Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																																				
a) General System-Wide Assets																																				
Buildings																																				
Administrative and Operational Buildings										Y			1	1			1	1	Y			1	1			1	1	Y			4	4			12	12
Roof (Sloped)																																				
Roof (Flat)																																				
Envelope																																				
Structure																																				
Foundation																																				
Gas																																				
Attached Equipment																																				
Substation Buildings										Y			1	1			1	1	Y			1	1			1	1	Y			4	4			12	12
Roof																																				
Envelope																																				
Structure																																				
Foundation																																				
Gas																																				
Attached Equipment																																				
Substations																																				
Buildings and Structural Components										Y			1	1			1	1	Y			1	1			1	1	Y			4	4			12	12
P&C Buildings																																				
Switchgear Buildings																																				
Equipment Support Structures																																				
Station Yard																																				
Station Load Break Switch																			Y		1		1		1		1	Y		4	1	1		12	3	3
Station Capacitor Voltage Transformers																																				
Station Circuit Breakers																																				
Indoor Breakers																																				
Outdoor Breakers (Metalclad)																																				
Station Power Transformers																																				
Surge Arrestors																																				
Bushings																																				
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Bushing Enclosure																																				
Conservator																																				
Monitoring and Protection Systems																																				
Online Dissolved Gas Analyzer																																				
Core, Windings, Oil																																				
Station Metering																																				
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Lightning Rods and Arrestors																																				
LV Power Transformers																																				
Cable Trenches																																				
Cable Trays																																				
Cables																																				
Station Lighting																																				
Service and Personnel																																				
Service Vehicles																			Y	1	4	4	1	1	4	4	1	N								
Service Equipment																																				
Staff and Occupational Health and Safety																																				
Operators										Y			1				1		Y			1	1			1	1	Y			9	4			27	12
Powerline Maintenance Staff										Y			1				1		Y			1	1			1	1	Y			9	4			27	12
Support Staff																												Y			4	1			12	3
Communications, Smart Grid and Metering																																				
Hydro fiber																																				
Residential Metering																																				
Third Party Services and Interactions																																				
Hydro One																												Y		9		9		27		27
Power Supply																																				
Shared Infrastructure																																				
Attached Equipment																																				
City of Ottawa																																				
Drainage																																				
Winter Maintenance																																				
Telecommunications																																				
Bell & Fibre Lines																																				
Fuel Supply																																				
Hydro Ottawa Subsidiaries																																				
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Emergency Resources																																				
Logistics (Food Services, Lodging)																																				
b) Old Subdivisions, Rural and Transmission																																				
Power Distribution - Overhead (East-West Orientation)																																				
Distribution Lines																			Y		4		4		4		4	Y		9	4	4		27	12	12
Primary Overhead Conductor																																				
Secondary Overhead Conductors																																				
Ground Conductors																																				
Third Party Equipment																																				
Poles																												Y		9	4	4		27	12	12
Pole (Wood)																																				
Pole (Concrete, Composite, Metal)																																				
Cross Arms																																				
Guy Wires and Anchors																																				
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Primary Bushing																																				
Secondary Bushing																																				
Tap Changer																																				
Hanging Lugs																																				
Overhead Load Breaker Switch																												Y		4	1	1		12	3	3
Ground Connection																																				
Surge Arrestors																																				
Fused Cut Out																												Y		1	1	1		3	3	3
Power Distribution - Overhead (North-South Orientation)																																				
Distribution Lines																			Y		4		4		4		4	Y		4	4	4		12	12	12
Primary Overhead Conductor																												Y		4	4	4		12	12	12
Secondary Overhead Conductors																												Y		4	4	4		12	12	12
Ground Conductors																												Y		4	4	4		12	12	12
Third Party Equipment																												Y		4	4	4		12	12	12
Poles																												Y		4	4	4		12	12	12
Pole (Wood)																																				
Pole (Concrete, Composite, Metal)																																				
Cross Arms																																				
Guy Wires and Anchors																																				
Insulators																																				
Surge Arrestors																																				

Asset/Infrastructure Element	High Winds – Climate 8									High Winds – Climate 9									High Winds – Climate 11									High Winds – Climate 10								
Current Climate	Easterly winds of 60 km/hr or higher (warm season [April -Sept.])									Easterly winds of 80 km/hr or higher (cool season [Oct.-March])									Annual wind speeds of 120 km/hr or higher									Annual wind speeds of 120 km/hr or higher (30-year occurrence)								
	Probability = 2									Probability = 2									Probability = 1									Probability = 3								
	Final									Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																																				
a) General System-Wide Assets																																				
Buildings																																				
Administrative and Operational Buildings																																				
Roof (Sloped)																																				
Roof (Flat)																																				
Envelope																												Y				4				12
Structure																																				
Foundation																																				
Gas																																				
Attached Equipment																												Y				4				12
Substation Buildings																																				
Roof																																				
Envelope																												Y				4				12
Structure																																				
Foundation																																				
Gas																																				
Attached Equipment																												Y				4				12
Substations																																				
Buildings and Structural Components																																				
P&C Buildings																																				
Switchgear Buildings																																				
Equipment Support Structures																																				
Station Yard																																				
Station Load Break Switch																																				
Station Capacitor Voltage Transformers																																				
Station Circuit Breakers																																				
Indoor Breakers																																				
Outdoor Breakers (Metalclad)																																				
Station Power Transformers																																				
Surge Arrestors																																				
Bushings																																				
Radiators																																				
Fans																																				
Control Cabinet																																				
Tap Changer																																				
Bushing Enclosure																																				
Conservator																																				
Monitoring and Protection Systems																																				
Online Dissolved Gas Analyzer																																				
Core, Windings, Oil																																				
Station Metering																																				
spaces)																																				
Batteries (INDOOR - ok; OUTDOOR…)																																				
Battery Charger																																				
Protection Relays																																				
Instrument transformer																																				
Electro-Mechanical Relays																																				
Microprocessor Relays																																				
Station Grounding and Ground Grid																																				
Equipment																																				
Station Miscellaneous Equipment																																				
Busbar																																				
Station Post Insulator																												Y		1		4		3		12
Lightning Rods and Arrestors																												Y		1		4		3		12
LV Power Transformers																																				
Cable Trenches																																				
Cable Trays																																				
Cables																																				
Station Lighting																																				
Service and Personnel																																				
Service Vehicles																																				
Service Equipment																																				
Staff and Occupational Health and Safety																																				
Operators										Y		4	4	4		8	8	8	Y		4	4	4		4	4	4	Y		4	4	4		12	12	12
Powerline Maintenance Staff	Y									Y		4	4	4		8	8	8	Y		4	4	4		4	4	4	Y		4	4	4		12	12	12
Support Staff																																				
Communications, Smart Grid and Metering																																				
Hydro fiber																																				
Residential Metering																																				
Third Party Services and Interactions																																				
Hydro One																												Y		9		9		27		27
Power Supply																																				
Shared Infrastructure																																				
Attached Equipment																																				
City of Ottawa																																				
Drainage																																				
Winter Maintenance																																				
Telecommunications																																				
Bell & Fibre Lines																																				
Fuel Supply																																				
Hydro Ottawa Subsidiaries																																				
Energy Ottawa																																				
Envari																																				
Emergency Resources																																				
Logistics (Food Services, Lodging)																																				
b) Old Subdivisions, Rural and Transmission																																				
Power Distribution - Overhead (East-West Orientation)																																				
Distribution Lines	Y									Y		4	4	4		8	8	8										Y		9	9	9		27	27	27
Primary Overhead Conductor																																				
Secondary Overhead Conductors																																				
Ground Conductors																																				
Third Party Equipment																																				
Poles										Y		4	4	4		8	8	8										Y		9	9	9		27	27	27
Pole (Wood)																																				
Pole (Concrete, Composite, Metal)																																				
Cross Arms																																				
Guy Wires and Anchors																																				
Insulators																																				
Surge Arrestors																																				
Overhead Transformer																												Y		1	1	1		3	3	3
Enclosure																																				
Primary Bushing																																				
Secondary Bushing																																				
Tap Changer																																				
Hanging Lugs																																				
Overhead Load Breaker Switch																																				
Ground Connection																																				
Surge Arrestors																																				
Fused Cut Out																																				
Power Distribution - Overhead (North-South Orientation)																																				
Distribution Lines	Y									Y	4	4	4	4	8	8	8	8										Y	9	9	9	9	27	27	27	27
Primary Overhead Conductor																																				
Secondary Overhead Conductors																																				
Ground Conductors																																				
Third Party Equipment																																				
Poles										Y	4	4	4	4	8	8	8	8										Y	9	9	9	9	27	27	27	27
Pole (Wood)																																				
Pole (Concrete, Composite, Metal)																																				
Cross Arms																																				
Guy Wires and Anchors																																				
Insulators																																				
Surge Arrestors																																				

Asset/Infrastructure Element	Snow – Climate 11									Frost (ground) – Climate 12									Fog – Climate 13								
Current Climate	Days with 30 cm or more of snowfall									Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C									Season with ≥ 50 fog days (Nov.-March)								
	Probability = 2									Probability = 2									Probability = 3								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																											
a) General System-Wide Assets																											
Buildings																											
Administrative and Operational Buildings	Y			1	1			2	2	Y																	
Roof (Sloped)																											
Roof (Flat)																											
Envelope																											
Structure																											
Foundation																											
Gas																											
Attached Equipment																											
Substation Buildings	Y			1	1			2	2	Y																	
Roof																											
Envelope																											
Structure																											
Foundation																											
Gas																											
Attached Equipment																											
Substations																											
Buildings and Structural Components	Y			1	1			2	2	Y																	
P&C Buildings																											
Switchgear Buildings																											
Equipment Support Structures																											
Station Yard																											
Station Load Break Switch																											
Station Capacitor Voltage Transformers																											
Station Circuit Breakers																											
Indoor Breakers																											
Outdoor Breakers (Metalclad)																											
Station Power Transformers																											
Surge Arrestors																											
Bushings																											
Radiators																											
Fans																											
Control Cabinet																											
Tap Changer																											
Bushing Enclosure																											
Conservator																											
Monitoring and Protection Systems																											
Online Dissolved Gas Analyzer																											
Core, Windings, Oil																											
Station Metering																											
spaces)																											
Batteries (INDOOR - ok; OUTDOOR…)																											
Battery Charger																											
Protection Relays																											
Instrument transformer																											
Electro-Mechanical Relays																											
Microprocessor Relays																											
Station Grounding and Ground Grid																											
Equipment																											
Station Miscellaneous Equipment																											
Busbar																											
Station Post Insulator																											
Lightning Rods and Arrestors																											
LV Power Transformers																											
Cable Trenches																											
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Cables																											
Station Lighting																											
Service and Personnel																											
Service Vehicles																											
Service Equipment																											
Staff and Occupational Health and Safety																											
Operators	Y		4	4	4		8	8	8										Y			1	1			3	3
Powerline Maintenance Staff	Y		4	4	4		8	8	8										Y			1	1			3	3
Support Staff	Y		1	1	1		2	2	2																		
Communications, Smart Grid and Metering																											
Hydro fiber																											
Residential Metering																											
Third Party Services and Interactions																											
Hydro One																											
Power Supply																											
Shared Infrastructure																											
Attached Equipment																											
City of Ottawa																											
Drainage																											
Winter Maintenance																											
Telecommunications																											
Bell & Fibre Lines																											
Fuel Supply																											
Hydro Ottawa Subsidiaries																											
Energy Ottawa																											
Envari																											
Emergency Resources																											
Logistics (Food Services, Lodging)																											
b) Old Subdivisions, Rural and Transmission																											
Power Distribution - Overhead (East-West Orientation)																											
Distribution Lines																											
Primary Overhead Conductor																											
Secondary Overhead Conductors																											
Ground Conductors																											
Third Party Equipment																											
Poles																			Y		4	1	1		12	3	3
Pole (Wood)																											
Pole (Concrete, Composite, Metal)																											
Cross Arms																											
Guy Wires and Anchors																											
Insulators																			Y		4	1	1		12	3	3
Surge Arrestors																											
Overhead Transformer																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Tap Changer																											
Hanging Lugs																											
Overhead Load Breaker Switch																											
Ground Connection																											
Surge Arrestors																											
Fused Cut Out																											
Power Distribution - Overhead (North-South Orientation)																											
Distribution Lines																											
Primary Overhead Conductor																											
Secondary Overhead Conductors																											
Ground Conductors																											
Third Party Equipment																											
Poles																			Y		4	1	1		12	3	3
Pole (Wood)																											
Pole (Concrete, Composite, Metal)																											
Cross Arms																											
Guy Wires and Anchors																											
Insulators																											
Surge Arrestors																											

Asset/Infrastructure Element	Performance Considerations				Maximum Temperature																		Minimum Temperature									Heat Wave									Extreme Rainfall									Freezing Rain/Ice Storm																		High Winds																																				Snow									Frost (ground)									Fog								
					Climate 1									Climate 2									Climate 3									Climate 4									Climate 5									Climate 6									Climate 7									Climate 8									Climate 9									Climate 11									Climate 10									Climate 11									Climate 12									Climate 13								
Current Climate	Level of Service: System Accessibility	Level of Service: Service Quality	Resource Efficiency	Asset Value - Financial	Daily maximum temp. of 35°C and higher									Daily maximum temp. of 40°C and higher									Daily minimum temp. of -35°C and colder									Heat wave: Consecutive days with Tmax ≥ 30°C and Tmin ≥ 25°C									50 mm of rainfall in 1 hour									Ice accumulation of 25 mm									Ice Accumulation of 40mm (30-year occurrence)									Easterly winds of 60 km/hr or higher (warm season [April -Sept.])									Easterly winds of 80 km/hr or higher (cool season [Oct.-March])									Annual wind speeds of 120 km/hr or higher									Annual wind speeds of 120 km/hr or higher (30-year occurrence)									Days with 30 cm or more of snowfall									Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C									Season with ≥ 50 fog days (Nov.-March)								
					Probability = 3									Probability = 2									Probability = 1									Probability = 1									Probability = 1									Probability = 1									Probability = 3									Probability = 2									Probability = 2									Probability = 1									Probability = 3									Probability = 2									Probability = 2									Probability = 3								
					Final									Final									Final									Final									Final									Final									Final									Final									Final									Final									Final									Final									Final									Final								
	Sa	Sq	Se	Sf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Overhead Transformer														Y		1		1		2		2																			Y																																																			Y	1	1	1	1	3	3	3	3																											
Enclosure																																																																																																																											
Primary Bushing																																																																																																																										
Secondary Bushing																																																																																																																											
Tap Changer																																																																																																																											
Hanging Lugs																																																																																																																												
Overhead Load Breaker Switch																																																																																																																											
Ground Connection																																																																																																																												
Surge Arrestors																																																																											Y	1	1	1	1	2	2	2	2										Y	1	1	1	1	3	3	3	3																											
Fused Cut Out																																																												Y	1	1	1	1	3	3	3	3																																																										Y	1	1	1	1	3	3	3	3
Power Distribution - Vaults																																																																																																																											
Vault Transformers (Located in Third Party																																																																																																																											
Enclosure																																																																																																																											
Primary Bushing																																																																																																																										
Secondary Bushing																																																																																																																											
Cooling Radiators																																																																																																																													
c) New Subdivisions																																																																																																																												
Power Distribution - Underground																																																																																																																													
Civil Structures																																																																																																				Y			4	1			8	2	Y			4	4			8	8									
Cable Chamber & Lid																																																																																																																												
Duct Windows																																																																																																																													
Equipment Pad (Above Ground)																																																																																																																												
Concrete Encased Duct Bank																																																																																																																												
Underground Cables					Y				1				3	Y		4		1		8		2																																																																																																								
Underground Primary Switchgear																								Y		1				1																																																																																																				
Enclosure																																																																																																																												
Concrete Base (Pad)																																																																																																																												
Underground Transformers														Y		1		1		2		2																			Y		4		4		4		4																																																																																		
Enclosure																																																																																																																												
Concrete Base																																																																																																																													
Power Distribution - Vaults																																																																																																																												
Vault Transformers (Located in Third Party																																																																																																																											
Enclosure																																																																																																																												
Primary Bushing																																																																																																																												
Secondary Bushing																																																																																																																											
Cooling Radiators																																																																																																																													
2) Village of Casselman (Same Performance rating as for Ottawa)																																																																																																																												
Substations																																																																																																																													
Buildings and Structural Components					Y				4				12	Y				4				8	Y				1				1										Y			1	1			1	1	Y			1	1			1	1	Y			4	4			12	12																																							Y			1	1			2	2	Y																	
P&C Buildings																																																																																																																												
Switchgear Buildings																																																																																																																												
Equipment Support Structures																																																																																																																												
Station Yard																																																																																																																												
Station Load Break Switch														Y		1				2			Y		1		1		1		1																			Y		1		1		1		1	Y		4	1	1		12	3	3																																																																			
Station Capacitor Voltage Transformers														Y		1				2																																																																																																																									
Station Circuit Breakers														Y		1				2			Y		1				1																																																																																																														
Indoor Breakers																																																																																																																												
Outdoor Breakers (Metalclad)														Y		1				2			y		1		1		1		1																																																																																																													
Station Power Transformers																																																																																																																												
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Batteries (INDOOR - ok; OUTDOOR…)																								Y		1				1																																																																																																					
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Station Grounding and Ground Grid																																																																																																																													
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Power Distribution - Overhead (East-West Orientation)																																																																																																																												
Distribution Lines														Y		1				2																														Y		4		4		4		4	Y		9	4	4		27	12	12	Y									Y		4	4	4		8	8	8										Y		9	9	9		27	27	27																											
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Pole (Wood)																																																																																																																													
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Power Distribution - Overhead (North-South Orientation)																																																																																																																												
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Primary Overhead Conductor																																																												Y		4	4	4		12	12	12																																																																												
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Ground Conductors																																																												Y		4	4	4		12	12	12																																																																												
Third Party Equipment																																																												Y		4	4	4		12	12	12																																																																											
Poles																																																												Y		4	4	4		12	12	12										Y	4	4	4	4	8	8	8	8										Y	9	9	9	9	27	27	27	27																			Y		4	1	1		12	3	3
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Ground Connection																																																																																																																													
Surge Arrestors																																																																												Y	1	1	1	1	2	2	2	2										Y	1	1	1	1	3	3	3	3																											
Fused Cut Out																																																												Y	1	1	1	1	3	3	3	3																																																																						Y	1	1	1	1	3	3	3	3

Asset/Infrastructure Element	Performance Considerations				Maximum Temperature																	
					Climate 1									Climate 2								
Current Climate	Level of Service: System Accessibility	Level of Service: Service Quality	Resource Efficiency	Asset Value - Financial	Daily maximum temp. of 35°C and higher									Daily maximum temp. of 40°C and higher								
					Probability = 3									Probability = 2								
					Final									Final								
	Sa	Sq	Se	Sf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Underground																						
Civil Structures																						
Cable Chamber & Lid																						
Duct Windows																						
Equipment Pad (Above Ground)																						
Concrete Encased Duct Bank																						
Underground Cables					Y				1				3	Y		4		1		8		2
Underground Primary Switchgear																						
Enclosure																						
Concrete Base (Pad)																						
Underground Transformers														Y		1		1		2		2
Enclosure																						
Concrete Base																						
Power Distribution - Vaults																						
Vault Transformers (Located in Third Party																						
Enclosure																						
Primary Bushing																						
Secondary Bushing																						
Cooling Radiators																						

Asset/Infrastructure Element	Minimum Temperature									Heat Wave									Extreme Rainfall								
	Climate 3									Climate 4									Climate 5								
Current Climate	Daily minimum temp. of -35°C and colder									Heat wave: Consecutive days with Tmax ≥ 30°C and Tmin ≥ 25°C									50 mm of rainfall in 1 hour								
	Probability = 1									Probability = 1									Probability = 1								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Underground																											
Civil Structures																											
Cable Chamber & Lid																											
Duct Windows																											
Equipment Pad (Above Ground)																											
Concrete Encased Duct Bank																											
Underground Cables																											
Underground Primary Switchgear	Y		1				1																				
Enclosure																											
Concrete Base (Pad)																											
Underground Transformers																			Y		4		4		4		4
Enclosure																											
Concrete Base																											
Power Distribution - Vaults																											
Vault Transformers (Located in Third Party																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Cooling Radiators																											

Asset/Infrastructure Element	Freezing Rain/Ice Storm																		High Winds								
	Climate 6									Climate 7									Climate 8								
Current Climate	Ice accumulation of 25 mm									Ice Accumulation of 40mm (30-year occurrence)									Easterly winds of 60 km/hr or higher (warm season [April -Sept.])								
	Probability = 1									Probability = 3									Probability = 2								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Underground																											
Civil Structures																											
Cable Chamber & Lid																											
Duct Windows																											
Equipment Pad (Above Ground)																											
Concrete Encased Duct Bank																											
Underground Cables																											
Underground Primary Switchgear																											
Enclosure																											
Concrete Base (Pad)																											
Underground Transformers																											
Enclosure																											
Concrete Base																											
Power Distribution - Vaults																											
Vault Transformers (Located in Third Party																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Cooling Radiators																											

Asset/Infrastructure Element	High Winds																										
	Climate 9									Climate 11									Climate 10								
Current Climate	Easterly winds of 80 km/hr or higher (cool season [Oct.-March])									Annual wind speeds of 120 km/hr or higher									Annual wind speeds of 120 km/hr or higher (30-year occurrence)								
	Probability = 2									Probability = 1									Probability = 3								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Underground																											
Civil Structures																											
Cable Chamber & Lid																											
Duct Windows																											
Equipment Pad (Above Ground)																											
Concrete Encased Duct Bank																											
Underground Cables																											
Underground Primary Switchgear																											
Enclosure																											
Concrete Base (Pad)																											
Underground Transformers																											
Enclosure																											
Concrete Base																											
Power Distribution - Vaults																											
Vault Transformers (Located in Third Party																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Cooling Radiators																											

Asset/Infrastructure Element	Snow									Frost (ground)									Fog								
	Climate 11									Climate 12									Climate 13								
Current Climate	Days with 30 cm or more of snowfall									Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C									Season with ≥ 50 fog days (Nov.-March)								
	Probability = 2									Probability = 2									Probability = 3								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Underground																											
Civil Structures	Y			4	1			8	2	Y			4	4			8	8									
Cable Chamber & Lid																											
Duct Windows																											
Equipment Pad (Above Ground)																											
Concrete Encased Duct Bank																											
Underground Cables																											
Underground Primary Switchgear																											
Enclosure																											
Concrete Base (Pad)																											
Underground Transformers																											
Enclosure																											
Concrete Base																											
Power Distribution - Vaults																											
Vault Transformers (Located in Third Party																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Cooling Radiators																											

Asset/Infrastructure Element	Performance Considerations				Maximum Temperature: Climate 1									Maximum Temperature: Climate 2									Minimum Temperature: Climate 3									Heat Wave: Climate 4									Extreme Rainfall: Climate 5								
Current Climate	Level of Service: System Accessibility	Level of Service: Service Quality	Resource Efficiency	Asset Value - Financial	Daily maximum temp. of 35°C and higher									Daily maximum temp. of 40°C and higher									Daily minimum temp. of -35°C and colder									Heat wave: Consecutive days with Tmax ≥ 30°C and Tmin ≥ 25°C									50 mm of rainfall in 1 hour								
					Probability = 5									Probability = 5									Probability = 1									Probability = 3									Probability = 1								
					Final									Final									Final									Final									Final								
	Sa	Sq	Se	Sf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																																																
a) General System-Wide Assets																																																
Buildings																																																
Administrative and Operational Buildings					Y				4				20	Y				4				20																			Y			1	1			1	1
Roof (Sloped)																																																
Roof (Flat)																																																
Envelope																																																
Structure																																																
Foundation																																																
Gas																																																
Attached Equipment																																																
Substation Buildings					Y				4				20	Y				4				20																			Y			1	1			1	1
Roof														Y				1				5																												
Envelope																																																
Structure																																																
Foundation																																																
Gas														Y				1				5																												
Attached Equipment																																																
Substations																																																
Buildings and Structural Components					Y				4				20	Y				4				20	Y				1				1										Y			1	1			1	1
P&C Buildings																																																
Switchgear Buildings																																																
Equipment Support Structures																																																
Station Yard																																																
Station Load Break Switch														Y		1				5			Y		1		1		1		1																			
Station Capacitor Voltage Transformers														Y		1				5																												
Station Circuit Breakers														Y		1				5			Y		1				1																					
Indoor Breakers																																																
Outdoor Breakers (Metalclad)														Y		1				5			y		1		1		1		1																			
Station Power Transformers																																																
Surge Arrestors																																																
Bushings																																																
Radiators																																																
Fans																																																
Control Cabinet																																																
Tap Changer																																																
Bushing Enclosure																																																
Conservator																																																
Monitoring and Protection Systems																																																
Online Dissolved Gas Analyzer																							Y				1				1																			
Core, Windings, Oil														Y		1				5																												
Station Metering																																																
spaces)																																																
Batteries (INDOOR - ok; OUTDOOR…)																							Y		1				1																					
Battery Charger																																																
Protection Relays																																																
Instrument transformer																																																
Electro-Mechanical Relays																																																
Microprocessor Relays																																																
Station Grounding and Ground Grid																																																
Equipment																																																
Station Miscellaneous Equipment																																																
Busbar																																																
Station Post Insulator																																																
Lightning Rods and Arrestors																																																
LV Power Transformers														Y				1				5																												
Cable Trenches																																																
Cable Trays																																																
Cables														Y				1				5																												
Station Lighting																																																
Service and Personnel																																																
Service Vehicles																																																
Service Equipment																							Y	1	4	4	1	1	4	4	1																	
Staff and Occupational Health and Safety																																																
Operators														Y			9	4			45	20	Y			1				1											Y			1				1	
Powerline Maintenance Staff														Y			9	4			45	20	Y			1				1											Y			1				1	
Support Staff																																																
Communications, Smart Grid and Metering																																																
Hydro fiber																																																
Residential Metering																																																
Third Party Services and Interactions																																																
Hydro One																																																
Power Supply														Y		1				5																												
Shared Infrastructure																																																
Attached Equipment																																																
City of Ottawa																																																
Drainage																																																
Winter Maintenance																																																
Telecommunications																																																
Bell & Fibre Lines																																																
Fuel Supply																																																
Hydro Ottawa Subsidiaries																																																
Energy Ottawa																																																
Envari																																																
Emergency Resources																																																
Logistics (Food Services, Lodging)																																																
b) Old Subdivisions, Rural and Transmission																																																
Power Distribution - Overhead (East-West Orientation)																																																
Distribution Lines														Y		1				5																												
Primary Overhead Conductor																																																
Secondary Overhead Conductors																																																
Ground Conductors																																																
Third Party Equipment																																																
Poles																																																
Pole (Wood)																																																
Pole (Concrete, Composite, Metal)																																																
Cross Arms																																																
Guy Wires and Anchors																																																
Insulators																																																
Surge Arrestors																																																
Overhead Transformer														Y		1		1		5		5																												
Enclosure																																																
Primary Bushing																																																
Secondary Bushing																																																
Tap Changer																																																
Hanging Lugs																																																
Overhead Load Breaker Switch																																																
Ground Connection																																																
Surge Arrestors																																																
Fused Cut Out																																																

Asset/Infrastructure Element	Freezing Rain/Ice Storm: Climate 6									Freezing Rain/Ice Storm: Climate 7									High Winds: Climate 8									High Winds: Climate 9									High Winds: Climate 11								
Current Climate	Ice accumulation of 25 mm									Ice Accumulation of 40mm (30-year occurrence)									Easterly winds of 60 km/hr or higher (warm season [April -Sept.])									Easterly winds of 80 km/hr or higher (cool season [Oct.-March])									Annual wind speeds of 120 km/hr or higher								
	Probability = 2									Probability = 4									Probability = 2									Probability = 2									Probability = 1								
	Final									Final									Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																																												
a) General System-Wide Assets																																												
Buildings																																												
Administrative and Operational Buildings	Y			1	1			2	2	Y			4	4			16	16																										
Roof (Sloped)																																												
Roof (Flat)																																												
Envelope																																												
Structure																																												
Foundation																																												
Gas																																												
Attached Equipment																																												
Substation Buildings	Y			1	1			2	2	Y			4	4			16	16																										
Roof																																												
Envelope																																												
Structure																																												
Foundation																																												
Gas																																												
Attached Equipment																																												
Substations																																												
Buildings and Structural Components	Y			1	1			2	2	Y			4	4			16	16																										
P&C Buildings																																												
Switchgear Buildings																																												
Equipment Support Structures																																												
Station Yard																																												
Station Load Break Switch	Y		1		1		2		2	Y		4	1	1		16	4	4																										
Station Capacitor Voltage Transformers																																												
Station Circuit Breakers																																												
Indoor Breakers																																												
Outdoor Breakers (Metalclad)																																												
Station Power Transformers																																												
Surge Arrestors																																												
Bushings																																												
Radiators																																												
Fans																																												
Control Cabinet																																												
Tap Changer																																												
Bushing Enclosure																																												
Conservator																																												
Monitoring and Protection Systems																																												
Online Dissolved Gas Analyzer																																												
Core, Windings, Oil																																												
Station Metering																																												
spaces)																																												
Batteries (INDOOR - ok; OUTDOOR…)																																												
Battery Charger																																												
Protection Relays																																												
Instrument transformer																																												
Electro-Mechanical Relays																																												
Microprocessor Relays																																												
Station Grounding and Ground Grid																																												
Equipment																																												
Station Miscellaneous Equipment																																												
Busbar																																												
Station Post Insulator																																												
Lightning Rods and Arrestors																																												
LV Power Transformers																																												
Cable Trenches																																												
Cable Trays																																												
Cables																																												
Station Lighting																																												
Service and Personnel																																												
Service Vehicles	Y	1	4	4	1	2	8	8	2	N																																				
Service Equipment																																												
Staff and Occupational Health and Safety																																												
Operators	Y			1	1			2	2	Y			9	4			36	16										Y		4	4	4		8	8	8	Y		4	4	4		4	4	4
Powerline Maintenance Staff	Y			1	1			2	2	Y			9	4			36	16	Y									Y		4	4	4		8	8	8	Y		4	4	4		4	4	4
Support Staff										Y			4	1			16	4																										
Communications, Smart Grid and Metering																																												
Hydro fiber																																												
Residential Metering																																												
Third Party Services and Interactions																																												
Hydro One										Y		9		9		36		36																										
Power Supply																																												
Shared Infrastructure																																												
Attached Equipment																																												
City of Ottawa																																												
Drainage																																												
Winter Maintenance																																												
Telecommunications																																												
Bell & Fibre Lines																																												
Fuel Supply																																												
Hydro Ottawa Subsidiaries																																												
Energy Ottawa																																												
Envari																																												
Emergency Resources																																												
Logistics (Food Services, Lodging)																																												
b) Old Subdivisions, Rural and Transmission																																												
Power Distribution - Overhead (East-West Orientation)																																												
Distribution Lines	Y		4		4		8		8	Y		9	4	4		36	16	16	Y									Y		4	4	4		8	8	8									
Primary Overhead Conductor																																												
Secondary Overhead Conductors																																												
Ground Conductors																																												
Third Party Equipment																																												
Poles										Y		9	4	4		36	16	16										Y		4	4	4		8	8	8									
Pole (Wood)																																												
Pole (Concrete, Composite, Metal)																																												
Cross Arms																																												
Guy Wires and Anchors																																												
Insulators																																												
Surge Arrestors																																												
Overhead Transformer																																												
Enclosure																																												
Primary Bushing																																												
Secondary Bushing																																												
Tap Changer																																												
Hanging Lugs																																												
Overhead Load Breaker Switch										Y		4	1	1		16	4	4																										
Ground Connection																																												
Surge Arrestors																																												
Fused Cut Out										Y		1	1	1		4	4	4																										

Asset/Infrastructure Element	High Winds: Climate 10									Snow: Climate 11									Frost (ground): Climate 12									Fog: Climate 13								
Current Climate	Annual wind speeds of 120 km/hr or higher (30-year occurrence)									Days with 30 cm or more of snowfall									Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C									Season with ≥ 50 fog days (Nov.-March)								
	Probability = 3									Probability = 2									Probability = 3									Probability = 4								
	Final									Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
1) City of Ottawa																																			
a) General System-Wide Assets																																			
Buildings																																			
Administrative and Operational Buildings										Y			1	1			2	2	Y																	
Roof (Sloped)																																			
Roof (Flat)																																			
Envelope	Y				4				12																										
Structure																																			
Foundation																																			
Gas																																			
Attached Equipment	Y				4				12																										
Substation Buildings										Y			1	1			2	2	Y																	
Roof																																			
Envelope	Y				4				12																										
Structure																																			
Foundation																																			
Gas																																			
Attached Equipment	Y				4				12																										
Substations																																			
Buildings and Structural Components										Y			1	1			2	2	Y																	
P&C Buildings																																			
Switchgear Buildings																																			
Equipment Support Structures																																			
Station Yard																																			
Station Load Break Switch																																			
Station Capacitor Voltage Transformers																																			
Station Circuit Breakers																																			
Indoor Breakers																																			
Outdoor Breakers (Metalclad)																																			
Station Power Transformers																																			
Surge Arrestors																																			
Bushings																																			
Radiators																																			
Fans																																			
Control Cabinet																																			
Tap Changer																																			
Bushing Enclosure																																			
Conservator																																			
Monitoring and Protection Systems																																			
Online Dissolved Gas Analyzer																																			
Core, Windings, Oil																																			
Station Metering																																			
spaces)																																			
Batteries (INDOOR - ok; OUTDOOR…)																																			
Battery Charger																																			
Protection Relays																																			
Instrument transformer																																			
Electro-Mechanical Relays																																			
Microprocessor Relays																																			
Station Grounding and Ground Grid																																			
Equipment																																			
Station Miscellaneous Equipment																																			
Busbar																																			
Station Post Insulator	Y		1		4		3		12																										
Lightning Rods and Arrestors	Y		1		4		3		12																										
LV Power Transformers																																			
Cable Trenches																																			
Cable Trays																																			
Cables																																			
Station Lighting																																			
Service and Personnel																																			
Service Vehicles																																			
Service Equipment																																			
Staff and Occupational Health and Safety																																			
Operators	Y		4	4	4		12	12	12	Y		4	4	4		8	8	8										Y			1	1			4	4
Powerline Maintenance Staff	Y		4	4	4		12	12	12	Y		4	4	4		8	8	8										Y			1	1			4	4
Support Staff										Y		1	1	1		2	2	2																		
Communications, Smart Grid and Metering																																			
Hydro fiber																																			
Residential Metering																																			
Third Party Services and Interactions																																			
Hydro One	Y		9		9		27		27																										
Power Supply																																			
Shared Infrastructure																																			
Attached Equipment																																			
City of Ottawa																																			
Drainage																																			
Winter Maintenance																																			
Telecommunications																																			
Bell & Fibre Lines																																			
Fuel Supply																																			
Hydro Ottawa Subsidiaries																																			
Energy Ottawa																																			
Envari																																			
Emergency Resources																																			
Logistics (Food Services, Lodging)																																			
b) Old Subdivisions, Rural and Transmission																																			
Power Distribution - Overhead (East-West Orientation)																																			
Distribution Lines	Y		9	9	9		27	27	27																										
Primary Overhead Conductor																																			
Secondary Overhead Conductors																																			
Ground Conductors																																			
Third Party Equipment																																			
Poles	Y		9	9	9		27	27	27																			Y		4	1	1		16	4	4
Pole (Wood)																																			
Pole (Concrete, Composite, Metal)																																			
Cross Arms																																			
Guy Wires and Anchors																																			
Insulators																												Y		4	1	1		16	4	4
Surge Arrestors																																			
Overhead Transformer	Y		1	1	1		3	3	3																										
Enclosure																																			
Primary Bushing																																			
Secondary Bushing																																			
Tap Changer																																			
Hanging Lugs																																			
Overhead Load Breaker Switch																																			
Ground Connection																																			
Surge Arrestors																																			
Fused Cut Out																																			

Asset/Infrastructure Element — Current Climate

Performance Considerations: Sa = Level of Service: System Accessibility; Sq = Level of Service: Service Quality; Se = Resource Efficiency; Sf = Asset Value - Financial

Asset/Infrastructure Element	Sa	Sq	Se	Sf
Power Distribution - Overhead (North-South Orientation)				
Distribution Lines				
Primary Overhead Conductor				
Secondary Overhead Conductors				
Ground Conductors				
Third Party Equipment				
Poles				
Pole (Wood)				
Pole (Concrete, Composite, Metal)				
Cross Arms				
Guy Wires and Anchors				
Insulators				
Surge Arrestors				
Overhead Transformer				
Enclosure				
Primary Bushing				
Secondary Bushing				
Tap Changer				
Hanging Lugs				
Overhead Load Breaker Switch				
Ground Connection				
Surge Arrestors				
Fused Cut Out				
Power Distribution - Vaults				
Vault Transformers (Located in Third Party Buildings)				
Enclosure				
Primary Bushing				
Secondary Bushing				
Cooling Radiators				
c) New Subdivisions				
Power Distribution - Underground				
Civil Structures				
Cable Chamber & Lid				
Duct Windows				
Equipment Pad (Above Ground)				
Concrete Encased Duct Bank				
Underground Cables				
Underground Primary Switchgear				
Enclosure				
Concrete Base (Pad)				
Underground Transformers				
Enclosure				
Concrete Base				
Power Distribution - Vaults				
Vault Transformers (Located in Third Party Buildings)				
Enclosure				
Primary Bushing				
Secondary Bushing				
Cooling Radiators				
2) Village of Casselman (Same Performance rating as for Ottawa)				
Substations				
Buildings and Structural Components				
P&C Buildings				
Switchgear Buildings				
Equipment Support Structures				
Station Yard				
Station Load Break Switch				
Station Capacitor Voltage Transformers				
Station Circuit Breakers				
Indoor Breakers				
Outdoor Breakers (Metalclad)				
Station Power Transformers				
Surge Arrestors				
Bushings				
Radiators				
Fans				
Control Cabinet				
Tap Changer				
Bushing Enclosure				
Conservator				
Monitoring and Protection Systems				
Online Dissolved Gas Analyzer				
Core, Windings, Oil				
Station Metering spaces)				
Batteries (INDOOR - ok; OUTDOOR…)				
Battery Charger				
Protection Relays				
Instrument transformer				
Electro-Mechanical Relays				
Microprocessor Relays				
Station Grounding and Ground Grid Equipment				
Station Miscellaneous Equipment				
Busbar				
Station Post Insulator				
Lightning Rods and Arrestors				
LV Power Transformers				
Cable Trenches				
Cable Trays				
Cables				
Station Lighting				
Power Distribution - Overhead (East-West Orientation)				
Distribution Lines				
Primary Overhead Conductor				
Secondary Overhead Conductors				
Ground Conductors				
Third Party Equipment				
Poles				
Pole (Wood)				
Pole (Concrete, Composite, Metal)				
Cross Arms				
Guy Wires and Anchors				
Insulators				
Surge Arrestors				
Overhead Transformer				
Enclosure				
Primary Bushing				
Secondary Bushing				
Tap Changer				
Hanging Lugs				
Overhead Load Breaker Switch				
Ground Connection				
Surge Arrestors				
Fused Cut Out				

Maximum Temperature — Climate 1: Daily maximum temp. of 35°C and higher — Probability = 5 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Underground Cables	Y				1				5
Buildings and Structural Components (Casselman)	Y				4				20

Maximum Temperature — Climate 2: Daily maximum temp. of 40°C and higher — Probability = 5 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Distribution Lines (North-South)	Y		1				5		
Overhead Transformer (North-South)	Y		1		1		5		5
Underground Cables	Y		4		1		20		5
Underground Transformers	Y		1		1		5		5
Buildings and Structural Components	Y				4				20
Station Load Break Switch	Y		1				5		
Station Capacitor Voltage Transformers	Y		1				5		
Station Circuit Breakers	Y		1				5		
Outdoor Breakers (Metalclad)	Y		1				5		
Core, Windings, Oil	Y		1				5		
LV Power Transformers	Y				1				5
Cables	Y				1				5
Distribution Lines (East-West)	Y		1				5		
Overhead Transformer (East-West)	Y		1		1		5		5

Minimum Temperature — Climate 3: Daily minimum temp. of -35°C and colder — Probability = 1 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Underground Primary Switchgear	Y		1				1		
Buildings and Structural Components	Y				1				1
Station Load Break Switch	Y		1		1		1		1
Station Circuit Breakers	Y		1				1		
Outdoor Breakers (Metalclad)	y		1		1		1		1
Online Dissolved Gas Analyzer	Y				1				1
Batteries (INDOOR - ok; OUTDOOR…)	Y		1				1		

Heat Wave — Climate 4: Heat wave: Consecutive days with Tmax ≥ 30°C and Tmin ≥ 25°C — Probability = 3 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf

Extreme Rainfall — Climate 5: 50 mm of rainfall in 1 hour — Probability = 1 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Overhead Transformer (North-South)	Y								
Underground Transformers	Y		4		4		4		4
Buildings and Structural Components	Y			1	1			1	1

Freezing Rain/Ice Storm — Climate 6: Ice accumulation of 25 mm — Probability = 2 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Distribution Lines (North-South)	Y		4		4		8		8
Buildings and Structural Components	Y			1	1			2	2
Station Load Break Switch	Y		1		1		2		2
Distribution Lines (East-West)	Y		4		4		8		8

Freezing Rain/Ice Storm — Climate 7: Ice Accumulation of 40mm (30-year occurrence) — Probability = 4 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Distribution Lines (North-South)	Y		4	4	4		16	16	16
Primary Overhead Conductor	Y		4	4	4		16	16	16
Secondary Overhead Conductors	Y		4	4	4		16	16	16
Ground Conductors	Y		4	4	4		16	16	16
Third Party Equipment	Y		4	4	4		16	16	16
Poles (North-South)	Y		4	4	4		16	16	16
Fused Cut Out (North-South)	Y	1	1	1	1	4	4	4	4
Buildings and Structural Components	Y			4	4			16	16
Station Load Break Switch	Y		4	1	1		16	4	4
Distribution Lines (East-West)	Y		9	4	4		36	16	16
Poles (East-West)	Y		9	4	4		36	16	16
Overhead Load Breaker Switch (East-West)	Y		4	1	1		16	4	4
Fused Cut Out (East-West)	Y		1	1	1		4	4	4

High Winds — Climate 8: Easterly winds of 60 km/hr or higher (warm season [April -Sept.]) — Probability = 2 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Distribution Lines (North-South)	Y								
Distribution Lines (East-West)	Y								

High Winds — Climate 9: Easterly winds of 80 km/hr or higher (cool season [Oct.-March]) — Probability = 2 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Distribution Lines (North-South)	Y	4	4	4	4	8	8	8	8
Poles (North-South)	Y	4	4	4	4	8	8	8	8
Surge Arrestors (North-South)	Y	1	1	1	1	2	2	2	2
Distribution Lines (East-West)	Y		4	4	4		8	8	8
Poles (East-West)	Y		4	4	4		8	8	8

High Winds — Climate 11: Annual wind speeds of 120 km/hr or higher — Probability = 1 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf

High Winds — Climate 10: Annual wind speeds of 120 km/hr or higher (30-year occurrence) — Probability = 3 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Distribution Lines (North-South)	Y	9	9	9	9	27	27	27	27
Poles (North-South)	Y	9	9	9	9	27	27	27	27
Overhead Transformer (North-South)	Y	1	1	1	1	3	3	3	3
Surge Arrestors (North-South)	Y	1	1	1	1	3	3	3	3
Station Post Insulator	Y		1		4		3		12
Lightning Rods and Arrestors	Y		1		4		3		12
Distribution Lines (East-West)	Y		9	9	9		27	27	27
Poles (East-West)	Y		9	9	9		27	27	27
Overhead Transformer (East-West)	Y		1	1	1		3	3	3

Snow — Climate 11: Days with 30 cm or more of snowfall — Probability = 2 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Civil Structures	Y			4	1			8	2
Buildings and Structural Components	Y			1	1			2	2

Frost (ground) — Climate 12: Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C — Probability = 3 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Civil Structures	Y			4	4			12	12
Buildings and Structural Components	Y								

Fog — Climate 13: Season with ≥ 50 fog days (Nov.-March) — Probability = 4 (Final)

Element	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Poles (North-South)	Y		4	1	1		16	4	4
Fused Cut Out (North-South)	Y	1	1	1	1	4	4	4	4
Poles (East-West)	Y		4	1	1		16	4	4
Insulators (East-West)	Y		4	1	1		16	4	4

Asset/Infrastructure Element	Performance Considerations				Maximum Temperature																	
					Climate 1									Climate 2								
Current Climate	Level of Service: System Accessibility	Level of Service: Service Quality	Resource Efficiency	Asset Value - Financial	Daily maximum temp. of 35°C and higher									Daily maximum temp. of 40°C and higher								
					Probability = 5									Probability = 5								
					Final									Final								
	Sa	Sq	Se	Sf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Overhead (North-South Orientation)																						
Distribution Lines														Y		1				5		
Primary Overhead Conductor																						
Secondary Overhead Conductors																						
Ground Conductors																						
Third Party Equipment																						
Poles																						
Pole (Wood)																						
Pole (Concrete, Composite, Metal)																						
Cross Arms																						
Guy Wires and Anchors																						
Insulators																						
Surge Arrestors																						
Overhead Transformer														Y		1		1		5		5
Enclosure																						
Primary Bushing																						
Secondary Bushing																						
Tap Changer																						
Hanging Lugs																						
Overhead Load Breaker Switch																						
Ground Connection																						
Surge Arrestors																						
Fused Cut Out																						
Power Distribution - Underground																						
Civil Structures																						
Cable Chamber & Lid																						
Duct Windows																						
Equipment Pad (Above Ground)																						
Concrete Encased Duct Bank																						
Underground Cables					Y				1				5	Y		4		1		20		5
Underground Primary Switchgear																						
Enclosure																						
Concrete Base (Pad)																						
Underground Transformers														Y		1		1		5		5
Enclosure																						
Concrete Base																						
Power Distribution - Vaults																						
Vault Transformers (Located in Third Party Buildings)																						
Enclosure																						
Primary Bushing																						
Secondary Bushing																						
Cooling Radiators																						

Asset/Infrastructure Element	Minimum Temperature									Heat Wave									Extreme Rainfall								
	Climate 3									Climate 4									Climate 5								
Current Climate	Daily minimum temp. of -35°C and colder									Heat wave: Consecutive days with Tmax ≥ 30°C and Tmin ≥ 25°C									50 mm of rainfall in 1 hour								
	Probability = 1									Probability = 3									Probability = 1								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Overhead (North-South Orientation)																											
Distribution Lines																											
Primary Overhead Conductor																											
Secondary Overhead Conductors																											
Ground Conductors																											
Third Party Equipment																											
Poles																											
Pole (Wood)																											
Pole (Concrete, Composite, Metal)																											
Cross Arms																											
Guy Wires and Anchors																											
Insulators																											
Surge Arrestors																											
Overhead Transformer																			Y								
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Tap Changer																											
Hanging Lugs																											
Overhead Load Breaker Switch																											
Ground Connection																											
Surge Arrestors																											
Fused Cut Out																											
Power Distribution - Underground																											
Civil Structures																											
Cable Chamber & Lid																											
Duct Windows																											
Equipment Pad (Above Ground)																											
Concrete Encased Duct Bank																											
Underground Cables																											
Underground Primary Switchgear	Y		1				1																				
Enclosure																											
Concrete Base (Pad)																											
Underground Transformers																			Y		4		4		4		4
Enclosure																											
Concrete Base																											
Power Distribution - Vaults																											
Vault Transformers (Located in Third Party Buildings)																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Cooling Radiators																											

Asset/Infrastructure Element	Freezing Rain/Ice Storm																	
	Climate 6									Climate 7								
Current Climate	Ice accumulation of 25 mm									Ice Accumulation of 40mm (30-year occurrence)								
	Probability = 2									Probability = 4								
	Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Overhead (North-South Orientation)																		
Distribution Lines	Y		4		4		8		8	Y		4	4	4		16	16	16
Primary Overhead Conductor										Y		4	4	4		16	16	16
Secondary Overhead Conductors										Y		4	4	4		16	16	16
Ground Conductors										Y		4	4	4		16	16	16
Third Party Equipment										Y		4	4	4		16	16	16
Poles										Y		4	4	4		16	16	16
Pole (Wood)																		
Pole (Concrete, Composite, Metal)																		
Cross Arms																		
Guy Wires and Anchors																		
Insulators																		
Surge Arrestors																		
Overhead Transformer																		
Enclosure																		
Primary Bushing																		
Secondary Bushing																		
Tap Changer																		
Hanging Lugs																		
Overhead Load Breaker Switch																		
Ground Connection																		
Surge Arrestors																		
Fused Cut Out										Y	1	1	1	1	4	4	4	4
Power Distribution - Underground																		
Civil Structures																		
Cable Chamber & Lid																		
Duct Windows																		
Equipment Pad (Above Ground)																		
Concrete Encased Duct Bank																		
Underground Cables																		
Underground Primary Switchgear																		
Enclosure																		
Concrete Base (Pad)																		
Underground Transformers																		
Enclosure																		
Concrete Base																		
Power Distribution - Vaults																		
Vault Transformers (Located in Third Party Buildings)																		
Enclosure																		
Primary Bushing																		
Secondary Bushing																		
Cooling Radiators																		

Asset/Infrastructure Element	High Winds																	
	Climate 8									Climate 9								
Current Climate	Easterly winds of 60 km/hr or higher (warm season [April -Sept.])									Easterly winds of 80 km/hr or higher (cool season [Oct.-March])								
	Probability = 2									Probability = 2								
	Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Overhead (North-South Orientation)																		
Distribution Lines	Y									Y	4	4	4	4	8	8	8	8
Primary Overhead Conductor																		
Secondary Overhead Conductors																		
Ground Conductors																		
Third Party Equipment																		
Poles										Y	4	4	4	4	8	8	8	8
Pole (Wood)																		
Pole (Concrete, Composite, Metal)																		
Cross Arms																		
Guy Wires and Anchors																		
Insulators																		
Surge Arrestors																		
Overhead Transformer																		
Enclosure																		
Primary Bushing																		
Secondary Bushing																		
Tap Changer																		
Hanging Lugs																		
Overhead Load Breaker Switch																		
Ground Connection																		
Surge Arrestors										Y	1	1	1	1	2	2	2	2
Fused Cut Out																		
Power Distribution - Underground																		
Civil Structures																		
Cable Chamber & Lid																		
Duct Windows																		
Equipment Pad (Above Ground)																		
Concrete Encased Duct Bank																		
Underground Cables																		
Underground Primary Switchgear																		
Enclosure																		
Concrete Base (Pad)																		
Underground Transformers																		
Enclosure																		
Concrete Base																		
Power Distribution - Vaults																		
Vault Transformers (Located in Third Party Buildings)																		
Enclosure																		
Primary Bushing																		
Secondary Bushing																		
Cooling Radiators																		

Asset/Infrastructure Element	High Winds (continued)																	
	Climate 11									Climate 10								
Current Climate	Annual wind speeds of 120 km/hr or higher									Annual wind speeds of 120 km/hr or higher (30-year occurrence)								
	Probability = 1									Probability = 3								
	Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Overhead (North-South Orientation)																		
Distribution Lines										Y	9	9	9	9	27	27	27	27
Primary Overhead Conductor																		
Secondary Overhead Conductors																		
Ground Conductors																		
Third Party Equipment																		
Poles										Y	9	9	9	9	27	27	27	27
Pole (Wood)																		
Pole (Concrete, Composite, Metal)																		
Cross Arms																		
Guy Wires and Anchors																		
Insulators																		
Surge Arrestors																		
Overhead Transformer										Y	1	1	1	1	3	3	3	3
Enclosure																		
Primary Bushing																		
Secondary Bushing																		
Tap Changer																		
Hanging Lugs																		
Overhead Load Breaker Switch																		
Ground Connection																		
Surge Arrestors										Y	1	1	1	1	3	3	3	3
Fused Cut Out																		
Power Distribution - Underground																		
Civil Structures																		
Cable Chamber & Lid																		
Duct Windows																		
Equipment Pad (Above Ground)																		
Concrete Encased Duct Bank																		
Underground Cables																		
Underground Primary Switchgear																		
Enclosure																		
Concrete Base (Pad)																		
Underground Transformers																		
Enclosure																		
Concrete Base																		
Power Distribution - Vaults																		
Vault Transformers (Located in Third Party Buildings)																		
Enclosure																		
Primary Bushing																		
Secondary Bushing																		
Cooling Radiators																		

Asset/Infrastructure Element	Snow									Frost (ground)									Fog								
	Climate 11									Climate 12									Climate 13								
Current Climate	Days with 30 cm or more of snowfall									Freeze-thaw cycles – Daily Tmax Tmin temp. fluctuation of ±4°C around 0°C									Season with ≥ 50 fog days (Nov.-March)								
	Probability = 2									Probability = 3									Probability = 4								
	Final									Final									Final								
	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf	Y/N	Sa	Sq	Se	Sf	Ra	Rq	Re	Rf
Power Distribution - Overhead (North-South Orientation)																											
Distribution Lines																											
Primary Overhead Conductor																											
Secondary Overhead Conductors																											
Ground Conductors																											
Third Party Equipment																											
Poles																			Y		4	1	1		16	4	4
Pole (Wood)																											
Pole (Concrete, Composite, Metal)																											
Cross Arms																											
Guy Wires and Anchors																											
Insulators																											
Surge Arrestors																											
Overhead Transformer																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Tap Changer																											
Hanging Lugs																											
Overhead Load Breaker Switch																											
Ground Connection																											
Surge Arrestors																											
Fused Cut Out																			Y	1	1	1	1	4	4	4	4
Power Distribution - Underground																											
Civil Structures	Y			4	1			8	2	Y			4	4			12	12									
Cable Chamber & Lid																											
Duct Windows																											
Equipment Pad (Above Ground)																											
Concrete Encased Duct Bank																											
Underground Cables																											
Underground Primary Switchgear																											
Enclosure																											
Concrete Base (Pad)																											
Underground Transformers																											
Enclosure																											
Concrete Base																											
Power Distribution - Vaults																											
Vault Transformers (Located in Third Party Buildings)																											
Enclosure																											
Primary Bushing																											
Secondary Bushing																											
Cooling Radiators																											