Planning for Extreme Weather and Climate Change: Advancing Resiliency and Adaptation Across Metrolinx

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Abstract

In the 2015-2020 Five Year Strategy, Metrolinx stated its commitment to establish a Corporate Climate Adaptation Plan covering facilities, practices and protocols by 2018. The urgency for its development was partly driven by a record precipitation and flood event that occurred on July 8th, 2013, when an intense storm caused extensive flooding to key transportation assets and services in the Greater Toronto and Hamilton Area. This event, and other stresses caused by a changing climate, has raised questions about the vulnerability of the regional transit system, and the need for the development and implementation of a resiliency and adaptation plan. While Metrolinx currently manages about $11 Billion in assets, the need to consider vulnerability and risk to future climate is further heightened in consideration of an additional $16 Billion - $50 Billion in transit investment that is expected over the next 10-20 years through the implementation of the Regional Transportation Plan, the expansion of the Regional Express Rail, and the construction of new Rapid Transit lines for light rail and buses. Understanding and effectively planning for increased vulnerability and risk to extreme weather and climate change is thus essential in terms of Metrolinx being able to manage existing and future infrastructure assets in a manner that ensures that the regional transit system is both sustainable and resilient.

This paper outlines progress to date at Metrolinx to develop a resiliency and adaptation program that will lead to the establishment of a Corporate Climate Adaptation Plan. The key steps that were undertaken in year 1 are covered, that includes the creation of an internal resiliency working group, a benchmarking report comparing Metrolinx to best practices, and the application of the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol to a selection of key critical assets, including rail corridors, stations, and maintenance facilities. In year 2 potential lessons learned from the PIEVC study are being used to inform the pathway forward that includes identifying high risk assets and developing climate adaptation management plans, and identifying opportunities where mainstreaming resiliency to extreme weather and climate change can be effectively applied across the organization in its practices and protocols.

I. Introduction

In the 2015-2020 Five Year Strategy, Metrolinx stated its commitment to establish a Corporate Climate Adaptation Plan covering facilities, practices and protocols by 2018 (Metrolinx 2014a). The urgency for its development was partly driven by a record precipitation and flood event that occurred on July 8th, 2013, when an intense storm caused extensive flooding to homes, businesses, and critical infrastructure assets, and disrupted the provision of essential services (including regional and local transit) in parts of the Greater Toronto and Hamilton Area (GTHA). This was followed in December, 2013, with a GTHA-wide ice storm caused direct and indirect impacts (e.g. through electricity blackouts lasting multiple days) that were more extensive across the region than the earlier flood, but not as costly in terms of insured losses. These events, and weather-related stresses in other jurisdictions impacted by extreme events (e.g. Hurricane Sandy), has raised questions about the vulnerability of the regional transit system, and the need for the development and implementation of a resiliency and adaptation plan. Photos and video of a partially submerged GO Train along the Lower Don River were quickly broadcast across the country, and since then the event (and images) have been used as an iconic illustration of how Canada's infrastructure may be vulnerable to climate change.

While Metrolinx currently manages over $11 Billion in assets, the need to consider vulnerability and risk to future climate is further heightened in consideration of an additional $16 Billion - $50 Billion in transit investment that is expected over the next 10-20 years through the implementation of the Regional Transportation Plan (RTP), the expansion of the Regional Express Rail (RER) – including electrification, and the construction of new Rapid Transit (RT) lines for light rail and buses. Noting that the lifecycle of these assets are expected to extend over many decades, understanding and effectively planning for increased vulnerability and risk to extreme weather and climate change is thus essential in terms of Metrolinx being able to manage existing and future infrastructure assets in a manner that ensures that the regional transit system is both less vulnerable and more resilient and adaptable. Vulnerability to climate change is the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, the adverse impacts of climate change (IPCC, 2007). Resiliency is the capacity of a community, business or natural environment to prevent, withstand, respond to, and recover from a disruption (United States Climate Resilience Toolkit, 2016). Adaptation to climate change refers to the adjustment in natural or human systems in response to actual or expected stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive responses, as well as autonomous and planned adaptation (IPCC, 2001).

The development of a Corporate Climate Adaptation Plan represents a challenging task, as there are few examples to draw upon from the literature or other transit agency experiences that deals with maintaining and operating such a diverse system, let alone implement a capital expansion program that will effectively quadruple its current level of service. There is also intense scrutiny of decision-making and the progress of capital projects, with the expectation that new infrastructure will be delivered on-time and on-budget. The approach forward must consider how to enhance operations and maintenance procedures to reduce vulnerability, and also how to "mainstream" resiliency into transportation planning, design and construction of future assets, and do so in a manner that is financially prudent. Adopting the right methodologies, using appropriate tools, and applying sound evaluation techniques are all essential steps to assessing vulnerability and risk, and then implementing effective resiliency measures. This requires not just looking at the hard infrastructure assets, but also operations (e.g. maintenance procedures, winter readiness protocols), information technology, planning, design and construction (e.g. including enhanced design standards), in addition to other business practices (e.g. emergency response planning).

This paper outlines progress to date at Metrolinx to develop a resiliency and adaptation program, which will culminate in the establishment of a Corporate Climate Adaptation Plan. The paper begins by briefly outlining the resiliency challenge at Metrolinx within the broader science and policy context. The key steps that were undertaken in year 1 are then presented, that includes the creation of an internal resiliency working group, the preparation of a benchmarking report comparing Metrolinx to best practices, and the application of Engineers Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol to a selection of six key critical assets, including two maintenance facilities, two GO stations, and segments of two rail corridors. The PIEVC study is the primary focus of this section. In year 2 potential lessons learned from these two reports are being used to inform the pathway forward that includes identifying opportunities where mainstreaming resiliency can be effectively applied across the organization, identifying high-risk assets, and ensuring that each of these assets have a climate adaptation management plan that addresses vulnerability and risk to extreme weather events and climate change.

II. Background

Metrolinx, an agency of the Government of Ontario under the Metrolinx Act, 2006, was created to improve the coordination and integration of all modes of transportation in the Greater Toronto and Hamilton Area (GTHA). Since then Metrolinx's responsibilities have grown to include medium- and long-range regional transportation planning through The RTP, the operation of GO Transit, the operation of the PRESTO electronic fare card system that allows riders to transfer seamlessly across multiple transit systems, the construction and operation of the Union-Pearson (UP) Express service, and the construction and delivery of other regional rapid transit projects like the Eglinton Crosstown LRT and Viva BRT.

The organization's mission is to champion, develop, and implement an integrated transportation system for the region that enhances prosperity, sustainability and quality of life. Metrolinx values innovation, customer service and safety within its business practices, and strives to deliver high quality services to all clients and stakeholders. Under its Customer Charter, for example, Metrolinx is committed to having their customers arrive on time, take their safety seriously, keep them in the know, make their experience comfortable, and to help them quickly and courteously.[1] In 2015, Metrolinx served an area with a population of over 6.6 million, provided 250 train trips along 7 lines totalling 450 route kilometers, and carried over 225,000 passengers between 63 stations. Complementing the rail service is a bus network that transports almost 70,000 passengers over 2,500 bus trips each weekday (Metrolinx, 2014b).

Metrolinx's ability to deliver on its mission regarding customer service and safety was severely tested in 2013, most notably by an intense rainstorm on July 8th, when 126 mm of rain was recorded at Toronto Pearson International Airport. More than a month's amount of rain that normally occurs in Toronto during the month of July fell during the evening rush hour. This event caused washouts along two rail corridors and resulted in a GO Train that was occupied by approximately 1,400 commuters becoming submerged by rapidly rising flood waters along the Lower Don River, an area prone to

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[1] *Note that delays due to weather events are excluded and are ineligible for financial reimbursement. However, customers who were onboard the train submerged by flood waters on July 8th, 2013, were eligible for a $100.00 credit towards future transit trips.*

flooding. A GTHA-wide ice storm that began on December 21st, 2013 also had implications for regional and local transit services across the region, including station functionality through the indirect impacts from wide spread power outages experienced by Toronto Hydro-Electric System Limited and other municipal utilities. Together these events resulted in over $1.25 Billion in insured costs, not including the costs incurred by Metrolinx.

In between these two publically reported extreme weather events, an ad hoc committee from senior management began to explore at a high level where infrastructure assets could be vulnerable to a changing climate. As with other transit agencies operating in a temperate climate it was expected that: tracks are vulnerable to hot and cold extreme temperatures, especially during heat waves when warping and sun kinks can occur; intense rainstorms can lead to flooding, embankment erosion and slope instability, including washouts along rail corridors; high wind gusts can lead to an increase in vegetative debris being blown onto tracks; extreme snowfall, blowing snow and ice build-up can pose problems for buses, track switches and train doors; some station tunnels are at risk of flooding during intense rainstorms; a reliable and uninterrupted power supply may be at risk to power outages caused by flooding and/or freezing rain, among others examples of vulnerability.

In response to these impacts and others, Metrolinx has implemented a number of measures. These include:

- Improved access to reliable weather information – through accu-weather forecasts;
- Operational improvements/changes in procedural protocols;
- Improvements in extreme weather/emergency response planning including the addition of an emergency response vehicle;
- Direct access to real time stream flow and depth monitoring data and flood alerts issued by the Toronto and Region Conservation Authority (TRCA) for the Lower Don River;
- Infrastructure replacement or upgrades – culverts, bank/slope erosion, and ballast sensors;
- Enhanced monitoring and detection for water levels at tracks along flood prone areas;
- Changes in staffing levels and customer information systems;
- Increased the rail-laying temperature along rail corridors; and
- Introduced emergency electricity backup systems at maintenance facilities, and have issued a new standard for back-up generators for GO Stations.

While these and other measures are anticipated to increase resiliency to extreme weather events comparable to those that have already been experienced, more measures are likely needed. To date most have been applied in an ad hoc manner, few have been implemented on a coordinated, system-wide basis, and none have been formally assessed from a climate change perspective. As a result, the implementation of such measures may solve an immediate risk and area of concern, but as historical records/trends are no longer expected to be a good indicator of future climate conditions, response measures that are based on historical design standards may be inadequate vis-a-vis future climate change conditions. It is likely that these changes may not in themselves be sufficient to ensure that the regional transit system is resilient and adaptive under various projections of climate change.

In 2014 Metrolinx moved to create a senior advisor position in resiliency and adaptation, and in their Five Year Strategy 2015-2020 published that year, they committed to establish a Corporate Climate Adaptation Plan covering facilities, practices and protocols by 2018. A senior advisor was hired in

January 2015, and before the end of May an internal Resiliency Working Group was formed, made up of a dozen representatives of various business units across the organization. A literature review of best practices was also initiated, including a review of assessment methods and tools used to determine the vulnerability and risk of infrastructure assets to extreme weather events and climate change. The initial focus of the working group was to put in place some key building blocks to establish an adaptation plan, specifically to apply and test best practice vulnerability and risk assessment tools to a selection of key critical infrastructure assets, to develop credible and evidence based climate change projections for the GTHA, and to use this exercise to engage others within the organization and increase awareness around the urgency of taking action on climate change.

While the initial focus was on existing assets, practices and protocols (e.g. operations and maintenance), it soon became obvious that in year 2 the focus needed to be broadened to include new capital projects, especially the planning, design, and construction processes for the RER and RT initiatives, in addition to practices and protocols such as emergency response planning. This shift was driven, in part, by the recognition of the additional capital investments this past year that were directed into the renovation of Union Station, construction of the UP (Union Pearson) Express, infrastructure improvements along the Georgetown South section of the Kitchener rail corridor, several new segments of Bus Rapid Transit, and tunnel excavation along the Eglinton Crosstown route, that totalled almost $2 Billion. These investments are just the beginning of a longer-term commitment to invest $50 Billion into infrastructure assets over the next 10-20 years through the implementation of RTP that includes the roll out of the RER and numerous RT projects. Under the RER there will be a significant upgrade and expansion of existing rail infrastructure to support a faster and more frequent (two-way, all day) service across all 7 rail corridors. This will also involve the phased-in electrification of a majority (portions of 5 of the 7 rail corridors) of the rail system. The list of new assets coming on board through “First Wave” and “Next Wave” projects includes:

- Approximately 150 km of new tracks;
- Up to 60 station renovation projects and creation of Mobility Hubs;
- Up to 130 bridge expansions;
- Approximately 19 rail-road and rail-rail grade separations; and
- Up to 500 km of overhead catenary.

As part of this expansion, Metrolinx is also constructing a number of RT lines across the GTHA, including the Finch West to Humber College LRT, the Hurontario LRT, the Hamilton LRT, the Sheppard East LRT, and the replacement of the current Scarborough RT. Once completed these RT assets will be operated and maintained by the respective municipal transit agencies for 30 years, before being returned to Metrolinx. For each LRT, for example, the infrastructure assets will include the track, layover yards, stations and stops, maintenance and storage facilities, and in some cases power plants to generate electricity. When completed, over 1,200 km of RT will be built – more than triple of what exists now – so that over 80 per cent of the projected 9 million residents across the GTHA (by 2031) will live within 2 km of rapid transit (Figure 1).

It is within this ambitious and unprecedented regional transit investment and expansion plan that resiliency measures to extreme weather and climate change need to become embedded into practices and protocols for operations and maintenance, as well as for the planning, design, and construction of new infrastructure assets that are expected to last for decades to come. This requires having an improved understanding of: (i) how climate conditions are projected to change across the GTHA, based on various emission scenarios and for different timelines; (ii) how our infrastructure assets are vulnerable to extreme weather conditions; (iii) the location and condition of our assets that are most vulnerable to these changes; (iv) which operations and maintenance protocols need to be strengthened by embedding resiliency; (v) what increases in design standards are required to reduce vulnerability and enhance resiliency; (vi) what are the most cost-effective resiliency measures to implement and where; and (vii) what are the priority areas for investing in and implementing resiliency measures across the regional network?

III. Science and Policy Context

In terms of climate change policy, 2015 was notable for COP 21 (21st Conference of the Parties Meeting) held in Paris, France, where over 190 countries agreed to reduce their greenhouse gas (GHG) emissions by 2030 to levels that would keep global temperatures from rising 2°C above pre-industrial levels, and thereby avoid causing "dangerous interference with the global climate system" (United Nations, 1992). The Canadian delegation included the newly elected Federal Government who committed to go beyond the previous government's 30 percent target below 2005 levels by 2030, while the Government of Ontario committed to go even further and reduce emissions 37 percent below 1990 levels by 2030. Ontario is the only province in Canada to meet its 2014 emissions reduction target, and has additional targets of 15 percent below 1990 levels by 2020 and 80 percent below 1990 levels by 2050 (MOE & CC, 2015a). Despite these efforts, carbon dioxide (CO_2) concentration levels in the atmosphere may soon reach the point where we are committed to some degree of climate change occurring, and given the build-up and lifespan of GHGs in the atmosphere, the heat being stored in the world's oceans, permafrost melting, etc., we may be on a pathway where an increase in annual average temperatures exceeds 2°C by mid-century. In fact, if GHG emissions continue unabated and CO_2 concentrations quadruple from pre-industrial levels, exceeding 1000 ppmv by 2100, global average temperatures could increase by 4-5°C (IPCC, 2013).

In Ontario, a majority of the policy focus has been on GHG emission reductions, with only limited consideration of how Ontarians should be reducing their vulnerability to inevitable impacts and enhancing their resiliency and adaptive capacity to more extreme weather events and climate change. Climate change has been formally added to the name of the Ministry of the Environment & Climate Change (MOE & CC), while resiliency tends to be shared with the Ministry of Economic Development, Employment and Infrastructure. The need to consider the risks from climate change and to become climate resilient is beginning to appear in other Ministerial policies and guidelines, such as the Provincial Policy Statement (PPS). The 2014 PPS provides the overall vision for land use planning in Ontario and supports land use patterns that promote a mix of uses and offers a diversity of transportation choices that together lead to strong, liveable and healthy communities that are economically and environmentally sound, and are resilient to climate change (MMAH, 2014). The need to integrate resiliency into planning is also becoming common practice as part of the requirements for a Provincial Environmental Assessment, specifically in terms of demonstrating how new infrastructure projects and their stormwater systems will be designed to accommodate climate change. While some provinces have provided guidance to determine risk and increase design standards, they do not tend to be prescriptive, leaving the final decision to be based on interpretation of best practices rather than building up to an accepted higher level of capacity (e.g. Nova Scotia Environment, 2014).

The key provincial legislation regarding infrastructure and resiliency to climate change is the *Infrastructure for Jobs and Prosperity Act, 2015*. This legislation, which was proclaimed on May 1st, 2016, provides a planning and implementation framework for public investment in infrastructure, including $130 Billion budgeted by the Provincial Government for projects across Ontario over the next 10 years. The Act establishes mechanisms to encourage principled, evidence-based and strategic long-term infrastructure planning that supports a variety of sustainability goals including job creation and training opportunities, economic growth and protection of the environment, and incorporating design excellence into infrastructure planning. Among the 14 Infrastructure Planning Principles, that public sector entities "shall" consider when making decisions respecting transportation infrastructure such as highways, bridges and transit stations, includes number 11:

> **"**infrastructure planning and investment should minimize the impact of infrastructure on the environment and respect and help maintain ecological and biological diversity, and infrastructure should be designed to be resilient to the effects of climate change (Statutes of Ontario, 2015)."

While the Act lacks clarity and detail regarding how public sector entities "shall" consider how infrastructure should be designed to be resilient to the effects of climate change, other documents by the Province provides some general guidance regarding how this should be done. In the Ontario Discussion Paper on Climate Change released in February, 2015, the MOE & CC supports the adoption of a risk assessment approach, supports the application of assessment tools such as Engineers Canada's Public Infrastructure Engineering Vulnerability Committee Protocol to evaluate climate risks for infrastructure assets, and supports the use of the most up to date climate change projections for Ontario (MOE &CC, 2015b). The Ministry of Transportation (MTO) has contributed towards the provision of climate information by updating Intensity-Duration-Frequency (IDF) curves across Ontario, as part of their efforts to better inform design standards for culverts, bridges and drainage systems along provincial highways. MTO has also assessed the resilience of a sample of Ontario highway drainage infrastructure to climate change and extreme precipitation events, notably a selection of bridges, culverts and storm sewers (Farghaly et al., 2015). This has involved coupling updated IDF curves to climate change projections, essentially estimating how the return periods for storm events will be affected by climate change. There is no scientific consensus however regarding how IDF curves should be coupled with climate change projections, and some agencies have advocated that a more prudent course of action would be to adopt a risk approach rather than depend upon a specific estimate of how precipitation could change in the future (e.g. CSA, 2012).

In Ontario the greatest progress to date in linking climate change science with policy and adaptation practices has been in the area of addressing risks for watershed management. Much of the early Provincial focus has been focused on source water protection (MOE, 2012), with less emphasis on riverine and stormwater flood management. In the latter case it is important to recognize that Provincial responsibilities related to stormwater management are distributed across 5 Ministries, in addition to the role of Conservation Authorities who are responsible for riverine flood management, and local and regional municipalities who are responsible for managing urban/overland/stormwater flooding. However, the primary policy instrument for managing and designing stormwater systems continues to be the *2003 Stormwater Management Planning and Design Manual* that provides guidance for planning, designing, operating and maintaining stormwater management infrastructure (MOE, 2003). These guidelines however do not take climate change into account, and as a result the design standards that meet these guidelines will be insufficient to manage future extreme weather events that are projected to increase in intensity and frequency. This has been identified as a serious policy gap in need of updating, both by the Ontario Expert Panel on Climate Change Adaption (The Expert Panel on Climate Change Adaptation, 2009) and the Environmental Commissioner of Ontario (ECO, 2014). Further, given that Canadian municipalities face an infrastructure deficit of $123 Billion (which will be much more if Federally and Provincially owned infrastructure is considered), existing stormwater systems are not likely to be designed to handle the projected increase in water flows. So even if Metrolinx had clearer guidance and direction on how to increase stormwater design standards to accommodate an increase in water flows, interdependencies matter and it is unlikely that enlarged culverts would connect very well with aging, outdated and undersized municipal systems.

IV. Year 1 Progress: Vulnerability and Risk Assessment

From a review of the literature and best practices among transit agencies addressing vulnerability and resiliency, there are some common elements underpinning how they are responding to extreme weather and climate change. These include doing nothing and not investing in resiliency measures and consequently maintaining the status quo based on past standards or historical climate conditions. This option is typically not recommended, and a preferred option is to choose between being reactive or proactive to the risk of extreme weather and climate change. Even then inadequate levels of investment may result in extensive damage still occurring to infrastructure, as well as reputational impacts, requiring considerable time and effort to regain the trust and confidence of its customers and investors. Increasing investment may be deemed adequate if an agency has identified climate risks and implemented measures that protect their infrastructure assets against them. They should be able to survive extreme weather events, and recover swiftly, thereby demonstrating to their customers that it has the capacity to withstand external risks.

Measures that enhance resiliency and adaptive capacity to extreme weather and climate change typically fall into a selection of core broad categories. An agency can *maintain and manage,* absorbing increased maintenance and repair costs and improving real-time response to severe events. This might involve incorporating monitors and sensors that can detect changes in weather-related conditions and infrastructure integrity, setting off alerts of approaching damage thresholds including potential flood conditions. Adjusting insurance coverage would also fall into this category. Measures could be implemented that are intended to strengthen and protect, where new infrastructure and assets are designed to withstand future climate conditions (e.g. larger drainage capacity, stronger structures to withstand high winds, materials suited to higher temperatures, etc.). This could also involve retrofitting existing structures and facilities, and building protective features such as retaining walls, levees, and vegetative buffers. Agencies could choose to enhance redundancy, where system alternatives are constructed (e.g. rail corridors, electricity power supply), including increased bus service in the event of rail service interruption, as well as a broader regional mobility perspective considering all transport modes. In more extreme cases a decision may be made to retreat, where transportation infrastructure that is located in highly vulnerable or indefensible areas are abandoned and decommissioned. This could involve relocating infrastructure, where new facilities are sited in less vulnerable locations.

Based on best practices, a key component of most programs to enhance resiliency in transportation and transit systems is to apply a climate change vulnerability and risk assessment framework to determine assets that are at high risk, and identify appropriate adaptation measures. Applying a risk assessment approach also helps ensure that infrastructure is not over designed. Vulnerability and risk assessment frameworks tend to incorporate a similar series of steps, sequentially moving from setting the context, to establishing a team, to creating credible climate change projections, identifying key critical assets to assess, determine asset sensitivity to climate, estimate future vulnerability and risks, develop adaptation options, and finally implement and monitor the adaptation measures applied. Outcomes and lessons learned can be applied on an asset specific basis, or be used more broadly and integrated into decision-making for asset and lifecycle management, environmental management, business continuity and emergency response planning, and other business management practices. In the case of new infrastructure, this includes integration into the planning, design, and construction phases of development.

The PIEVC Protocol

Based on a review of best practices, the resiliency working group engaged Engineers Canada and a team of consultants to apply a nationally recognized vulnerability and risk assessment tool to a selection of key critical assets. In August 2005, Engineers Canada established a national committee known as the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee the planning and execution of a long-term national engineering assessment of the vulnerability of Canadian public infrastructure to climate change. The PIEVC developed an engineering vulnerability assessment protocol (otherwise known as the PIEVC Protocol) as a means for public infrastructure owners to systematically conduct climate change vulnerability assessments of their infrastructure. To date, over 40 case studies have been done (or are in progress) on various types of infrastructure, systems and operations across Canada using the PIEVC Protocol (Engineers Canada, 2016). This includes case studies of transportation assets (e.g., highways, airports, and bridges), water resource and management systems (e.g. stormwater, waste water, potable water systems, and dams), buildings, coastal protection systems, and electrical systems. The PIEVC Protocol has also been applied to various infrastructure assets across the GTHA, including the TRCA, the City of Toronto, the Greater Toronto Airport Authority, and the Toronto Hydro-Electric System Limited, among others. As a result, there is a wide body of literature, information and lessons learned from previous studies that helped to inform the application of the PIEVC Protocol to Metrolinx's assets.

Under the study, six representative assets were analyzed so that specific, actionable recommendations could be presented for Metrolinx consideration regarding the vulnerability of its infrastructure to the impacts from climate change and extreme weather events. Assets were selected based on their level of "criticality", considering ridership, strategic importance, vulnerability history, system-wide significance, among other factors. The project "team" included experts from within Metrolinx who had knowledge of the operational history of the particular asset, and also an integrated understanding of climate change and infrastructure; AECOM who brought expertise in risk assessment, project management, and also technical expertise in the particular assets; Risk Sciences International (RSI) who brought expertise as climatologists and meteorologists, including climate change projections; and the TRCA, for expertise in flood analysis and their knowledge of local flooding conditions, as well as their connections to the Ontario Climate Consortium. The key assets evaluated in the project covered both rail and bus modes, and also included station and maintenance facilities. They were:

a) a bus maintenance facility;
b) a rail maintenance facility;
c) two GO stations; and
d) two segments of rail corridors.

The purpose of the report prepared by the consultant team was to describe the application of the PIEVC Protocol to the six assets, and to examine how the results of the study could be used to plan and monitor the resiliency of Metrolinx's infrastructure to climate change. Although the focus was on a selection of existing assets, some lessons learned could also be applied to future assets.

<u>Climate Data</u>

The study included the identification of key climate parameters and their impact thresholds relevant to the vulnerability assessment of the six assets under study, and estimates of their corresponding probabilities for input into the PIEVC model. Climate and weather observations were taken from a variety of sources and tailored for the six assets under study. The primary source of climate data was the historical record from Toronto Pearson International Airport. RSI also provided a high-level analysis of the spatial variation in historical climate conditions and future climate change projections, across the City of Toronto and the GTHA. Given the scope and purpose of the analysis, it was decided that drawing primarily from Toronto Pearson International Airport weather data and limiting projections to the year 2050 was both cost effective and scientifically acceptable.

Three main tasks were required:

1. Identify climate parameters that may impact the asset (i.e., high temperature, wind gusts, snowfall, etc.);
2. Identify the threshold(s) at which the particular climate parameter may become a concern for the asset (i.e., temperature over 40°C, wind gusts over 120 km/h); and
3. Estimate the probability that the climate parameter will exceed the threshold during the study period (2015 – 2050).

The climate parameters and thresholds of concern were established by consensus by the Project Team working collaboratively, and then tested at a multi-stakeholder workshop involving almost 40 participants that included Metrolinx representatives from across the organization, experts from the three consultant agencies, and also from local municipalities and utilities across the GTHA. The twelve key climate parameters used in this study are listed in Table 1, along with the reasons for inclusion.

In addition, projected average temperatures and rainfall for the region were developed by RSI, and presented at the workshop in map format. Average annual temperature and precipitation are projected to increase by 2050 compared to 1981-2010 climate normals. Climate change projections were developed for each of the identified climate parameter thresholds to the extent possible within the constraints of available data and resources. Projections were based on outputs from an ensemble of over 40 global climate models (GCMs) from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), released in late 2013. The scenario adopted was the highest of four representative concentration pathways (RCP8.5) reflecting an emissions trajectory comparable to business as usual GHG emissions by 2050. It was believed that the impact of meeting COP 21 reduction commitments by 2030 would not be expected to yield a significant difference in climate change projections by 2050.

The probability of occurrence for the study period, incorporating both *historical* and *projected* climate probabilities, were then calculated. This refers to the probability of the event occurring *at least once* at any point within the 35 year time period between 2015 and 2050 (Table 2). The results of the climate parameter probability analysis and scoring are provided in Table 3, which shows the climate parameters, corresponding thresholds, annual historical and projected probabilities, study period probability, and the corresponding PIEVC scores for annual and study period probabilities.

The most striking changes can be found with the extreme temperature parameters. Extreme heat events are expected to increase significantly under future projected conditions, with 40°C maximum days increasing from extremely rare at present to annual or near-annual occurrences by the 2050s, and the frequency of days over 32°C increasing by more than a factor of 4. In spite of recent cold winters, extreme low temperatures continue to become less likely. Winter temperatures are also expected to warm faster than summer temperatures, and therefore the annual average temperature range is expected to decrease further into the future. Even when considering "polar vortex" winters, which are expected to increase in frequency with climate change, these may not result in either the extreme low temperatures, nor the large temperature ranges considered here, as evidenced by the recent 2012-13 and 2013-14 winters. Low visibility days showed a marked decrease over the historical study period but these changes appear to have since stabilized, and low visibility days remain an annual occurrence.

All other parameters suggest no *marked* changes in probability between the historical and future periods. However, this may be more strongly related to the coarseness of the probability scoring method itself, coupled with the lack of available projections for rare and extreme events, as much as any lack of *meaningful* changes in risk posed by these hazards. High impact and/or localized events such as freezing rain, high winds, extreme rainfall, and snow loads, *may* be increasing enough to be of concern, but the PIEVC probability scoring method requires significant changes in event frequency in order for a given score to register a change, particularly at the low end of the probability scale. As a result, these parameters have not been forecasted in any detail; PIEVC scoring has largely been based on historical experience.

There are currently no projections available for the most localized, complex, rare and poorly recorded events (i.e., hail, tornadoes), and therefore future changes in these events remain unknown. In a similar vein to other localized thunderstorm events, the *conditions* required to produce these events appear to be increasing, but changes in frequency and intensity, particularly on a regional basis, remain indeterminate. While average conditions do not appear to be significantly different across the region serviced by Metrolinx, local differences begin to emerge in the behaviour of extreme events, including both basic parameters such as high temperatures, as well as more complex meteorological events such as hail storms. These differences may be significant enough to result in differences in vulnerabilities of similar assets in different parts of the region, particularly when evaluating assets further from the downtown area especially as one considers the communities surrounding the City of Toronto.

Flood Mapping and Vulnerabilities

Vulnerabilities in connection with flood events received particular focus in this study because of recent Metrolinx experience with washouts, delays, and cancelations as a result of flooding and runoff in the recent past. Although treated by the PIEVC as a climate variable, forecasts of flooding were treated separately under the study as they are understood to be more complex as climate is only one factor contributing to the likelihood and severity of flooding. For each asset, the AECOM team investigated the intensity and duration of rainfall that would be needed to create flood impacts, either from the effect of *riverine flooding* (flooding from high water levels in nearby watercourses), or from *urban flooding* (an exceedance of the capacity of local drainage infrastructure to convey runoff away from the asset resulting in localized flooding).

Because of their geography, two assets were assessed regarding their risk of flooding: a segment of a rail corridor; and a GO Station adjacent to a creek. For the rail corridor in particular, it was already well established that there is vulnerability to riverine flooding from the adjacent Don River, and it was possible in this case to establish rainfall thresholds associated with key flood impact levels. In contrast, urban flooding is more difficult to characterize with the information available, and in fact this is an area of active and ongoing research. Thus, it was not possible to establish rainfall thresholds associated with urban flood impacts, since asset information and operations records were insufficient to determine the conditions under which localized flooding would occur. More detailed 2-dimensional hydrologic modelling is needed to determine overland flows and resulting flood risk.

For the segment of the rail corridor further analysis was possible because of the history of flooding impacts on the Metrolinx services in this area, and the level of information available through previous studies and ongoing monitoring associated with this portion of the track. This analysis included the review of existing studies to obtain information on previously defined thresholds and vulnerable areas. Metrolinx staff was also engaged to inform the analysis on which river levels currently trigger management to begin assessing if service should be delayed or cancelled. Water levels, weather information, and expert judgment were used to establish two thresholds that could be used to represent a moderate rainfall event and an extreme rainfall event (the latter being comparable to July 8, 2013) to facilitate discussions around vulnerabilities and impacts associated with each asset undergoing analysis.

Vulnerability Assessment

To identify engineering vulnerabilities, the Protocol employs a risk-based method to sort interactions between an infrastructure component and climate-related event into risk categories which are then either deemed as vulnerable, not vulnerable, or require further analysis. In the risk-based method, a score for the probability of a climate-infrastructure component interaction is multiplied by the score assigned to the severity or consequence of that interaction:

Risk = Probability x Severity

Similar to the probability scores from 1 to 7 for the various climate parameters, scores for severity are also rated on a scale of 0 – 7. Two severity scoring scales are recommended by the Protocol, and shown in the table below. Both scoring scales were employed in this study because they provided complementary descriptions of the severity impacts to infrastructure. Severity scores were assigned to the climate-infrastructure interaction at the project workshop.

Multiplying probability and severity scores together yields a risk score (on a 0 – 49 point scale) for the climate-infrastructure interaction. These scores are sorted into three categories based on risk-tolerance cut-off values. The Protocol suggests cut-off values between the low to medium, and medium to high risks at scores of 12 and 28. These thresholds help set the level at which climate-infrastructure interactions are deemed to either be vulnerable, not vulnerable, or may require further analysis to better understand the nature of the vulnerability (see Table 5). During the workshop and various follow-up meetings, a detailed risk assessment matrix was produced. As per the PIEVC Protocol, the risk matrix was made up of two columns. The first column listed the breakdown of infrastructure components being evaluated. The header row of the spreadsheet contained the list of climate parameters under consideration.

General Findings and Vulnerabilities

Summary-level findings from the workshop included:

- Almost 450 interactions (climate-infrastructure interaction marked as a “Yes”) between infrastructure components and the 21 climate parameters were considered in the course of the workshop and follow-up discussions;
- Of all interactions, more than 90 percent of them were ranked as low risk interactions (score less than 12) or medium risk interactions (score between 12 and 27);
- Of all interactions, less than 10 percent of them were ranked as high risk interactions (score of 28 or greater).

There are many areas in which Metrolinx has good adaptive capacity through its built infrastructure, operating practices or backup systems. Interviews with facility operators and other staff also indicated that well-designed facilities and pro-active intervention by Metrolinx’s dedicated staff has helped to protect the safety of passengers and staff during a wide variety of weather events experienced to date. However, the study found a number of areas where improvements can be made in order to provide greater confidence in the system's ability to withstand predicted future climate conditions, including unusual extreme events.

Based on information gathered from research, interviews and workshop activities under this study, the AECOM team arrived at some general conclusions/observations regarding the adaptive capacity of the six Metrolinx assets under study, and provided a wide range of recommendations pertaining to the short-, medium- and long-term needs to enhance resiliency. Some areas have a great deal of adaptive capacity and are quite robust; however, there are areas of serious concern about future climatic probabilities and what that will mean for operations and safety. The assets were looked at in isolation and not comparatively or at a system-wide level. While the study results will be very useful in enhancing the climate change resilience of each of the studied assets, further work is required to extend results across the entire Metrolinx portfolio of assets. As more assets are assessed, the number of recommendations for operational changes and design improvements will require some means of prioritizing for budgeting and implementation purposes.

The most obvious effect of climate change in the study area will be a temperature increase, particularly summer high temperatures that will become increasingly higher through 2050. This will have significant impacts on the thermal expansion of rail, has the potential for heat stress and reduction in employee productivity in hot summer weather, and possible future requirement to consider the effects of heat stress on waiting passengers. The Preferred Rail Laying Temperature (PRLT) should continue to be applied at a higher temperature range, while co-generation systems should be provided at more maintenance facilities to allow full operation during an extreme weather event that causes blackouts (or brownouts).

Flood risk remains a concern, especially along the Lower Don River, which can result in significant disruption to Metrolinx' Richmond Hill Corridor train service. Many studies have been undertaken along this corridor, and a flood risk analysis should be considered that takes into account climate change. Overland flood risk is somewhat problematic, and more information is required to understand what types of flood events could impact specific sites, and what kinds of weather events could cause them. Further characterization and research of local drainage infrastructure (e.g. culverts, drainage ditches, etc.) at or along all Metrolinx assets should be supported. Collaboration with local municipalities and Conservation Authorities is required to address flood risk, as the solutions to the problem extends beyond the responsibility of Metrolinx. Thunderstorm, wind intensity, and freezing rain are also climate parameters where further study is required, including the amount of ice build up on rails that may be too much for a GO train to crush safely under normal operating conditions. Although not part of this study, an analysis of the impacts of freezing rain on catenary wire should be undertaken that could inform plans for electrification.

While averaged climate conditions appear to be somewhat homogenous within the study area, the same cannot be said for climatic extremes. In particular, it was noted that areas in the northern GTHA are likely to experience more severe thunderstorm events more frequently, and temperature extremes vary between locations within the study area, and even more so at the northern limits of Metrolinx operations. Important differences may exist across the Metrolinx area of operations that could affect the vulnerability of assets, and further research is needed in this area. A data gap identified in this process was the lack of data on system and infrastructure failures and service disruptions due to climatic events. Metrolinx recognizes this shortcoming, and has begun to enhance its data collection and analysis of weather-related cancellations or delays.

In addition, the recommendations for enhancing long-term resiliency across the organization should include adding resiliency improvements to future capital improvement projects. Future design contracts could include, as a standard requirement, an analysis of medium- and high-risk items, and include the design of known vulnerabilities as a part of the next expansion or rehabilitation project at the subject site. Future work can build upon the lessons learned from this study, apply information of known vulnerabilities to other assets and conduct a system-wide assessment that includes all types of assets (stations, maintenance facilities, right-of-way, etc.). Using the results of this study, Metrolinx is now in a better position to design and implement a system-wide approach that would apply the PIEVC (or another protocol) across the entire system in order to be able to compare and rank risk results of different assets on a combined scale.

It is recommended that Metrolinx management and inspection practices be reviewed and updated as needed to ensure that best practices are not only implemented but also documented and communicated to all staff. Furthermore, policies, procedures and communications with respect to operating the system (e.g. rolling stock, facilities) prior to, during and after extreme events should be reviewed to determine whether guidance regarding handling of these circumstances is clear. Many of the weather-related impacts considered under this study would include the need for emergency response as a part of the mitigating procedures. It would be beneficial to include Metrolinx Safety and Security personnel in future discussions relating to operating and response procedures described above. It may be necessary to consider early warning systems to communicate immediate risks, and establish and practice response procedures for these warnings. For example, if extreme winds at or beyond 120 km/h gust threshold are expected or reported nearby, it would be appropriate to have response measures in place to communicate the situation, and to anticipate and address potential impacts.

V. Next Steps: Year 2 Activities

In moving forward, there are five key areas where resiliency can be advanced across Metrolinx. First, it will be important to address the key findings and recommendations of the PIEVC Study, as they pertain to the six specific assets, and in addition to the lessons learned for other assets across the organization. Second, as the PIEVC study only considered a selection of representative assets, other infrastructure assets need to be assessed regarding their vulnerability to extreme weather and climate change. The application of the PIEVC Protocol requires extensive effort, time and resources, and a simplified process may be more appropriate in order to identify key assets at high risk in a more expeditious manner, of which some of these could still be subject to full PIEVC treatment. Key assets at risk may also require the development of climate adaptation management plans, comparable to any resiliency planning that is required in response to the high-level recommendations provided in the PIEVC vulnerability assessment.

Third, there are opportunities to embed resiliency into operations and maintenance procedures, in addition to planning, design and construction practices and protocols. These opportunities need to be identified, prioritized, and acted upon, engaging internal stakeholders from the appropriate business units. This should also include engagement with safety and security, in regards to emergency response planning in response to situations where extreme weather events may occur, and worst case scenarios may need to be addressed. Collectively, key lessons learned from these activities should be incorporated into the Corporate Climate Adaptation Plan, which lays out a strategy moving forward over the next 1 to 10 years, with the potential for periodic update on a regular basis. Lastly, education and awareness building is an essential component of moving forward, both internally and externally, that includes the public and the broader transit community. Responding to extreme weather and climate change is not just the responsibility of Metrolinx, but a integrative and collaborative effort is needed if resiliency and adaptive capacity is to be achieved and vulnerability is to be reduced.

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Tables

Table 1: Climate Parameters Used in the Study

Parameter	Reason for Inclusion
Extreme Temperatures	Design parameters for HVAC systems, Occupational Health and Safety for staff
Temperature Range	Expansion/contraction of rail
Reduced Visibility	Minimum sight distances for trains
Frost Penetration	Frost heave, damage to pads, foundations
High Winds (gusts)	Structural damage to buildings and other above ground infrastructure; debris
Horizontal Rain	Penetration into HVAC, cladding, other building envelope concerns; passenger safety
Tornadoes	High impact, low probability events, potential for severe impacts to assets
Heavy Rain	Overland flooding impacts, rail washout, riverine flooding
Freezing Rain	OHS of staff, switch gear, falling ice, incoming power
Snow	Impacts to service, access to sites
Hail	Damage to equipment, vehicles in parking lots
Lightning	Communications, electrical systems

Table 2. PIEVC Probability Scoring Methods

Score	Probability Method A	Probability Method B
0	Negligible Not Applicable	< 0.1 % < 1 in 1,000
1	Highly Unlikely Improbable	1 % 1 in 100
2	Remotely Possible	5% 1 in 20
3	Possible Occasional	10% 1 in 10
4	Somewhat Likely Normal	20 % 1 in 5
5	Likely Frequent	40 % 1 in 2.5
6	Probable Often	70 % 1 in 1.4
7	Highly Probable	> 99 %

Table 3: Select Climate Parameters – Probabilities and Scores

Climate Parameter	Threshold	Annual Probability		Prob. of Occurrence for Study Period (2015-2050)	PIEVC Scoring		
		Historical	2050s		Annual: Historical	Annual: 2050s	Study Period (35 year)
Extreme Temperatures	40°C	~0.01 per year	1-7 days per year	~100%	1	7	7
	32°C	6.5 days per year	27.5 days per year	100%	7	7	7
	-30°C	0.05 days per year[2]	<0.01 days per year	<70%	2	0-1[3]	5-6[4]
	-23°C	1.1 days per year	0.1 days per year	100%	7	3	7
Temperatures Range	60°C in one year	0.1 days per year	<0.01 events per year	<90%	3	0-1	6
High Winds (Gusts)	90 km/h	2 per year	>2.5 per year	100%	7	7	7
	120 km/h	0.05 days per year	Likely ↑	~85% or higher	2	2	6-7
Overland Flood/Heavy Rainfall	≥25 mm in 2 hour	~ 0.8 events per year	Very likely ↑	100%	6	6	7
	≥60 mm in 2 hours	≤ 0.03 events or less per year	Very likely ↑	~70%	1-2	2[5]	6
Freezing Rain	≥ 10 mm	~0.2 days per year	~0.3 days per year	~100%	4	4-5	7
	≥ 25 mm	0.06 days per year	>0.09 days per year	>95%	2	3	7
Snow	Blowing snow	7.8 days per year	Trends not significant to scoring	100%	7	7	7
	≥ 20 cm in one day	0.1 days per year	Conflicting trends, likely remaining similar	>95%	3	3	6-7
Lightning	Direct strikes	~0.3% per year	Likely ↑	>99%	1	Unknown	3

2. *Used longer data set (55 years) due to rarity of event, reduced historical frequency further from original 0.07 annual probability.*
3. *A score of 0-1 is given for this parameter since the probability of occurrence is less than 1%, but is still likely in excess of the 1-in-1000 probability indicated by a score of 0. While projections indicate a zero probability of such events occurring by the 2050's, other potential drivers of extreme cold, such as equatorial volcanic eruptions, cannot be ruled out.*
4. *May be lower. Only 3 events since 1961, all in anomalously cold years, last event 1994. This, combined with downward trends in extreme cold days, suggests may be less likely than suggested by this analysis.*
5. *Climate studies of extreme rainfall indicate that the most extreme rainfall events are expected to have the greatest response to increases atmospheric moisture, with many indications of percentage rainfall rates outpacing increases in atmospheric moisture.*

Table 4: Severity Score Factors

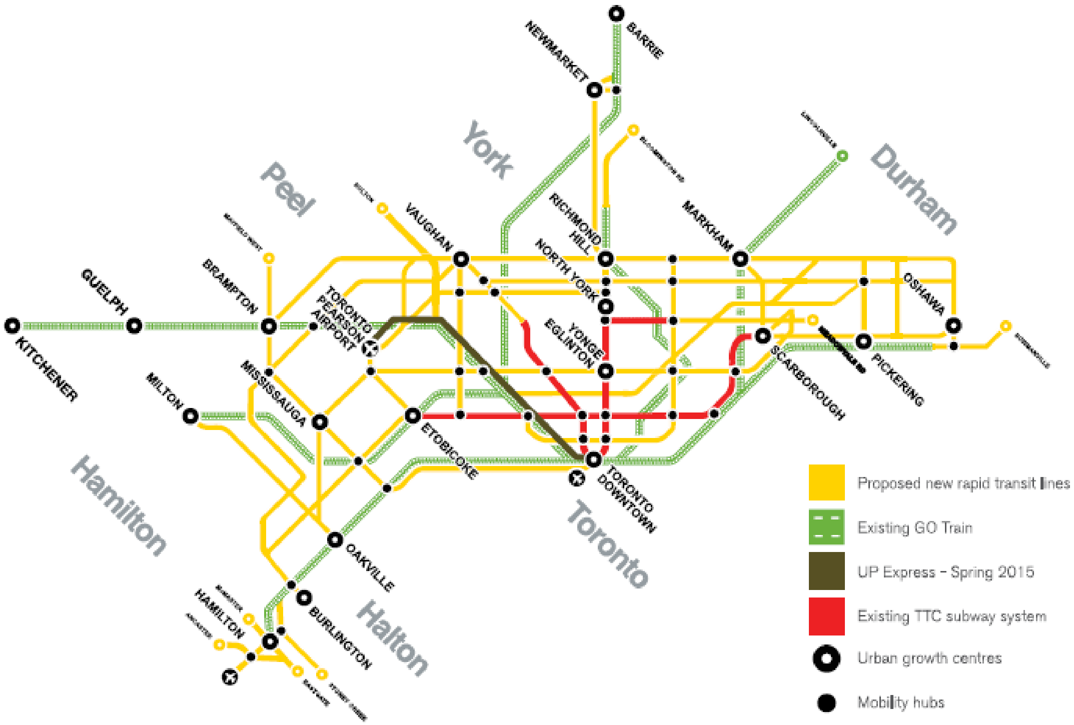
Score	Method D	Method E
0	No Effect	Negligible
1	Measurable	Very Low – Some measurable change
2	Minor	Low – Slight loss of serviceability
3	Moderate	Moderate loss of serviceability, some loss of capacity, but no loss of function
4	Major	Major loss of serviceability, some loss of capacity & function
5	Serious	More loss of capacity & function
6	Hazardous	Major – Loss of Function
7	Catastrophic	Extreme – Loss of Asset/Loss of Life

Table 5: Risk Tolerance Thresholds

Risk Range	Threshold	Response
< 12	Low Risk	Monitoring or no further action necessary
12 < 28	Medium Risk	Vulnerability may be present. Action may be required, further analysis may be required to determine nature of vulnerability
28+	High Risk	Vulnerability present, action required

Figures

Figure 1: The Big Move/Regional Transportation Plan



Source: Metrolinx (2014b)