Appendix F CLIMATE CHANGE ASSESSMENT REPORT

Climate Change Assessment Report – MCEA Study, Bass Pro Mills Drive, from Highway 400 to Weston Road

November 30, 2021

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APPENDIX A: CLIMATE PROFILE OVERVIEW

Executive Summary

The Vaughan Mills Center Secondary Plan (VMCSP, 2014) of the City of Vaughan (the proponent) recommends the extension of Bass Pro Mills Drive westerly to Weston Road which would support future development in the area and will help to distribute east-west traffic, alleviating Rutherford Road to the north, and providing another route connection for York Region Transit (YRT). The proposed extension of Bass Pro Mills Drive, from Highway 400 westerly to Weston Road would include a 2m sidewalk with a 0.4m separation from a 2m cycling lane which is separated from vehicles by a 2.3m boulevard (with drainage outlet to retention swale).

The Natural Environment of the Project site includes the following:

- Primarily meadow with some shallow marsh
- Stormwater management pond inside the southbound ramp at the Bass Pro Mills Drive/Highway 400 interchange
- Potential habitat for significant species, including turtle nesting/wintering habitat
- Black Creek tributary located on west side of study area may support warmwater fish species

A Climate Change Resilience Assessment (CCRA) has been prepared as part of the Municipal Class Environmental Assessment (MCEA) process required by the Ministry of Environment, Conservation and Parks (MECP), Ontario for the proposed extension of Bass Pro Mills Drive westerly to Weston Road (Project). The CCRA has been prepared in accordance with the ISO 31000:2018 Risk Management Standard and the ISO 14090:2019 Adaptation to Climate Change – Principles, Requirements, and Guidelines Standard. Stantec's CCRA approach also aligns with widely accepted climate change risk management protocols, such as the Institute for Catastrophic Loss and Climate Risk Institute (formerly Engineers Canada's) PIEVC Protocol for climate risk assessment which is identified in the MECP guidance document on incorporating climate change in the environmental assessment process (https://www.ontario.ca/page/considering-climate-change-environmental-assessment-process) as an acceptable approach to use for these applications.

The assessment identifies the climate risks to the Project at a broad systems-level based on a future climate scenario and provides a discussion of the potential climate impacts on the project over its construction and operational life. It is intended to inform the design and project management team of projected changes in climate and associated risks to consider at the project's detailed design stage, and to inform the City of Vaughan (City) regarding the impact of climate change on the Project infrastructure through the expected service life of the Project.

The design and specifications of the Project have not yet been finalized. The operational life of the proposed project is expected to be a minimum of 32 years which aligns with the average expected useful life for the collector roads in Ontario. The timescale selected for assessment of future climate change impacts on the Project are the latter years of the expected operational lifespan, i.e., the 2050s (2041-2070). The assessment summarizes climate projections for the greenhouse gas emissions scenario referred to as Representative Concentration Pathway (RCP) 8.5, as defined by the Intergovernmental Panel on Climate Change (IPCC).

This assessment has identified the following climate parameters that may pose hazards to the Project:

- High temperature extremes
- Extreme cold
- Freeze-thaw Cycles
- Short duration - high intensity rain
- Long duration rain
- Heavy snowfall
- Freezing rain events
- Wind gusts

Infrastructure interactions to each climate parameter were examined and an associated risk rating was determined for each potential interaction. The climate parameters that presented the highest risks to the Project are high temperature extremes, freeze-thaw cycles, high intense rainfall, freezing rain, heavy snowfall, and high wind events. The highest risks identified for the project are summarized below:

- High temperature extremes resulted in “high” risks to the roadway surfaces, O&M staffs and natural environment. High temperature extremes could result in more maintenance requirements and decrease the service life of the components of the roadway surfaces.
- “High” risks were associated with freeze-thaw cycles in both current and future climate conditions. Freeze thaw cycles might cause contraction/expansion of soils and thus might cause extra pressure on pavement structure resulting in crack, instability, pothole formation, etc.
- Short duration high intensity rain resulted in “moderate” risks to the roadway and “high” risks to the stormwater management system. High intensity rain could increase the runoff and overwhelm the stormwater drainage system resulting in local flooding.
- Freezing rain could have potential impacts on the road conditions and resulted in “high” risks for the roadway surfaces and O&M staffs. Freezing rain might result in power failure.
- “High” risks were associated with heavy snowfall in both baseline and future climate. Heavy snowfall could result in increased maintenance requirements of the roadway surfaces and could result in safety issues for the O&M staffs and users.

- “Moderate” risks were associated with the high intensity rain, freezing rain and heavy snowfall, while “high” risks were associated with high temperature extremes for the natural environment. High intensity rain could result in increased runoff to the tributary, meadows and marshes, and increased delivery of nutrients and sediments. High temperature extremes might cause more evaporation losses and more stresses to the vegetations and habitats of meadows, marshes, and the creek. This might threaten the survival of sensitive species.
- “High” risks were associated with high wind speed for the lighting/signage and landscaped vegetation in both current and future climate conditions. High wind speeds might cause the safety issues to the O&M staffs and users. High wind speeds might cause trees to fall onto power lines resulting in power failure.

The main recommendations to minimize risks are summarized below:

- Consider incorporating design criteria specific to known future climate risks into the Project’s procurement to ensure the Project constructor takes future climate parameters into account.
- Consider consultation with internal and external stakeholders (i.e., Toronto and Region Conservation Authority) during the detailed design stage to ensure the design and future construction and operation of the Project consider the identified climate risks.
- Consider reviewing climate risk assumptions and implement necessary measures at the time of retrofits or replacements – end-of-service life of components, or assets.
- Consider developing O&M policies around monitoring for and addressing adverse weather conditions (i.e., clearing snow, clearing debris, ponded water).
- Consider green infrastructure practices, such as, tree planting to provide shade along pedestrian and cycling lanes and the use of bio-retention swales to slow down the runoff and to increase stormwater infiltration resulting in reduced stormwater flows.
- Health and Safety - Consider health and safety of the users/staff through the development of a health and safety plan that includes risks associated with climate exposure and extreme weather events. Items related to heat stress, intense rain, freezing rain, heavy snow, and high wind events including risks from flying debris and fallen tress should be addressed through internal policy and staff and public education.
- Natural environment - Consider the protection and rehabilitation of riparian vegetation to maintain current water temperatures to minimize negative impacts on sensitive species under a warming climate. Incorporate measures to reduce habitat fragmentation and increase habitat connectivity by creating corridors for species movement. Consider the use of on-site storage/ponds to manage the stormwater runoff and associated contaminants that could affect the habitats provided by the meadows, marshes, and the creek. Incorporate environmental focused strategies for applying salt and de-icing materials on roadway to limit soil and water contamination that could affect the natural habitats.

Abbreviations

CCRA	Climate Change Resilience Assessment
ECCC	Environment and Climate Change Canada
GHG	Greenhouse gas
GCM	Global Climate Models
IDF	Intensity, Duration, Frequency
INFC	Infrastructure Canada
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
MCEA	Municipal Class Environmental Assessment
MECP	Ministry of Environment, Conservation and Parks
NRCAN	Natural Resources Canada
O&M	Operations and Maintenance
Project	Extension of Bass Pro Mills Drive westerly to Weston Road
RRFB	Rapid Rectangular Flashing Beacon
RCP	Representative Concentration Pathways
UNEP	United Nations Environment Programme

VMCSP	Vaughan Mills Center Secondary Plan
WMO	World Meteorological Organization
YRT	York Region Transit

1.0 INTRODUCTION

This report summarizes the Climate Change Resilience Assessment (CCRA) performed as part of the Municipal Class Environmental Assessment (MCEA) process required by the Ministry of Environment, Conservation and Parks (MECP), Ontario for the proposed extension of Bass Pro Mills Drive, from Highway 400 westerly to Weston Road (Project). A Climate Change Resilience Assessment has been prepared in accordance with the ISO 31000:2018 Risk Management Standard and the ISO 14090:2019 Adaptation to Climate Change – Principles, Requirements, and Guidelines Standard. Stantec's CCRA approach also aligns with widely accepted climate change risk management protocols, such as the Institute for Catastrophic Loss and Climate Risk Institute (formerly Engineers Canada's) PIEVC Protocol for climate risk assessment which is identified in the MECP guidance document on incorporating climate change in the environmental assessment process (https://www.ontario.ca/page/considering-climate-change-environmental-assessment-process) as an acceptable approach to use for these applications.

The assessment identifies the climate risks to the Project at a broad systems-level based on a future climate scenario and provides a discussion of the potential climate impacts on the project over its construction and operational life. It is intended to inform the design and project management team of projected changes in climate and associated risks to consider at the project's detailed design stage, and to inform the City regarding the impact of climate change on the Project infrastructure through the expected service life of the Project.

1.1 PROJECT OVERVIEW

The Vaughan Mills Center Secondary Plan (VMCSP, 2014) recommends the extension of Bass Pro Mills Drive westerly from Highway 400 to Weston Road to support future development in the area and help distribute east-west traffic, alleviating traffic volumes on Rutherford Road to the north, and providing another route connection for York Region Transit (YRT) (City of Vaughan, 2019a). The proposed extension of Bass Pro Mills Drive from Highway 400 westerly to Weston Road (Figure 1) consists of a four lane roadway with 2m sidewalks and 2m cycling lanes on each side which is separated from vehicles by a 2.3m boulevard (See Figure 2, (Stantec, 2021)).

The Natural Environment of the Project site includes the following (Source: City of Vaughan, 2021):

- Primarily meadow with some shallow marsh
- Stormwater management pond inside the southbound ramp at the Bass Pro Mills Drive/Highway 400 interchange
- Potential habitat for significant species, including turtle nesting/wintering habitat
- Black Creek tributary located on west side of study area may support warmwater fish species

The design and specifications of the Project have not yet been finalized. The operational life of the proposed project is expected to be a minimum of thirty-two (32) which aligns with the average expected useful life for the collector roads in Ontario (Source: Statistics Canada, 2020).

Figure 1 Project Location (extension of Bass Pro Mills Drive, from Highway 400 westerly to Weston Road) (Source: City of Vaughan, 2019)

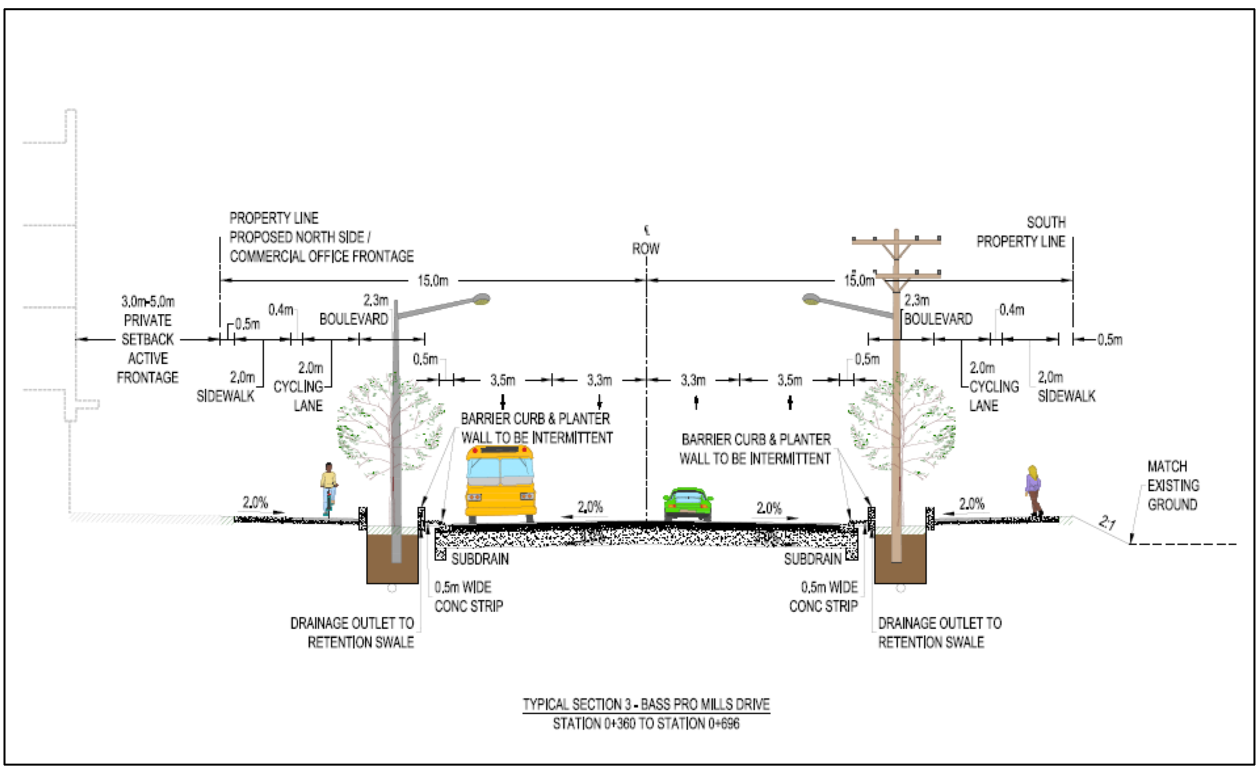

Figure 2 Potential Cross-section of Bass Pro Mills Drive Extension (Source: Technically Recommended Design, Stantec, 2021)

1.2 GENERAL CLIMATE PROFILE

Climate is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of meteorological variables such as temperature, precipitation, and wind over a period of time. A climate profile is a description of current and future climate; therefore, they rely on both historical climate records and on climate projections that attempt to predict future climate (developed by global climate models or GCMs). The historical and future climate projection data in York region (Fausto et al., 2015) were reviewed and a climate profile overview was prepared for the Project area for current and future climate conditions considering the Representative Concentration Pathway 8.5 (RCP 8.5) emission scenario. The climate profile overview for the project area is presented in Appendix A.

When developing a profile of the historic climate of an area, the most valuable data is typically temperature, precipitation, and wind. Due to year-to-year variability, climate data are typically averaged over a 30-year period. In the climate profile overview of the project area, the time horizons of 1981-2010 were selected as current conditions establishing the climate baseline. The future climate conditions are based on the period from 2041-2070 (2050s time horizon) to assess the climate risks to the Project over its expected operational life. The risks and recommendations of this report are specific to the RCP 8.5 scenario as it is considered to best represent the current global GHG emissions. Section 2.4 provides additional details about GHG emission scenarios.

The baseline conditions of the project area are retrieved from Fausto et al. (2015), which was based on the gridded historical climate station-based time series data acquired from Natural Resources Canada (Canadian Gridded Station Observation, CANGRD dataset) (McKenney et al. 2011). The CANGRD datasets were used to determine the baseline of most of the climate parameters such as mean temperature, extreme temperature, frost days/ ice days, freeze-thaw cycles, precipitation accumulation, etc. for the project area. The baseline conditions for wind and snow related parameters are based on the observations from local Environment and Climate Change Canada (ECCC) weather stations (Figure 3).

Climate projections are descriptions of the future climate and are most often collected from GCMs developed by many organizations across the world. These GCMs are complex, in that they all rely on many different assumptions about how they work and what will happen in the future (i.e., they focus more on different physical phenomena to estimate future climate, whether it be greenhouse gas (GHG) concentrations in the atmosphere or absorption of solar radiation by the ocean). Since different GCMs focus more than others on different physical phenomena, there is a noticeable difference in the future climate that is predicted. Therefore, it is not recommended to rely only on one or two GCMs to estimate future climate. Instead, an average of several GCMs tends to give a more reliable estimate of future climate.

There are nearly 40 GCMs that have contributed to the Fifth Coupled Model Intercomparison Project (CMIP5) (Taylor et al., 2012), which forms the basis of the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC). The Pacific Climate Impacts Consortium (PCIC) has taken a subset of 24 of these models to produce reliable, high-resolution downscaled climate projections localized to specific areas of interest in Canada. In the climate profile overview for the project area, the climate projections from a selection of 24 models from the CMIP5 were used with the application of an updated version of the statistical downscaling method.

The historic and projected intensity-duration-frequency (IDF) data for RCP 8.5 scenario published by the Institute for Catastrophic Loss Reduction (ICLR) at Western University, London, Ontario is used to evaluate the future changes in intensity, duration, and frequency of precipitation events. IDF data relates short-duration, high rainfall intensity with its frequency of occurrence. When IDF data is not available from the representative weather station within the climate zone, “ungauged” historical IDF data, calculated through interpolation between Environment Canada weather stations in the region can be used.

The Toronto North York weather monitoring station (ID: 615S001) (Figure 3) provides 34 years of record of IDF data, covering the 1964 - 2014 time period. Therefore, for the project area, the historical IDF data from the Toronto North York weather monitoring station (ID: 615S001) is used to evaluate the future changes in intensity, duration, and frequency of precipitation events. Projections for future climate IDF data are available based on results from 24 Global Circulation Models that simulate future climate conditions. The projected IDF data used in this assessment is based on bias-corrected results from nine downscaled climate models under the RCP 8.5 emission scenario from the Pacific Climate Impacts Consortium.

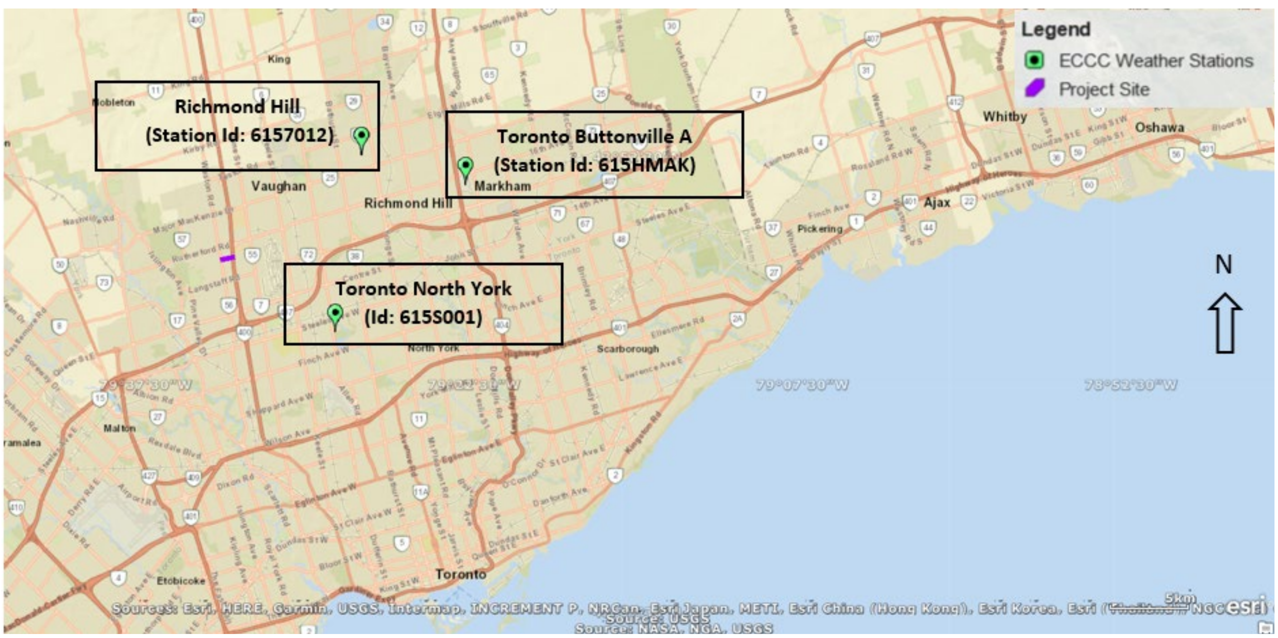

Figure 3 ECCC Weather Monitoring Stations nearby the Project Site

1.2.1 Climate in the Project Area

The regional climate for the City of Vaughan area is defined as humid continental which is typically characterized by cold winters and warm summers with frequent heavy precipitation throughout the year.

The City of Vaughan has declared a climate emergency addressing the climate change related hazards such as sever storms, flooding, tornadoes, and high winds as part of the natural emergency (City of Vaughan, 2019b). Other climate hazards related to extreme temperatures, freeze-thaw cycles, heavy rainfall, heavy snowfall, freezing rain events, etc. can pose risks to the City's infrastructure. Stantec's research into the climate trends and projections for the City of Vaughan area is summarized in the climate profile overview (in Appendix A) and briefly presented here:

- The City of Vaughan area has experienced (and is projected to continue experiencing) temperature increases for annual mean daily temperature, and annual maximum daily temperature. This trend applies to all seasons. By the 2050s, the average annual daily mean and daily maximum temperature are projected to increase by 3.4°C under RCP 8.5.
- The number of extreme heat events – i.e., days with maximum temperatures ≥ 35°C – has averaged around 0.2 days/year from 1981 to 2010. By the 2050's, the number of days over 35°C is projected to increase to 8.0 days/year under RCP 8.5.
- The number of cold temperature days – i.e., days with minimum temperature ≤ - 30°C is expected to decline from 0.1 days per year (1981-2010) to rare events by 2050s under RCP 8.5.
- Total annual precipitation is projected to increase by 7.4% in 2050s under RCP 8.5, with the largest percentage change (+15.3%) occurring during the winter months.
- Precipitation events are projected to become 0.4% to 35.9% more intense by the 2050s under RCP 8.5, for design storms ranging from 5 minute to 24-hour duration, and f the return frequency of 2 to 100-year. This could translate to an increased risk of over land flooding due to the overwhelming of storm water management systems. Flooding is also likely to occur due to more rapid snow melt periods, and an increase in the number and intensity of rainfall events.
- The number of frost days is expected to decrease by 25.6% by the 2050s under RCP 8.5. With warmer temperatures projected for the coming decades, the number of freeze-thaw events for the City of Vaughan area is projected to decrease by 17.2% by the 2050s.
- The effects of climate change with respect to wind are not as well understood as variables such as temperature. The percentage increases in future daily wind gust events of ≥90 km/h from the current condition could be 20%–30% in future climate for the City of Vaughan area (Cheng et al., 2014).
- Historical data on tornado occurrences in Canada are insufficient to develop any conclusions regarding potential trends in tornado activity in the City of Vaughan region.

2.0 CLIMATE RISK AND RESILIENCE APPROACH

Stantec's CCRA methodology uses similar risk assessment approaches as those of Institute for Catastrophic Loss Reduction (ICLR) and the Climate Risk Institute (CRI) (formerly Engineers Canada's) PIEVC Protocol, the Climate Lens General Guidance v.1.2. (Infrastructure Canada 2019) and other risk assessment methodologies that conform to the ISO 31000:2018 Risk Management Standard. Stantec's CRRA also aligns with the following international standards.

ISO 31000:2019 - Risk Management - Principles and Guidelines
ISO 14090:2019 - Adaptation to climate change — Principles, requirements and guidelines
ISO 14091:2021 - Adaptation to climate change — Guidelines on vulnerability, impacts and risk assessment.
ISO 14092:2020 - Adaptation to climate change – Requirements and guidance on adaptation planning for local governments and communities

The focus of this assessment is on the physical assets proposed for the Project and the natural environment of the project site including meadows, marshes, and the Black Creek tributary. The Third-Party Services such as Power Transmission, Telecom, etc. have also been considered in this assessment. Other third-party goods or services, suppliers, administration, etc. are not considered in this assessment. A review of this assessment will inform the Project team of potential risks that should be considered during subsequent design and operational phases of the Project.

2.1 RISK ASSESSMENT PROCESS

This climate resilience assessment evaluates the future climate impacts on the Project's proposed components and associated infrastructure and identifies the potential risks associated with future changes in climate and extreme weather events. It is a high-level assessment of risks to the infrastructure due to extreme weather and climate uncertainty based on current climate and future climate projections for the Project. Extreme weather events may include, but are not limited to, extreme temperatures, freeze-thaw cycles, short duration high intensity rainfall events, large freezing rain events, heavy snowfall events, high wind events, and occurrences of tornadoes.

The climate resilience assessment identifies infrastructure components and their response to selected climate parameters, under current and future climate conditions. These interactions are used to assign risk ratings to each infrastructure / climate interaction. This assessment will inform the Project team of potential risks that should be considered during subsequent design and operational phases of the Project. Figure 4 below shows the general process used for the risk assessment.

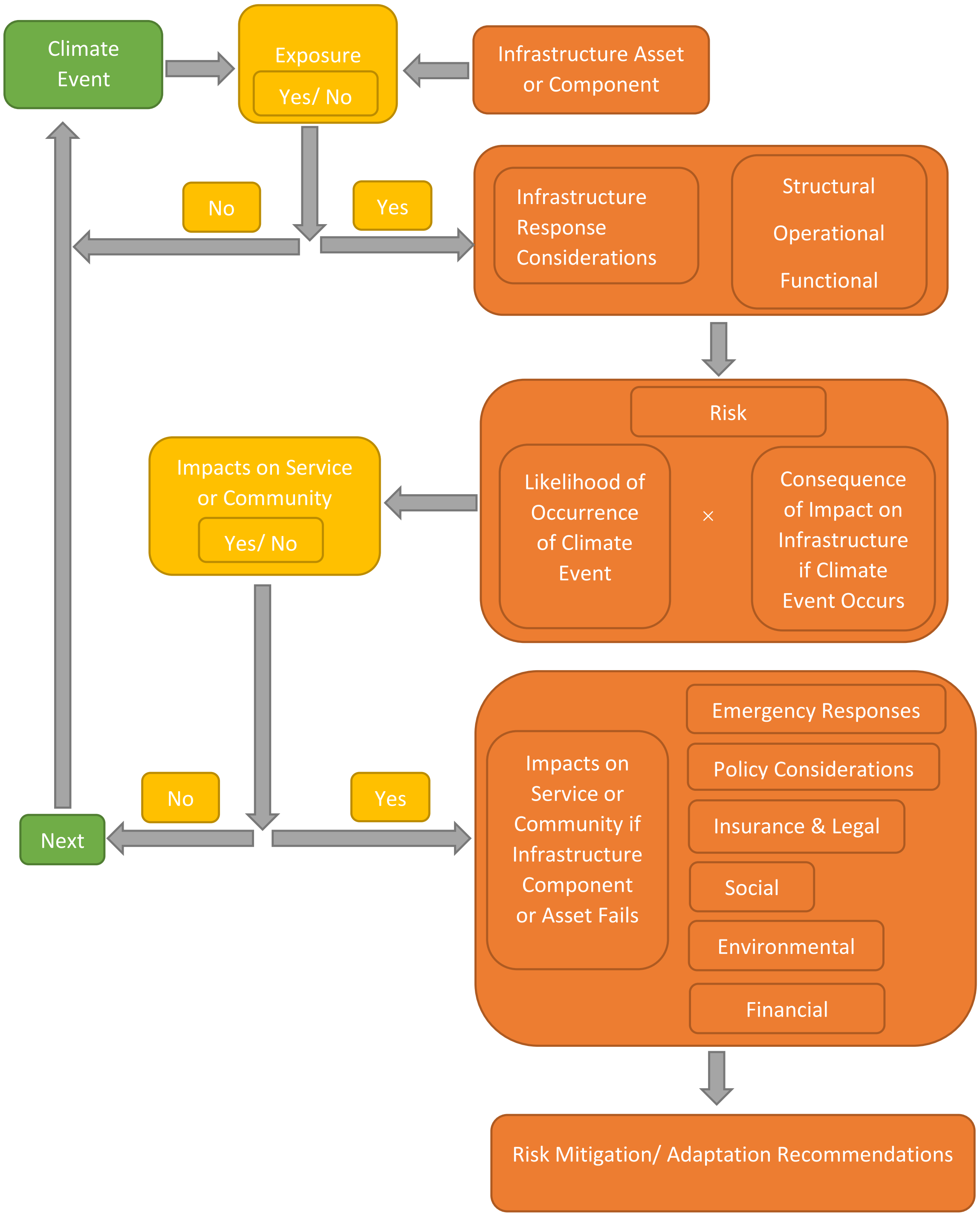

Figure 4 Illustration of the Risk Assessment Process

2.2 TIMESCALE OF ASSESSMENT

As the Project is expected to be in service for at least 32 years, climate projections are aligned with the Project's operational lifespan or the period 2041 to 2070 (2050s). The time period of 1981-2010 has been selected for current climate conditions establishing the climate baseline for the project area.

2.3 LIMITATIONS OF CCRA

This climate change resilience assessment was completed using the best information available to the assessment team at the time of the study. The assessment represents the risks associated with the current climate and future climate projections for the planned assets and infrastructure components selected by the project team.

The climate data and trends (current and future projections) used in this study were obtained through various sources. Cross-verification between climate information sources was conducted where possible to identify potential discrepancies between the data sources used.

The availability of weather data to define the intensity thresholds of the selected climate hazards, as well as their occurrence in current climate are based on data from the Environment and Climate Change Canada (ECCC) weather stations. It is recognized that extreme weather events are often very localized, so it is possible that some climate events are not recorded by the weather stations. This uncertainty is considered by the climate resilience assessment methodology during the analysis, including the knowledge of the team members in the analysis of asset vulnerabilities or infrastructure elements.

2.4 PLAUSIBLE CLIMATE SCENARIOS

Climate modeling uses various greenhouse gas (GHG) emissions scenarios, known as Representative Concentration Pathways (RCPs), to project future climate variables under different concentrations and rates of release of GHGs to the atmosphere, as well as different global energy balances. Various future trajectories of GHG emissions are possible depending on the global mitigation efforts.

RCPs are established by the Intergovernmental Panel on Climate Change (IPCC), the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (IPCC, 2014)

The IPCC has set four GHG emissions scenarios through RCPs as shown in Figure 5. RCP 8.5 is the internationally recognized the most pessimistic - "business as usual" GHG emissions scenario. Other GHG emissions scenarios represent more substantial and sustained reductions in GHG emissions. For example, the RCP 2.6 emissions scenario may be achievable with extensive adoption of biofuels/renewable energy and large-scale changes in global consumption habits, along with carbon capture and storage. RCP 2.6 is representative of a scenario that aims to keep global warming below 2°C above pre-industrial temperatures. RCP 4.5 is considered the 'medium stabilization' scenario where global mitigation efforts result in intermediate levels of GHG emissions (IPCC, 2014).

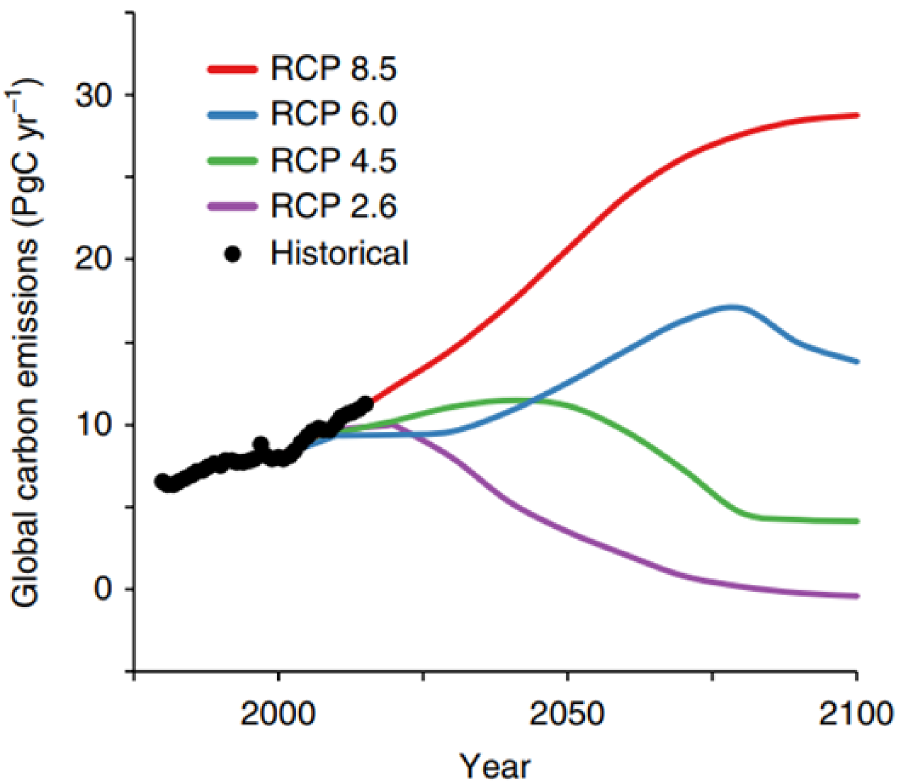

Figure 5 Historical CO_2 emissions for 1980-2017 and projected emissions trajectories to 2100 for the four Representative Concentration Pathway (RCP) scenarios. (Source: Smith and Myers, 2018)

Although some progress has been made, current estimates of GHG emissions are still close to following the RCP 8.5 path, therefore this assessment is based on climate parameters estimated under the RCP 8.5 scenario. The IPCC Special Report on Global Warming of 1.5ºC (October 8, 2018) supports the selection of the RCP 8.5 for this assessment.

2.5 IDENTIFICATION AND ASSESSMENT OF CLIMATE HAZARDS

Climate hazards used for this resilience assessment were chosen based on experience with previous climate resilience studies for similar types of infrastructure and on the climate information retrieved from the City's Climate Change website (https://www.vaughan.ca/cityhall/environmental_sustainability/Pages/Climate-Change.aspx). The climate hazards leading to damage to the similar types of infrastructure include:

- Temperature extremes, which can lead to structural damages of the proposed roadway (e.g., asphalt surfaces), and increased discomfort for the users.
- Freeze-thaw cycles, which can increase maintenance requirements for the roadway (e.g., asphalt, shoulders, road base, curbs, etc.).
- Short duration high intensity rainfall, which can cause local flooding, can lead to structural damage of the infrastructure components (erosion), and can increase maintenance requirements for the roadway.
- Heavy snowfall, which may impact the pavement conditions of the roadways, shoulders and sidewalks and can increase maintenance requirements for the roadway.
- Freezing rain may impact the pavement conditions of the roadways, shoulders and sidewalks resulting in increased maintenance requirements, and may reduce the functionality of traffic light, road signage during the events.
- Extreme winds, tornadoes, which can lead to the structural damages to the traffic light, road signage, street lights/ poles and landscaping (i.e. trees) resulting in increase maintenance/replacement requirements for the infrastructure elements.

The climate variables selected for this resilience assessment are shown in Table 1. The impacts of tornadoes are associated with high wind speeds, and therefore, tornadoes are not considered separately as a climate variable in this resilience assessment.

Once the climate parameters are determined, a threshold value is chosen for each climate parameter. The threshold value is normally associated with a consequence or effect on an infrastructure asset and helps establish the likelihood that a particular climate event will occur. The likelihood that a climate event will occur is based on the historical climate data and climate projections. The historical climate for the project site was characterized by the observations from Environment and Climate Change Canada (ECCC) weather stations. Future climate for the region were retrieved from climate projections produced by Global Climate Models (GCMs).

Table 1 also presents the confidence level associated with the projections for each climate parameter. For example, projections based on Global Climate Models (GCMs) and downscaling of such models are considered:

- adequate (higher confidence) for general temperature and precipitation projections
- less adequate (lower confidence) for extreme parameters
- less adequate (lower confidence) for high wind events
- inadequate for combined events (low confidence) such as snow storms, freezing rain, tornadoes, etc.

Combined events are inferred based on other parameters, resulting in lower confidence for projections of combined event parameters. For example, freezing rain is a complex process and the projected prevalence of freezing rain events under future climate conditions is not as well understood as other parameters. Confidence may also refer to whether other studies have been done for the climate events projections in the geographical area.

Table 1 Climate Parameters Selected for Resilience Assessment (2050s-Time Horizon)

Climate Parameter	Threshold	Trend	Confidence Level
Temperature			
High temperature extremes	Days (per year) with maximum temperature ≥ 35°C	Increasing	High
Extreme cold	Days (per year) with minimum temperature ≤ -30°C	Decreasing	Moderate to High
Freeze-Thaw Cycles	Occurrence of 30 freeze-thaw cycles per year	Slightly Decreasing	High
Precipitation			
Short duration - high intensity rain	50 mm of rainfall in 1 hr	Increasing	Moderate
Long duration rain	130 mm or more rainfall in 24 hrs	Increasing	Moderate
Heavy snowfall	25 cm or more in 24 hrs or less	Decreasing	Moderate
Freezing rain	10-15 mm of freezing rain in 24 hrs	Slightly Increasing	Low
Wind			
Wind gusts	Wind gusts greater than or equal to 90 km/hr	Slightly Increasing	Low

2.6 ASSETS UNDER ASSESSMENT

The Project infrastructure assets and systems were grouped into the categories presented in Table 2. It should be noted that only assets that are associated with the proposed project were considered. Other infrastructure that may be developed along with the project components was not considered.

Table 2 List of Project Components Being Assessed

Asset	Infrastructure Category	Infrastructure Element
Roadway	Roadway	Asphalt
		Road base
		Road marking
		Subdrains
	Surface infrastructure	Curbs, Planter walls
		Cycling lanes
		Sidewalks
		Protection works (e.g., riprap)
		Guardrails
		Road signage
		Street luminaires/poles
		Traffic lights
		Landscaping (Trees/flower beds)
	Stormwater drainage system	Drainage outlet to retention swale
		Culverts
		Stormwater management pond
	Natural Environment	Meadow/ Marsh
		Black Creek Tributary
	Other	Personnel (O&M staff)
		Third party utilities (above ground)
		Third party utilities (below ground)

2.6.1 Consequence of Impact

Table 3 shows the three consequence of impacts that were considered as part of this assessment. This list provides a framework for considering the potential impacts of climate on the Project's infrastructure components.

Table 3 Consequence of Impact

Consequence of Impact
Structural Integrity *For example, climate change may lead to premature failure of structure from increased stresses.*
• Component Failure • Component Deterioration due to wear, age, etc. • Increased Loading / Stress • Change in Materials Performance

Table 3 Consequence of Impact

Consequence of Impact
Operations & Maintenance (O&M) *For example, climate change may impact the ability to access worksite for maintenance or require updates to occupational health & safety procedures in maintaining access to worksites or lead to accelerated deterioration of material performance.*
• Occupational Safety, Health & Safety • Increased Maintenance / Replacement Cycles and Frequencies • Increased Operation and Maintenance Cost • Change in Operational Performance
Functionality *For example, climate change may impact the ability of the infrastructure component to deliver at normal levels of service.*
• Component operates below original design standard • Reduced Serviceability • Loss of Capacity (Temporary/ Permanent)

2.6.2 Impact on Project Assets

The potential impacts from both extreme events and incremental or slow onset climate parameters on Project assets are presented in Table 4.

Table 4 Climate Impacts on The Project Assets

Climate Parameter	Infrastructure Component Impacted	Description of Impact
Temperature		
High temperature extremes	Roadway- Asphalt	• High temperature extremes can reduce the durability of asphalt layer of the pavement resulting in more maintenance requirements. • High temperature extremes deteriorate the asphalt material properties (cracking, fissuring, etc.) and decrease the service life of the components.
	Surface infrastructure – Cycling lane, Landscaping (Trees/flower beds)	• High temperature extremes deteriorate the asphalt material properties (cracking, fissuring, etc.) and decrease the service life of the components. • High temperature extremes may affect landscaped vegetation.
	Stormwater drainage system - Stormwater management pond	• High temperatures may result in increased algae bloom and more maintenance requirements of the storm water retention ponds.
	Natural environment- Meadow/ Marsh, Black Creek Tributary	• High temperature extremes may cause more evaporation losses and increase stresses to the vegetations and ecosystems of meadows, marshes, and the creek. This may threaten the survival of the sensitive species.
	Other- Personnel (O&M staff)	• High temperature extremes may cause discomfort to the O&M staffs and users.

Table 4 Climate Impacts on The Project Assets

Climate Parameter	Infrastructure Component Impacted	Description of Impact
Extreme Cold	Roadway- Asphalt, Road base, Subdrains	• Extreme cold temperature causes contraction and cracking of asphalt resulting in increased maintenance requirements. • Extreme cold temperature may cause contraction of road base and reduce the structural integrity of the pavement. • Extreme cold temperature may cause freezing of the subdrains. • Extreme cold may increase the usage of salts for de-icing, resulting in a decrease in the service life of the roadway components.
	Surface infrastructure- Cycling lane, Sidewalk, curbs, planter walls, Landscaping (Trees/flower beds)	• Extreme cold temperature causes contraction and cracking of asphalt resulting in increased maintenance requirements. • Extreme cold may increase the usage of salts for de-icing, resulting in a decrease in the service life of the surface infrastructure components. • Extreme cold temperature may affect landscaped vegetation.
	Stormwater drainage system – Drainage outlet to retention swale	• Extreme cold temperature may cause freezing, reduce the functionality of the drainage outlet.
	Natural environment- Meadow/ Marsh, Black Creek Tributary	• Extreme cold temperature may affect the vegetations and habitats of meadows, marshes, and the creek.
	Other- Personnel (O&M staff), Third party utilities (above ground)	• Extreme cold temperature may cause discomfort to the O&M staffs and users. • Extreme cold temperature may cause power supply issues.
Freeze-thaw cycles	Roadway- Asphalt, Road base, Subdrains	• Freeze thaw cycles may cause contraction/expansion of soils and thus may cause extra pressure on pavement structure resulting in crack, instability, pothole formation, etc. • Freeze thaw cycles may cause extra pressure on subdrains due to contraction/expansion of soils and may result in structural damage to the subdrain. • Freeze thaw cycles may reduce the durability of asphalt/ concrete layer resulting in increased maintenance requirements.
	Surface infrastructure- Curbs, Cycling lane, Sidewalk, curbs, planter walls, Protection works (e.g., riprap), Landscaping (Trees/flower beds)	• Freeze thaw cycles may cause structural damage to the curbs, planter walls, cycling lane, sidewalk, and slope protection works. • Freeze thaw cycles may affect landscaped vegetation.
	Stormwater drainage system- Drainage outlet to retention swale, Culverts	• Freeze thaw may cause ice formation on culverts, pipes and drains reducing the functionality of the system.
Precipitation		

Table 4 Climate Impacts on The Project Assets

Climate Parameter	Infrastructure Component Impacted	Description of Impact
Short duration high intensity rain	Roadway- Asphalt, Road base, Road marking,	• High intensity rain may deteriorate the material properties of asphalt resulting in increased maintenance requirements. • High intensity rain may cause erosion of road base. • High intense rains may cause ponding and local flooding of the roadways.
	Surface infrastructure- Curbs, Cycling lane, Sidewalk, Landscaping (Trees/flower beds)	• High intensity rain may cause building up of water/pooling along curbs resulting in localized flooding. • High intense rains may cause ponding and local flooding of the cycling lane and sidewalk. • High intensity rain may impact landscaped vegetation.
	Stormwater drainage system- Drainage outlet to retention swale, Culverts, Stormwater management pond	• High intensity rain may increase runoff and overwhelm the stormwater drainage system resulting in local flooding. • High intensity rain may cause extra strain on the sites stormwater system and reduce the functionality of drainage outlet, culverts, etc.
	Natural environment- Meadow/ Marsh, Black Creek Tributary	• High intensity rain may result in increased runoff to the tributary, meadows and marshes, and increased delivery of nutrients and sediments. This may affect the vegetations and habitats of meadows, marshes, and the creek.
	Other- Personnel (O&M staff)	High intensity rain may cause flooding and safety issues for the O&M staffs and users.
Long duration rain	Roadway- Asphalt, Road base, Road marking, Subdrains	• Long duration rain may increase infiltration and impact the road base and subdrain system. • Long duration rain may impact the material properties of asphalt resulting in reduced service life.
	Surface infrastructure- Curbs, Cycling lane, Sidewalk, Protection works (e.g., riprap), Landscaping (Trees/flower beds)	• Long duration rain may cause flooding and impact cycling lane and sidewalk. • Long duration rain may cause erosion of the slope protection works. • Long duration rain may result in soil saturation and ponding that may impact landscaped vegetation.
	Stormwater drainage system- Drainage outlet to retention swale, Culverts, Stormwater management pond	• Long duration rain may cause flooding and impact the functionality of drainage outlet, culverts, etc. • Saturated soils from long duration rain may increase stormwater runoff and exceed the capacity of the stormwater management pond.
	Natural environment - Meadow/ Marsh, Black Creek Tributary	• Long duration rain may result in increased runoff and increased delivery of nutrients and sediments, which may affect the vegetations and habitats of meadows, marshes, and the creek.
	Other- Personnel (O&M staff), Third party utilities (below ground)	• Long duration rain may cause flooding and safety issues for the O&M staffs and users.

Table 4 Climate Impacts on The Project Assets

Climate Parameter	Infrastructure Component Impacted	Description of Impact
		• Long duration rain may increase infiltration raising the ground water table impacting underground utilities (gas and water pipes, etc.).
Freezing rain	Roadway- Asphalt, Road marking	• Freezing rain may impact the road conditions resulting in increased maintenance requirements.
	Surface infrastructure- Cycling lane, sidewalk, Road signage, Street luminaires/poles, Traffic light, Landscaping (Trees/flower beds)	• Freezing rain may impact the conditions of cycling lane and sidewalk resulting in increased maintenance requirements. • Freezing rain accumulating on signs and traffic lights may become a safety issue when the ice falls. • Freezing rain may impact the landscaped vegetation.
	Natural environment - Meadow/ Marsh, Black Creek Tributary	• Salt and de-icing materials used to remove ice accumulation during freezing rain events may affect the vegetations and habitats of meadows, marshes, and the creek.
	Other - Personnel (O&M staff), Third party utilities (above ground)	• Freezing rain may impact the pavement conditions and cause safety issues for the O&M staffs and users. • Freezing rain may result in power failure.
Heavy snowfall	Roadway- Asphalt, Road marking	• Heavy snowfall will result in increased maintenance requirements.
	Surface infrastructure – Cycling lane, Sidewalk, Landscaping (Trees/flower beds)	• Heavy snowfall will result in increased maintenance requirements. • Heavy snowfall may impact the landscaped vegetation.
	Stormwater drainage system- Culverts	• Heavy snowfall may reduce the functionality of culverts and result in increased maintenance requirements.
	Natural environment - Meadow/ Marsh, Black Creek Tributary	• Usage of salts for clearing snow may affect the vegetations and habitats of meadows, marshes, and the creek.
	Other- Personnel (O&M staff)	• Heavy snowfall may impact the pavement conditions and cause safety issues for the O&M staffs and users.
Wind		
Wind gusts (≥ 90 km/h)	Surface infrastructure - Road signage, Street luminaires/poles, Traffic light, Landscaping (Trees/flower beds)	• High wind speeds may cause damages to the lighting systems and signage resulting in increased maintenance requirements. • High wind speeds may cause damage to landscaped vegetation and trees.
	Other- Personnel (O&M staff), Third party utilities (above ground)	• High wind speeds may cause the safety issues to the O&M staffs and users. • High wind speeds may cause trees to fall onto power lines resulting in power failure.

2.7 RISK ANALYSIS AND EVALUATION

Risk rating is defined as the product of two ratings.

Risk Rating = Likelihood Rating x Consequence Rating

- **Likelihood Rating** represents the probability (likelihood) of occurrence of a climate event above a selected threshold, ranging from 1 (very low) to 5 (very high)
- **Consequence Rating** is a measure of the impacts on the infrastructure asset or component should the climate event occur, ranging from 1 (very low) to 5 (very high)

Risks are evaluated under current climate conditions to establish a baseline. Future risks are assessed considering future (projected) climate changes. The condition of the infrastructure in the future climate is assumed to be well maintained and thus will maintain a similar level of resilience to climate events. Deterioration of the Project components is not considered as part of this assessment.

The trends indicated for each climate parameter are based on the change in probability from the current climate to the future climate. For this assessment, a rating scale of 1 to 5 for the likelihood of a climate event occurring was adopted (Table 5). The likelihood score is assigned based on the evaluation of historical occurrences and future climate projections for each climate variable.

Table 5 Likelihood Ratings Based on Climate Event Occurrence (Adapted from Climate Lens General Guidance, Infrastructure Canada, 2019)

Occurrence	Qualitative Descriptor	Descriptor	Rating
>1:50 year	Very Low	Not likely to occur in assessment period; or Not likely to become critical/beneficial in period	1
1:30-50 year	Low	Likely to occur once between 30-50 years; or Likely to become critical/beneficial in 30 to 50-years	2
1:10-30 year	Moderate	Likely to occur once every 10 to 30 years; or Likely to become critical/beneficial in 10-30 years	3
1: 1-10 year	High	Likely to occur at least once per decade; or Likely to become critical/beneficial in a decade	4
>1/year	Very High	Likely to occur once or more annually; or will become critical/beneficial within several years	5

Using Table 5, the likelihood ratings for the selected climate parameters are presented in Table 6. The current likelihood ratings are based on historic observations (1981-2010) from the ECCC weather stations.

Table 6 Current and Future Likelihood Rating for Selected Climate Parameters

Climate Parameter	Threshold	Likelihood Rating	
		Current	Future (2050s)
High temperature extreme	Days (per year) with maximum temperature ≥35°C	4	5↑
Extreme cold	Days (per year) with min temps less than or equal to -30°C	3	2↓
Freeze-Thaw Cycles	Occurrence of 30 freeze-thaw cycles per year	5	5
Short duration - high Intensity rain	50 mm of rainfall in 1 hr	4	4
Long duration rain	130 mm or more rainfall in 24 hrs	1	2↑
Freezing rain	10-15mm of freezing rain in 24 hrs.	4	4
Heavy snowfall	25 cm or more in 24 hrs or less	4	4
Wind gusts	Wind gusts greater than or equal to 90 km/hr	4	5↑

The consequence scores are presented in Table 7. The ratings are based on the degree to which a climate event causes damage to the infrastructure or an associated loss or disruption of service. For example, taking a component such as road base - a minor rating from high intensity rainfall might mean temporary local flooding while high rating may result in signific flooding resulting in the road being closed for a period of time. Service in the context of the Project is defined as the various offerings and services provided to the local community by the project components.

Table 7 Consequence Ratings

Consequence Score	Criteria / Comments
1	**Very Low -** No serious impact from a weather event, routine maintenance will repair any damage.
2	**Low -** Some extra cost repairs and maintenance require but can be handled by operations staff. No loss of service.
3	**Moderate -** Some damage to infrastructure. Extra costs and labour required to complete repairs. Some specialized labour or equipment required to complete repairs. Some loss of service.
4	**High -** Significant damage to infrastructure. Significant extra costs and labour required to complete repairs. Specialized labour or equipment is required to complete repairs. Significant loss of service.
5	**Very High -** Complete loss of the asset after a weather event. Repair not possible. Replacement of component required. Extended period of loss of service.

Using the equation “Risk Rating = Likelihood Rating x Consequence Rating” provides numerical risk ratings from 1-25 as shown in Figure 6. In Table 8, risk ratings are explained with suggested risk treatments.

Consequence							
	Very High	5	5	10	15	20	25
	High	4	4	8	12	16	20
	Moderate	3	3	6	9	12	15
	Low	2	2	4	6	8	10
	Very Low	1	1	2	3	4	5
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
			Likelihood				

Figure 6 Risk Ratings - Evaluation Matrix (Adapted from Climate Lens General Guidance, Infrastructure Canada, 2019)

Table 8 Risk Classification and Recommended Actions (Adapted from Climate Lens General Guidance, Infrastructure Canada, 2019)

Risk Classification	Risk Rating	Description of Risk	Risk Treatment
Negligible	1,2	• No permanent damage. • No service disruption occurs.	Risks do not require further consideration
Low	3,4,6	• Minor asset/infrastructure damage. • Minor service disruption may be possible. • No permanent damage. • Minor repairs or restoration expected.	Controls likely, but not required.
Moderate	5,8,9	• Expected limited damage to asset or to equipment components. • Minor repairs and some equipment replacement may be required. • Brief service disruption may occur.	Some controls required to reduce risks to lower levels. Risk to be monitored for changes over time.
High	10,12, 15,16	• May result in significant permanent damage; or loss of asset or component that may require complete or partial replacement. • Extended period of service disruption is likely.	High priority control measures required.
Extreme	20,25	• May result in permanent damage; or loss of asset or component that will require complete replacement. • Significant service disruptions will occur.	Immediate controls required.

3.0 RISK EVALUATION RESULTS

3.1 RISK PROFILE

The purpose of this assessment is to identify the climate risks to the Project at a broad systems-level for a current and future climate scenario. A risk profile for project assets and components under future climate conditions was prepared and the risk ratings of the infrastructure elements for each climate hazards. The confidence in future climate projections was considered in assessing the risks shown in the risk profile. The distribution of the risks under current and future climate conditions are presented in Table 9.

A total of 207 risks were identified. The number of high risks increase from 20.3% under current climate to 28.3% under future climate. Approximately 35.4 % of total risks identified were classified as "moderate" risks in current climate, which decreases to 24.5% under future climate conditions. The decrease in "moderate" risks and corresponding increase in high risks under future climate is directly related to climate change.

Table 9 Project Risk by Category Under Current and Projected Future Climate

	Baseline (1981-2010)		2050s (2041-2070)	
Risk Category	Risk Count	Percentage of Total Risk	Risk Count	Percentage of Total Risk
Extreme	0	0.0%	0	0.0%
High	43	20.3%	60	28.3%
Moderate	75	35.4%	52	24.5%
Low	52	24.5%	85	40.1%
Very Low	42	19.8%	15	7.1%

3.2 ADAPTATION AND RESILIENCE MEASURES

Risk control measures are required for the "extreme", "high" and "moderate" risks for the project and are presented in Table 10.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
High temperature extreme [Days (per year) with max temps greater than or equal to 35°C]	Roadway - Asphalt	• High temperature extremes can reduce the durability of asphalt pavement resulting in more maintenance requirements.	12	15↑	• Consider the effects of extreme temperature on the durability of asphalt in design stage and consider using higher-performance asphalt mixes for improved performance/reduced maintenance.
	Surface infrastructure – Cycling lane, Landscaping (Trees/flower beds)	• High temperature extremes deteriorate the material properties (cracking, fissuring, etc.) and decrease the service life of the components. • High temperature extremes may affect landscaped vegetation.	8	10↑	• Consider the effects of extreme temperature on the durability of asphalt in design stage and consider using higher-performance asphalt mixes for improved performance/reduced maintenance. • Consider green infrastructure practices (i.e., tree planting) to provide shade along cycling lanes and pedestrians pathways. • Choose vegetation types suited to an increasing frequency of high temperature events.
	Stormwater drainage system - Stormwater management pond	• High temperature extremes result in increased occurrence of algae blooms and more maintenance requirements of stormwater ponds.	8	10↑	• Consider the development of forest canopies and protection and rehabilitation of riparian vegetation to maintain cool water temperature. • Develop O&M policies around regular maintenance that includes risks associated with high temperature extremes.
	Natural environment - Meadow/ Marsh, Black Creek Tributary	• High temperature extremes may cause more evaporation losses and more stresses to the vegetations and habitats of meadows, marshes, and the creek. This may threaten the survival of the sensitive species.	12	15↑	• Consider the protection and rehabilitation of riparian vegetation to maintain lower water temperatures.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
	Other- Personnel (O&M staff)	• High temperature extremes may cause discomfort to O&M staffs and users.	12	15↑	• Consider the development of a health and safety training that includes risks associated with working during high temperatures. • Consider public outreach for the health and safety of the users through the providing a public service health and safety training.
Freeze- thaw cycle [Occurrence of 30 freeze-thaw cycles per year]	Roadway- Asphalt, Road base, Subdrains	• Freeze thaw cycles may cause contraction/expansion of soils and thus may cause extra pressure on pavement structure resulting in cracks, instability, etc. • Freeze thaw cycles may cause extra pressure on subdrain due to contraction/expansion of soils and may result in structural damage to the subdrain.	10	10	• Consider impact of freeze-thaw cycles on the asphalt/ concrete layer to ensure durability. • Design/compact soils to minimize impacts of freeze-thaw cycles on asphalt base and subdrain.
	Surface infrastructure - Curbs, Cycling lane, Protection works (e.g., riprap), Landscaping (Trees/flower beds)	• Freeze thaw cycles may cause contraction/expansion of soils and cause structural damage to the curbs, planter walls, cycling lane, sidewalk, and slope protection works. • Freeze thaw cycles may affect landscaped vegetation.	10	10	• Consider the impact of freeze thaw cycles during the design of infrastructure components. • Develop O&M policies around regular maintenance inspections of concrete structures to minimize damage by freeze-thaw cycles. • Plant landscape vegetation resistant to the effects of freeze-thaw cycles.
	Stormwater drainage system – Drainage outlet to retention swale, Culverts	• Freeze thaw may cause ice formation on culverts, pipes and drains reducing the functionality of the system.	10	10	• Develop O&M policies around regular maintenance that includes risks associated with freeze thaw cycles.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
Short duration - High Intensity Rain [50 mm or more rain in 1 hr]	Roadway- Asphalt, Road base, Road marking, Subdrains	• High intensity rain may deteriorate the material properties of asphalt resulting in increased maintenance requirements. • High intensity rain may cause erosion of road base. • High intense rains may cause ponding and local flooding of the roadways. • High intensity rain may increase runoff and overwhelm the subdrain system resulting in local flooding.	8	8	• Consider designing the site grading and subdrain system based on future climate IDF curves. • Create adequate catchment areas for runoff to reduce possible ponding/flooding. • Impacted infrastructure should be inspected after each severe climate event. • Develop O&M policies around regular maintenance including monitoring and clearing of ponding water.
	Surface infrastructure - Curbs, Landscaping (Trees/flower beds)	• High intensity rain may cause building up of water/pooling along curbs resulting in localized flooding. • High intensity rain may impact landscaped vegetation.	8	8	• Consider the changes in intensity-duration-frequency (IDF) data under future climate conditions during the design stage. • Install sufficient catchment basins/grates along curbs to minimize water pooling/local flooding during high intensity rainfall events. • Consider green infrastructure practices, such as, tree planting and bioswales to increase absorption runoff in soils and storage capacity to reduce peak stormwater flows. • Develop O&M policies that includes regular maintenance and inspections of catch basins/grates for blockages after severe weather events.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
	Stormwater drainage system – Drainage outlet to retention swale, Culverts, Stormwater management pond	• High intensity rain may increase runoff and overwhelm the stormwater drainage system resulting in local flooding. • High intensity rain may cause extra strain on the sites stormwater system and reduce the functionality of drainage outlet, culverts, etc. • High intensity rains may require additional maintenance to clean grates and catch basins to prevent localized flooding.	12	12	• Consider designing the stormwater drainage systems based on future climate IDF curves. • Create adequate catchment areas for runoff to reduce possible ponding/flooding. • Consider the use of on-site storage/ surge ponds to reduce the load on the drainage systems. • Consider green infrastructure practices, such as bio-retention swales to slow down runoff and to increase the stormwater infiltration resulting in reduced stormwater flows. • Consider the route design to limit the changes in land uses of the catchment areas.
	Natural environment - Meadow/ Marsh, Black Creek Tributary	• High intensity rain may result in increased runoff to the tributary, meadows and marshes, and increased delivery of nutrients and sediments. This may affect the vegetations and habitats of meadows, marshes, and the creek.	8	8	• Consider the use of on-site storage/ponds to manage the stormwater runoff and the route design to limit the stress on the habitats of meadows, marshes, and the creek. • Incorporate measures to reduce habitat fragmentation and increase habitat connectivity by creating corridors for species movement.
	Other- Personnel (O&M staff)	• High intensity rain may cause flooding and safety issues for the O&M staffs and users.	8	8	• Consider health and safety of the staff through the development of a health and safety plan that includes risks associated with working in flooded areas. • Establish clear communications with staff who are required to work during high intensity rainfall events.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
Freezing rain [10-15 mm freezing rain in 24 hrs]	Roadway - Asphalt	• Freezing rain may impact the road conditions resulting in increased maintenance requirements.	12	12	• Consider developing O&M policies around monitoring and clearing (sanding/salting) of surfaces exposed to freezing rain.
	Surface infrastructure – Cycling lane, sidewalk	• Freezing rain may impact the conditions of cycling lane and sidewalk resulting in increased maintenance requirements.	12	12	• Consider developing O&M policies around monitoring and clearing (sanding/salting) of surfaces exposed to freezing rain.
	Natural environment- Meadow/ Marsh, Black Creek Tributary	• Salt and de-icing materials used to remove ice accumulation during freezing rain events may affect the vegetations and habitats of meadows, marshes, and the creek.	8	8	• Consider environmental focused strategies for applying salt and de-icing materials on roadway to limit the stress on the habitats of meadows, marshes, and the creek.
	Other- Personnel (O&M staff), Third party utilities (above ground)	• Freezing rain may impact the pavement conditions and cause safety issues for the O&M staffs and users. • Freezing rain may result in power failure.	16	16	• Consider developing O&M policies around sanding/salting paved/concrete surfaces exposed to freezing rain. • Consider health and safety of the staff through the development of a health and safety training that includes risks associated with working during freezing rain. • Develop emergency operations plan should a power outage occur.
Heavy snowfall [25 cm or more in 24 hrs or less]	Roadway - Asphalt, Road marking	• Heavy snowfall will result in increased maintenance requirements.	12	12	• Develop O&M policies around regular maintenance including sanding/salting for clearing the snow.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
	Surface infrastructure – Cycling lane, sidewalk, Landscaping (Trees/flower beds)	• Heavy snowfall will result in increased maintenance requirements. • Heavy snowfall may impact the landscaped vegetation.	8	8	• Develop O&M policies around regular maintenance including sanding/salting and clearing the snow. • Choose vegetation types less susceptible to the exposure to heavy snow. • Impacted infrastructure should be inspected after each severe climate event.
	Stormwater drainage system - Culverts	• Heavy snowfall may impact the site drainage system by potentially blocking the system. • Heavy snowfall may reduce the functionality of culverts and result in increased maintenance requirements.	12	12	• Impacted infrastructure should be inspected after each severe climate event.
	Natural environment- Meadow/ Marsh, Black Creek Tributary	• Salt and de-icing materials used for snow removal may affect the vegetations and habitats of meadows, marshes, and the creek.	8	8	• Consider environmental focused strategies for applying salt and de-icing materials on roadway to limit the stress on the habitats of meadows, marshes, and the creek.
	Other- Personnel (O&M staff)	• Heavy snowfall may impact the pavement conditions and cause safety issues for the O&M staffs and users.	12	12	• Consider health and safety of the staff/users through the development of a health and safety training that includes risks associated with working during snow storms.

Table 10 Project Risk Profile Under Projected Future Climate

Climate Hazards	Infrastructure Element	Description of Climate Interaction	Current Risk Rating	Future Risk Rating	Adaptation Considerations
Wind gusts [Wind gusts greater than or equal to 90 km/hr]	Surface infrastructure - Road signage, Street luminaires/poles, Traffic light, Landscaping (Trees/flower beds)	• High wind speeds may cause damages to the lighting systems and signage resulting in increased maintenance requirements. • High wind speeds may cause damage to landscaped vegetation and trees.	12	15↑	• Select appropriate materials and installation methods for lighting/signage to account for the impact of high winds. • Consider deeply rooted tree species for landscaping. • Selective trimming and pruning of trees, plants/shrubs can limit impact from high winds. • Develop O&M policies around regular maintenance including inspection and clearing the debris, fallen trees, etc. after each severe climate event.
	Other- Personnel (O&M staff), Third party utilities (above ground)	• High wind speeds may cause the safety issues to the O&M staffs and users. • High wind speeds may cause trees to fall onto power lines resulting in power failure	12	15↑	• Consider health and safety of the staff through the development of a health and safety training that includes risks associated with the working during high wind events. • Develop emergency operations plan should a power outage occur.

3.3 HIGHEST RISKS

A summary of the highest climate risks identified for the project is presented below:

- High temperature extremes resulted in “high” risks to the roadway surfaces, O&M staffs and natural environment. The risk scores increased from the baseline climate to future climate conditions. High temperature extremes could result in more maintenance requirements and decrease the service life of the components of the roadway surfaces.
- “High” risks were associated with freeze-thaw cycles in both current and future climate conditions. Freeze thaw cycles might cause contraction/expansion of soils and thus might cause extra pressure on pavement structure resulting in crack, instability, pothole formation, etc. The risk scores were constant for both baseline and future climate.
- Short duration high intensity rain resulted in “moderate” risks to the roadway and “high” risks to the stormwater management system. High intensity rain could increase the runoff and overwhelm the stormwater drainage system resulting in local flooding. The risk scores were constant for both baseline and future climate.
- Freezing rain could have potential impacts on the road conditions and resulted in “high” risks for the roadway surfaces, cycling lane, and O&M staff. Freezing rain might result in power failure. The risk scores were constant for both baseline and future climate.
- “High” risks were associated with heavy snowfall in both baseline and future climate. Heavy snowfall could result in increased maintenance requirements of the roadway surfaces and could result in safety issues for the O&M staffs and users. The risk scores were constant for both baseline and future climate.
- “Moderate” risks were associated with the high intensity rain, freezing rain and heavy snowfall, while “high” risks were associated with high temperature extremes for the natural environment. High intensity rain could result in increased runoff to the tributary, meadows and marshes, and increased delivery of nutrients and sediments. High temperature extremes might cause more evaporation losses and more stresses to the vegetations and habitats of meadows, marshes, and the creek. This might threaten the survival of the sensitive species. The risk scores were constant for high intensity rain, freezing rain and heavy snowfall for both baseline and future climate, while the risk scores increased from the baseline to future climate for high temperature extremes.
- “High” risks were associated with high wind speed for the lighting/signage and landscaped vegetation in both current and future climate conditions. The risk scores increased from the baseline climate to future climate conditions. High wind speeds might cause the safety issues to the O&M staffs and users. High wind speeds might cause trees to fall onto power lines resulting in power failure.

It is important to note that the climate change impacts risk profile is a prioritization of impacts relative to each other, not against an external benchmark. Designations of “very high, high and moderate” risks should be considered in the context that many risks can be mitigated through future operations and maintenance policies and procedures.

It is outside the scope of this assessment to complete a detailed review of O&M policies for their effectiveness in reducing climate risks. However, this assessment may motivate an internal review of O&M policies with a focus to adapting to climate risks.

4.0 RESILIENCY AND ADAPTATION MEASURES

4.1 RESILIENCY AND ADAPTATION MEASURES

The following resilience measures are recommended during the detailed design stage and operational life of the project:

- Consider incorporating climate-adjusted design criteria specific into the Project's procurement process to ensure the Project constructor takes future climate parameters into account.
- Consider consultation with internal and external stakeholders (i.e., Toronto and Region Conservation Authority) during the detailed design stage to ensure the design and future construction and operation of the Project consider the identified climate risks.
- Consider reviewing climate risk assumptions and implement necessary measures at the time of retrofits or replacements – end-of-service life of components, or assets.
- Consider appropriate materials and installation methods (i.e., adequate strength of foundation during pole installation, consideration of appropriate cable support system for signal installation, etc.) for the infrastructure components (i.e., road signage, street luminaires/poles, traffic lights, etc.) to account for high winds.
- Consider developing O&M policies around monitoring for and addressing adverse weather conditions (i.e., clearing snow, clearing debris, ponded water).
- Consider establishing clear communications on facility operation during adverse weather conditions.
- Consider green infrastructure practices, such as, tree planting to provide shade along the cycling lanes and pedestrians pathways; to intercept the rainfall by leaves, branches, and trunks and to increase the runoff storage capacity through absorbing groundwater by tree roots resulting in delayed and reduced peak flow. Consider the green infrastructure practices, such as bio-retention swales to slow down the stormwater flow and to increase the stormwater infiltration resulting in reduced stormwater runoff.
- Health and Safety - Consider health and safety of the users/staff through the development of a health and safety plan that includes risks associated with climate exposure and extreme weather events. Items related to heat stress, intense rain, freezing rain, heavy snow, and high wind events including risks from flying debris and fallen tress, should be addressed through internal policies and staff and public education.
- Natural environment - Consider the protection and rehabilitation of riparian vegetation to maintain current water temperatures to minimize negative impacts on sensitive species under a warming

climate. Incorporate measures to reduce habitat fragmentation and increase habitat connectivity by creating corridors for species movement. Consider the use of on-site storage/ponds to manage the stormwater runoff and associated contaminants that could affect the habitats provided by the meadows, marshes, and the creek. Incorporate environmental focused strategies for applying salt and de-icing materials on roadway to limit soil and water contamination that could affect the natural habitats.

Many climate related risks to infrastructure that can be efficiently and effectively addressed through operations and maintenance procedures. It is recommended O&M policies and procedures be reviewed and revised as necessary to ensure they have an emphasis on improving system resilience, and health and safety requirements of users and Project staff, under a changing climate.

4.2 CONSIDERATION OF RESILIENCE PRINCIPLES IN CRRA

The analysis and recommendations in this Resilience Assessment are based on the information available to the assessment team through Technically Recommended Design, findings from Phases 2 and 3 of the MCEA process of the proposed project and on the Stantec's experience with climate risks assessments. This assessment represents a level of effort and detail consistent with the criticality of the Project's service and the level of detail of information available.

This assessment has identified that many climate risks to the Project can be addressed through adjusting design criteria to account for the impacts of r future climate conditions in the detail design stages of the project. Making design adjustments early in the design stages of the project is the most cost-effective approach, as having to make changes later in the project life cycle often results in higher costs and project schedule delays. The opportunity exists to incorporate design criteria specific to known future climate risks into the Project's procurement process to ensure the Project constructor takes future climate parameters into the final designs. Effective policies, practices and procedures that consider the impacts of climate change and extreme weather on the operations and maintenance of the Project should be developed and implemented to maximize the service life of the Project.

4.2.1 GHG Considerations

At the current stage of Project, it is too early to fully consider the “unintended consequences” of risk transference or mitigation strategies. Stantec recommends this to be considered in detail during the design-build of the Project. In general, O&M measures for climate adaptation are not GHG intensive. For potentially energy- and GHG-intensive risk mitigation strategies, Stantec recommends incorporating design targets for the reduction of operational GHGs to avoid long-term unintended environmental consequences.

4.3 RESILIENCE MEASURES SELECTION

Stantec recommends resilience measures be further developed and evaluated as the Project progress through detailed design, construction, and operation. It is outside the scope of this climate resilience assessment to complete detailed review of existing design criteria and O&M policies or to comment on potential policies for the proposed new construction and future operations. However, this climate assessment may motivate internal development of design criteria adjustments and O&M policies with a focus to adapting to climate risks for the Project as identified in this assessment.

5.0 RECOMMENDATIONS

The climate parameters that presented the highest risks to the Project are freeze-thaw cycles, high temperature extremes, high intense rainfall, freezing rain, heavy snowfall, and high wind events. Although “extreme”, “high” and “moderate” risks have been identified at this stage of the project, many risks can be monitored and/or mitigated as part of O&M policies and procedures during the life-cycle of the assets. Recommended climate risk management measures include:

- Consider incorporating design criteria specific to known future climate risks into the Project’s procurement to ensure the Project constructor takes future climate parameters into account.
- Consider consultation with internal and external stakeholders (i.e., Toronto and Region Conservation Authority) during the detailed design stage to ensure the design and future construction and operation of the Project consider the identified climate risks.
- Consider reviewing climate risk assumptions and implement necessary measures at the time of retrofits or replacements – end-of-service life of components, or assets.
- Consider developing O&M policies around monitoring for and addressing adverse weather conditions (i.e., clearing snow, clearing debris, ponded water).
- Consider green infrastructure practices, such as, tree planting to provide shade along pedestrian and cycling lanes and the use of bio-retention swales to slow down the runoff and to increase stormwater infiltration resulting in reduced stormwater flows.
- Health and Safety - Consider health and safety of the users/staff through the development of a health and safety plan that includes risks associated with climate exposure and extreme weather events. Items related to heat stress, intense rain, freezing rain, heavy snow, and high wind events including risks from flying debris and fallen tress should be addressed through internal policy and staff and public education.
- Natural environment - Consider the development of forest canopies and protection and rehabilitation of riparian vegetation to maintain cool water temperature. Incorporate measures to reduce habitat fragmentation and increase habitat connectivity by creating corridors for species movement. Consider the use of on-site storage/ponds to manage the stormwater runoff and associated contaminants that could affect the habitats provided by the meadows, marshes, and the creek. Incorporate environmental focused strategies for applying salt and de-icing materials on roadway to limit soil and water contamination that could affect the natural habitats.

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APPENDIX A:

Climate Profile Overview

Climate Profile Overview: City of Vaughan Region

Climate Parameters	Trend	Baseline Based on CANGRID Data (1981-2010)	Projections Based on IPCC-AR5 RCP 8.5 2050s (2041-2070)
Temperature			
			Average Change in Mean Temperature from 1981-2010 Baseline
Daily Mean Temperature			
Annual Daily Mean Temperature	Increasing	7.3°C	3.4°C
Winter Daily Mean Temperature	Increasing	-5.3°C	3.8°C
Spring Daily Mean Temperature	Increasing	6.0°C	3.0°C
Summer Daily Mean Temperature	Increasing	19.4°C	3.4°C
Fall Daily Mean Temperature	Increasing	9.0°C	3.2°C
Daily Maximum Temperature			
Annual Daily Maximum Temperature	Increasing	12.1°C	3.4°C
Winter Daily Maximum Temperature	Increasing	-1.3°C	3.4°C
Spring Daily Maximum Temperature	Increasing	11.2°C	3.1°C
Summer Daily Maximum Temperature	Increasing	25.0°C	3.6°C
Fall Daily Maximum Temperature	Increasing	13.6°C	3.4°C
Daily Minimum Temperature			
Annual Daily Minimum Temperature	Increasing	2.4°C	3.4°C
Winter Daily Minimum Temperature	Increasing	-9.3°C	4.3°C
Spring Daily Minimum Temperature	Increasing	0.8°C	2.9°C
Summer Daily Minimum Temperature	Increasing	13.7°C	3.2°C
Fall Daily Minimum Temperature	Increasing	4.5°C	3.1°C
			Average Annual Number of Days
Extreme Temperature			
Days with Maximum Temperature > 35°C	Increasing	0.2	8.0
Days with Minimum Temperature <-30°C	Decreasing	0.1	0.0
Frost Days/ Ice days/ Freeze-thaw Cycles			
Frost Days (Days with Minimum Temperature of < 0°C)	Decreasing	146.4	108.9
Ice days (Days with Maximum Temperatures of < 0°C)	Decreasing	61.6	35.3

Climate Parameters	Trend	Baseline Based on CANGRID Data (1981-2010)	Projections Based on IPCC-AR5 RCP 8.5
			2050s (2041-2070)
Freeze-thaw Cycles (Average Number of Days with Tmax > 0°C and Tmin < -1°C)	Decreasing	72.6	60.1
Precipitation			
			Percent Change in Total Precipitation from 1981-2010 Baseline
Total Annual Precipitation	Increasing	853.5mm	7.4%
Total Winter Precipitation	Increasing	187.0mm	15.3%
Total Spring Precipitation	Increasing	202.3mm	13.2%
Total Summer Precipitation	Increasing	228.7mm	-1.4%
Total Fall Precipitation	Increasing	235.4mm	4.3%
			Average Annual Maximum Precipitation Accumulation
Maximum 1-day Precipitation Accumulation	Increasing	39.3mm	47.0mm
Maximum 5-day Precipitation Accumulation	Increasing	61.4mm	71.0mm
			Occurrence of Rainfall Events
Frequency of 130.0mm or More Rain in 24 hours	Increasing	1 in 100 yr	1-in-43+ yr
Frequency of 50mm or More Rain in 1 hour	Increasing	1 in 8+ yr	1 in 8 yr
Snow			
25cm or More Snowfall in 24 hours	Likely to Increase	1 in 6.5 yr*	
Wind			
Days with Maximum Wind Gusts of More than 90 km/hr	Likely to Increase	1 in 1.3 yr*	

* Based on ECCC Weather Observations