Climate Change Risks to the Movement of Goods in Peel Region: Preliminary Evidence and Proposed Assessment Framework

Prepared for

The Region of Peel and Toronto and Region Conservation Authority

Prepared by

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Introduction

Maintaining efficient and uninterrupted movement of goods into and out of the Region of Peel is critical to the local economy, employment and broader economic stability of the Great Lakes Basin region (Anderson et al., 2019; CPCS, 2018; Region of Peel, 2017). The goods movement sector adds $49 billion annually to the Ontario's GDP with $1.8 billion being moved through the Region of Peel every day. The sector accounts for four out of nine jobs in in Peel which is distributed through a range of intermodal hubs, such as the CN Brampton Yard which handles 60% of CN's intermodal goods transportation (Region of Peel, 2017, p. 10). With climate change expected to increasingly affect the transportation sector (Ness et al., 2021, pp. 42–44), there is significant need to draw on previous studies and fill key knowledge gaps in order to prepare for a range of possible impacts to the movement of goods movement in the Region of Peel (Auld et al., 2016; Ness et al., 2021; Woudsma et al., 2017).

On December 19, 2019, the Region of Peel's Audit and Risk Committee (ARC-5/2019) directed staff to report on the impacts of climate change to non-domestic property and goods movement in the region. This report outlines findings of key climate related hazards most likely to impact the goods movement sector and proposes a framework to quantify the potential economic impacts. Key risks to transportation related infrastructure are identified. including roads, railways, bridges, and stationary infrastructure (such as bus terminals and train stations).

The report is divided into the following four sections.

- Section 1 discusses previous research, highlighting the most likely hazardous weather events to occur in the region as a result of climate change.
- Section 2 identifies the potential impacts of the respective climate hazards on ground transportation infrastructure.
- Section 3 proposes a framework to assess the impact of climate risks to ground transportation (rail, road, and bridges) and, subsequently, the movement of goods in the Region of Peel. The framework focuses on impacts to infrastructure,

workforce and the broader economy. In addition, the report identifies datasets necessary to complete a full assessment of risks.

- Section 4 lists future research needed to address knowledge gaps regarding the impacts of climate change on the goods movement sector.

1 Key Climate Hazards

The following subsections are divided according to the type of adverse climate event and provide a rough estimation of the likelihood of both occurrence and potential impacts. The impacts may also be evaluated in terms of whether or not they are isolated to certain systems or geographies, or cascading impacts which would result in long-term impairment to commerce across sectors both within and outside of the Peel Region (IPCC, 2012; Wilbanks & Fernandez, 2014). Identifying and evaluating both isolated and cascading impacts is important to ensuring adequate planning activities for the development of resilient systems at the scales of both cities and regions. This allows for greater cost-effective and collaborative planning (Schweikert et al., 2015).

1.1 Extreme Precipitation and Flooding

Regional studies on projected meteorological changes in the Peel Region due to global climate change pointed to the likelihood of increasing frequency and intensity of storms and precipitation (Auld et al., 2016, p. 60; Region of Peel, 2019, p. 33). This includes short-lived but intense storms, and major storms occurring more frequently than in previously recorded periods (IPCC, 2012; Zscheischler et al., 2018). Historic storms in the region have shown the vulnerability of key infrastructure, especially those related to transportation. The 2013 flood in Toronto cost CAD$1 billion in insured damages, according to the Insurance Bureau of Canada (Barrasa, 2018). The 2018 floods from a short, intense period of rainfall caused CAD$80 million worth of damages. Cumulative annual damages are expected to increase significantly as the effects of climate change worsen (Rabson, 2020). Intense rainfall events will result in more flooding events, whether occurring over several hours or a longer period, with potential to overwhelm current stormwater dispersal infrastructure and creating waterlogging and transportation disruption (Evans et al., 2020; Feltmate & Moudrak, 2021; Meyer & Weigel, 2011).

Another problem expected to arise due to increased flooding is the subsequent increase in erosion. Erosion caused by floods affects both the underlying soil structure and built infrastructure designed to meet specified ranges in the underlying ground conditions (IPCC, 2012; Ness et al., 2021). Residential, commercial and logistical infrastructure, especially in proximity to Lake Ontario, is vulnerable to increased erosion (Harris, S. et al., 2016). As a result of increased erosion, key rail and road infrastructure will be under increased stress and may need to be reinforced to ensure long-term integrity and stability (Ness et al., 2021; Palko et al., 2017).

In summary, the region can expect increasingly frequent and intense periods of waterflow, impacting the current road and rail infrastructure and putting water dispersal systems under increased pressure. While current systems are expected to be able to handle the increased pressure up to a certain level, whether the same holds true at higher ranges of variation in precipitation levels requires further investigation (Brinckerhoff, 2014; Region of Peel, 2018a).

1.2 Higher than Average and Extreme Heat Days

The increase in hot-temperature days as a result of climate change poses a significant hazard considering the broad range of ways it impacts intermodal transportation. One consequence of increasing temperatures is the impact on the quality of goods vulnerable to temperature conditions. This will likely require increased investment in temperature-controlled transportation units and storage facilities, especially for food processing (Zeuli et al., 2018), but also for many other commodities such as medicine. Important to note is that ideal operating conditions for specific types of production and operations are now likely to be exceeded (Fichtinger et al., 2015). Both Fichtinger et al. and Zeuli et al. in their respective published studies have stated the importance of timely movement of goods to the next process or customer. This will most likely be disrupted and hence could lead to economic damage to the corresponding companies as well as to the general consumers in the region and beyond (Fichtinger et al., 2015; Zeuli et al., 2018).

Another critical consideration regarding the increased number of heat days is the impact on the health and well-being of employees working in the goods movement sector (Paterson et al., 2012). Extreme heat may have more severe consequences in situations requiring intense outdoor work-related activity and could lead to higher incidences of injury, long-term health consequences, and even fatalities (IPCC, 2012; Palko et al., 2017; Paterson et al., 2012). Aside from investigations at the household level with regard to flooding of residential areas, worker vulnerability and adaptation to extreme heat is a topic that has not received adequate attention (Feltmate & Moudrak, 2021; Paterson et al., 2012).

Stress on critical infrastructure caused by extreme heat days must also be monitored. Multiple studies suggest the current state of infrastructure is able to withstand significant variations in temperature, however, thresholds remain unknown (Region of Peel, 2018a). Furthermore, it is not clear what the consequences will be as a result of the greater number of days with continuously high temperatures (Ness et al., 2021; Palko et al., 2017). This is particularly important for critical railway components and varying grades of paved roads, damages to which may in turn lead to damage to transportation vehicles and other equipment (Molarius et al., 2014). This also applies to warehouses, in which it is critical to ensure the resilience of both equipment and workers to continuous heat (Fichtinger et al., 2015; Singh, 2018). More frequent temperature variations and overall increases in average temperature are also expected to be an issue during winter, owing to unpredictable, sudden changes in driving conditions (e.g., rain on snow, freezing rain, and ice storms) which may cause more accidents and increased disruption (Woudsma et al., 2017).

In summary, the consequences of more frequent extreme heat days, as well as average increases in year-round temperatures, are expected to be multi-faceted and require increased planning for measuring and remedying adverse consequences on infrastructure, employees, and users of the intermodal transportation system in the region.

1.3 Compound Extreme Events

A 2012 IPCC report draws attention to the increased likelihood of extreme weather events, of which the impacts will be difficult to measure considering their compounding, cascading consequences (IPCC, 2012, pp. 127–128). This is particularly true of various sectors that have difficult-to-measure, interlinked nodes that, if damaged or otherwise disrupted, have both immediate and long-term economic consequences (Zscheischler et al., 2018). It is also important to understand that compound extreme events may also extend far beyond the region's borders into areas from which key supply chain components are sourced. This has become particularly apparent during the COVID-19 pandemic, which has caused disruptions to multiple supply chains around the world (Harden & Greene, 2020). This is expected to worsen as the climate continues to change.

Infrastructure and economic activities will be strained or compromised by compound extreme events, such as more high water levels in and around Lake Ontario coupled with flooding from excess precipitation (Harris et al., 2016; Region of Peel, 2018b). A further example is the combination of drought and heatwaves, resulting in immediate consequences such as a higher cost of living, increased energy demand, and food supply issues (Zeuli et al., 2018).

Multi-disciplinary and multi-agency stakeholder collaboration is essential to pin down immediate priorities for investment in resilience within and around Peel Region. This could include early warning systems to deal with precursor events (e.g., excess rainfall) which may mitigate impacts felt across the sector. In sum, the vulnerability of the goods movement infrastructure in the Peel Region to increasingly frequent, intense, and unpredictable floods and temperatures will lead to unpredictable and likely severe consequences without adequate assessment and preparation.

2 Key Vulnerabilities to Goods Movement System

The proposed framework draws on the identification of key hazards to estimate impact based on the combination of the *level of risk* with the *vulnerability* of respective components in the system. As previous reports have stated, the goods movement sector as well as others that rely on this sector are considerably vulnerable to climate change (Anderson et al., 2019; Woudsma et al., 2017). This section will analyze the level of vulnerability based on the current literature and reporting in this field.

Drawing from previous examinations of projected changes in temperature across the Greater Golden Horseshoe Region (GGH) have found that annual average temperatures are projected to increase by about 2°C by 2021–2050, 4°C by 2051–2080, and 5°C by 2081–2100 compared to the historical 1981-2010 baseline (Climatedata.ca, 2021; Government of Canada, 2021). Average annual extreme precipitation is projected to increase by about 13% by 2020s, 21% by 2050s, and up to 25% by 2080s compared to the 1981 - 2010 baseline even under RCP 4.5 which is representative of an intermediate projected increase in concentration of greenhouse gases (Auld et al., 2016, p. 66).

Extreme temperature and precipitation events, including heat waves, periods of droughts, and flooding are also projected to increase in intensity, last longer, and occur more frequently than in the past (Bush & Lemmen, 2019). Climate projections for the region are expected to be more unpredictable, for example the projections for annual average temperature and average annual precipitation may vary by up to 2°C and 100mm, respectively across the region (Bush & Lemmen, 2019; Climatedata.ca, 2021; Government of Canada, 2021). These projections align with those developed for the Peel Region in 2016 to be considered in planning for resilience measures, including: rapid increases in temperature over summer, higher levels of precipitation throughout the year, and fewer days of very low temperatures during winter (Auld et al., 2016). The resulting implications for the transportation system follow from the physical consequences of such changing climate conditions which include flooding, erosion and heat waves which are expected to become more frequent and thus test the designed limits of existing infrastructure with consequential impacts on the regional economy (Abulibdeh et al., 2015; Woudsma et al., 2017).

This section will focus on the consequences of hazards of immediate concern and also on what are defined as compound extreme events, whereby a confluence of multiple hazards can create a cascading negative impact (IPCC, 2012, 2021; UNDRR, 2015).

Based on the scope of the assigned project, the impact will focus on the intermodal transportation system which is a key part of the Peel Region's economy, since it is used to transport approximately $1.8 billion worth of goods through the region every day and contributes $49 billion to the GDP (Region of Peel, 2017, p. 10). This necessitates an urgent evaluation of key exposures to prioritize investments in developing resilience to the impacts of climate change for rapid recovery of operational capacity.

2.1 Impact of Flooding on the Intermodal Transportation System

The impact of floods on Canada's vast road and rail system has been examined multiple times over the past decade with increasing awareness of the effects of climate change and increasing concerns about the significant economic impact. An increasing area of concern is the impact on bridges that are part of the network. Few studies provide a comprehensive evaluation of the changes needed in design features of future road and rail bridges to deal with the impact of climate change nor the investment required to upgrade current ones (Chang et al., 2021; Ness et al., 2021). The economic impact that results both from immediate disruptions and remedial actions as well as the long-term consequences on the supply chains in various regions is a key concern (Palko et al., 2017, pp. 203–204).

The 2016 study of the Peel Region's potential weather pattern changes due to climate change looked at the projected trends of precipitation. While summer and autumn precipitation were projected to remain the same and, in some cases, decrease, precipitation is expected to increase in the spring and winter. Between 1981 and 2010, major rainfall events that have led to flooding have been largely driven by local scale convective storms (e.g., thunderstorms, and lake-breeze convergence) (Auld et al., 2016, pp. 59–63). This and other studies have shown that in similar regions close to a large body of water, a warmer atmosphere with increased moisture holding capacity is likely to lead to greater frequency of such storms (IPCC, 2012, 2021). The degree of intensity of such storms is expected to increase along with the risk of flooding of key road and railways as well as other critical infrastructure (Woudsma et al., 2017).

Other studies have focused on the ability of current stormwater systems to manage more frequent moderate rainfall as well as more intense storm events that result in sudden surges of water in specific locations. Much of the current stormwater infrastructure has been designed to disperse water as quickly as possible rather than infiltration and storage. Such infrastructure is designed to handle water accumulation within certain expected historical ranges and it is an open question whether it can handle increases in future precipitation (Evans et al., 2020; Meyer & Weigel, 2011; Ness et al., 2021). The impact of water accumulation on key roads to critical infrastructure nodes in the region is demonstrated by the concerns related to the road system supporting Pearson International Airport. A 2017 examination of the preparedness of the transportation system in Ontario for the impact of climate change looked at the roads and the airport itself and found that greater capacity to handle water runoff from storms was needed (Woudsma et al., 2017, pp. 167–169). With Pearson projected to process more cargo than other international airports in Canada, the investment is necessary (Region of Peel, 2017, p. 20). In addition to the airport, there are concerns regarding the impact of flooding from Lake Ontario on adjacent marine transportation. The strategic plan for goods movement states that marine transportation of goods plays a minor role in the region (Region of Peel, 2017, p. 23) but the consequent impact on other modes should be monitored if flooding exceeds certain levels, subsequently affecting all modes of transportation such as road and rail close to water bodies.

The impact of flooding on rail systems is found to be multi-faceted. While the paths themselves are less exposed to the impact of flooding, there are a number of concerns related to key installations such as junctions, stations, and roads connected to the Peel Region rail system (CPCS, 2018; Ness et al., 2021; Region of Peel, 2017, 2018a). Considering the concentration of critical rail on and offloading points as well as road systems, monitoring mechanisms, etc., it is important to assess vulnerability to the consequences of floods which may affect operations (Brinckerhoff, 2014; CPCS, 2018; Woudsma et al., 2017). As will also be explained in the section related to the impact of extreme heat, the rail system has a set of interconnecting components that lend themselves to failure much more easily than roads which may have alternative paths to ensure continuous operations (Chinowsky et al., 2019; Delgado & Aktas, 2016; Palko et al., 2017).

The role of rail in developing a low emissions transportation system is vital, but will require careful planning in developing a resilient system capable of undertaking expected, or even unforeseen, pressures from the impact of climate change (Pinto et al., 2018). The consequences of disruptions in the rail system are much more impactful considering the cargo volume and the resulting impact on the scheduling of movement through the system (Anderson et al., 2019; Woudsma et al., 2017, p. 147). The other key consideration for planning is the exposure that key rail infrastructure has to the effects of floods. Generally it has been found that the rail system is more exposed to the impact of higher temperatures (see next section) (Brinckerhoff, 2014, pp. 264–266).

Given that flooding poses a key risk to the Peel Region's intermodal transportation system, it is thus important to develop a component in the framework that examines both the possible incidence and severity of adverse impact as well as develop a mechanism to improve resilience.

2.2 Impact of Extreme Heat on the Intermodal Transportation System

The consequences of persistent high-temperature days over the summer is expected to impact transportation processes and infrastructure (Woudsma et al., 2017). The resulting impact on the supply chain is expected to be significant considering the volume and variety of time-sensitive goods, such as food and chemicals, that are transported through the system which will be degraded or at risk of degradation in conditions of high heat (Stellingwerf et al., 2018; Zeuli et al., 2018).

Previous studies which have looked at the impact of high temperatures on transportation units have identified two key considerations because of increasing temperatures. First, increasingly higher temperatures put pressure on machinery to maintain motion and adequate storage conditions (Stellingwerf et al., 2018; Woudsma et al., 2017). This has not only been caused by climate change, but is expected to contribute further to climate change by increasing fuel use to maintain optimum conditions during transportation and storage. This is especially important given the welfare of the drivers and other transportation aids that require a specific range of operational parameters (Meyer et al., 2014). Exceeding parameters leading to damage to equipment and operators could lead to incidents and long-term repercussions. Business disruption is also an inevitable result of exceeding operational parameters impacting overall economic performance due to such factors as the degradation of the goods transported (Anderson et al., 2019; Zeuli et al., 2018).

Another consideration which has been examined in considerable detail is the impact of heat on the infrastructure of the intermodal transportation system. In order to simplify the assessment, the examination of the impact of hot temperatures will be divided into two aspects of the transportation system: the stationary components of the intermodal transportation network and the corridor infrastructure that enables movement by rail and road (Brinckerhoff, 2014; Meyer et al., 2014; Woudsma et al., 2017).

The road system in the Peel Region has a series of key stationary installations that include parking, rest areas, fuel points, and maintenance areas. Studies in regions with frequent incidences of high temperature days have found that it is important to design for high temperatures to prevent frequent maintenance and erosion from large variations in temperature from winter to summer periods (Meyer et al., 2014).

Regarding rail transportation, key junction and track change points as well as station related equipment now have to withstand consistent high-temperature periods (Brinckerhoff, 2014). The stationary components related to air and marine transportation are also a key part of the consideration of the impact of extreme heat. With Pearson International Airport being such a critical node in the transportation network in the Peel Region, it is worth remembering that increasing heat conditions will put considerable pressure on workers at the airport. An additional consideration for the impact of extreme heat as it relates to air travel is the inability of flights to take off in Peel or in other regions coming into Peel. Other considerations include higher fuel expenses and the disruption to supply chains of food and other amenities as a result of disruptions in flights (Bartle et al., 2021; ICAO, 2018; PIEVC, 2014). With regard to marine transportation, as there are minimal installations in the region (Region of Peel, 2017, p. 23), it is important to evaluate the impact of high temperature on stationary installations in consideration of leisure and residential activities as prioritized for economic growth of specific neighbourhoods and business areas (Harris, S. et al., 2016).

With regards to corridor infrastructure, studies in the United States and other regions around the world have shown that high temperatures lead to more rapid degradation of paved surfaces. This is worsened by a greater range of temperature variations for the summer, autumn, and winter seasons (IPCC, 2012; Jaroszweski et al., 2013; Meyer et al., 2014).

The rail paths' vulnerability to the impact of climate change is related to both the tracks themselves as well as underlying structures on which the tracks are placed. As stated earlier, it is also important to consider the impact on operational viability as a result of higher temperatures (Brinckerhoff, 2014). Buckling of rail tracks in summer must therefore be monitored and remedied for consistent operational activities.

Another consideration for corridor infrastructure is the impact of high temperatures on the runways at Pearson International Airport as well as Hamilton International Airport. The latter is not located in Peel Region but the strategic goods movement plan highlights its importance for companies located in the region (Region of Peel, 2017, p. 20); it will be important to monitor and maintain runway surfaces in light of consistently high temperatures. This is in addition to maximum takeoff weight considerations as a result of consistently high temperatures (Coffel et al., 2017).

In summary, mitigating the impact of high temperatures on working conditions and the condition of infrastructure is critical to developing greater resilience. The range of temperature variation is now a significant concern which brings us to the third critical hazard consideration: freeze-thaw cycles and erosion within the system.

2.3 Impact of Erosion and Freeze-Thaw Cycles on Infrastructure and Dependent Systems

Erosion is a major concern arising from various weather patterns related to climate change. Molarius (2014) highlighted the role of increased precipitation in creating a steady increase in erosion that evolves into more serious issues in a transportation system (Molarius et al., 2014). A 2014 report on key issues faced by transportation systems in the United States highlighted the impact of erosion resulting from excess precipitation both during regular operational maintenance and during construction of new infrastructure additions (Meyer et al., 2014, pp. 17–19). A 2021 report published by Feltmate and Moudrak raised the issue of flood-related erosion on Canada's urban infrastructure with the conclusion that planning for increased levels of resilience measures need to be undertaken (Feltmate & Moudrak, 2021). One critical erosion related problem highlighted is the issue of scouring – a slow degradation that could affect the viability of key pathways especially in proximity to key installations such as bridges (Camp et al., 2013, p. 364; Meyer et al., 2014, pp. 66–65). Ness et al. also raised similar concerns about the exposure of Canada's roads and railways to increased levels of erosion as a result of increased precipitation where, in some cases, entire sub-sections could be untenable for traffic flow due to weakening of the road and rail track foundations (Ness et al., 2021, pp. 42–43). In summary, erosion is expected to accelerate due to both intense precipitation events such as sustained rainfall of various duration, and also due to scouring which could gradually weaken many key points.

Another source of erosion is the cracking of paved surfaces and key rail infrastructure due to the freeze-thaw cycle, coupled with increased precipitation (Palko et al., 2017, pp. 279–280). Considering the site and situation in Peel Region, the number of cycles is expected to decline in number. However, with the higher-than-expected precipitation concurrent with freeze-thaw cycles, the intensity of degradation is expected to become more costly (Kwiatkowski et al., 2020; Meyer et al., 2014). The damage is caused by seeping of precipitation into the underlying soil of the road and underneath the tracks; the water then expands during winter in freezing conditions and the consequent melting of the ice to water is expected to lead to greater maintenance costs due to the subsequent erosion (Brinckerhoff, 2014, pp. 280–282). A study undertaken on Dutch roads raised an interesting question about whether the key is to develop resilient infrastructure at the design phase or whether it is better to undertake reactive measures once the extent of potential damage becomes clearer. Considering the broad network of roads in the Peel Region, it will depend on how critical a path is to movement patterns or if there is a lack of alternative routes (Kwiatkowski et al., 2020).

The impact of freeze-thaw cycles compounded by increased precipitation is also a concern for the future resilience of the rail system in the Region of Peel. The rail system is a key part of the transportation network in the region and is a critical part of future economic growth planning (CPCS, 2018; Kataure, 2021; Region of Peel, 2017). It is also important to monitor the impact of erosion from freeze-thaw cycles and higher precipitation on critical rail and road infrastructure (Woudsma et al., 2017).

In summary, erosion-related hazards are expected to increase with consequent costs in maintenance and monitoring to prevent any form of disruption to the transportation system.

2.4 Compound Extreme Events

Recent and past IPCC reports have raised the issue of more extreme compound events because of climate change (Auld et al., 2016; IPCC, 2012, 2021). Considering the projected changes in weather patterns in the Peel Region (Auld, 2016), such compound extreme events are expected to occur here as well. These events will test the capacity of national, provincial and local governments to respond to disasters affecting the transportation system and to develop a rapid recovery plan (IPCC, 2012, pp. 118–122, 2021, pp. 11–12). Drawing on an examination of projected weather patterns, it is likely that the Peel Region will experience similar intensifying concurrent weather patterns leading to the need for preplanning for critical services to residents and services. The cascading impact on the sector due to compound extreme events is due to the systemic nature of modern commercial activity in general and the intermodal transportation sector in particular. For example, it is important for the region to plan for water availability and cooling centres for workers in the transportation sector as more frequent extended heatwaves are expected to occur (Auld et al., 2016, pp. 9–11). Another example would be that in the case of intense flooding leading to blockage of traffic, this could hamper transfer of critical commodities such as fuels which could worsen the severity of the incident (AECOM, 2017, pp. 10–11). Other considerations include whether power outages in key areas leads to lag in recovery of operations and economic damage to commodities being transferred (Stone et al., 2021).

The impact of precipitation on the handling of vehicles, trains, and even aircraft is also a concern for various regions in Ontario (Meyer et al., 2014; Woudsma et al., 2017). With several critical highways that pass through the region, it is important to consider the impact of water levels on the surface as it affects the transportation equipment and worker welfare. It is also important to consider the consequent impact that any resulting disruptions could have both on traffic and on the businesses relying on timely transportation (Anderson et al., 2019; CPCS, 2018). In summary, compound extreme events are an increasing risk and the impact on the intermodal goods transportation system is expected to become more profound with the expanding economy and population.

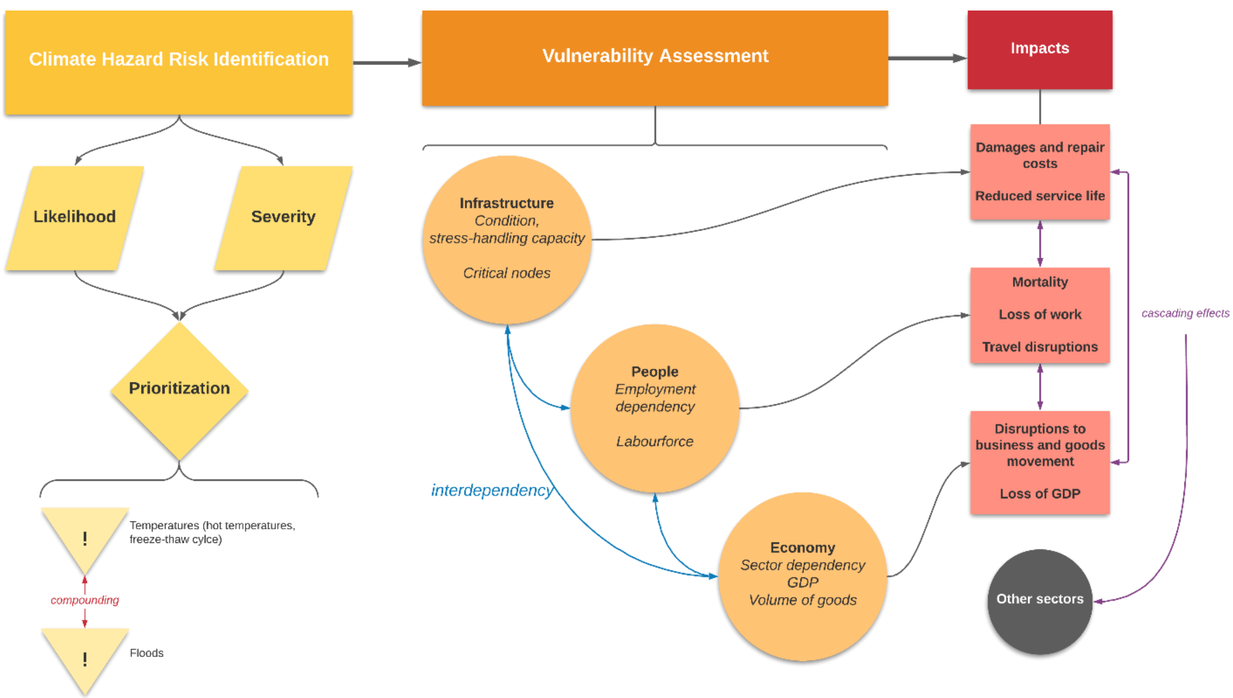
3 Proposed Framework and Data Requirements

The proposed framework draws from multiple studies with differing mechanisms to examine the consequences of climate change on the transportation system. One common conceptual foundation for a number of studies is that the site and setting of the region being examined influence the ultimate priorities for the assessment of risks (Brinckerhoff, 2014, pp. 3–4; Meyer et al., 2014, pp. 8–9). Peel Region is a key population centre of the Greater Toronto Hamilton Area as well as an area with diverse, high-value economic activity (CPCS, 2018; Kataure, 2021). The region is critical for transportation and distribution of various commercial and consumer goods in the broader Great Lakes Basin. It is estimated that around $1.8 billion worth of goods is transferred through the region every day (Region of Peel, 2017, p. 10). Any disruption to the movement of goods could have significant consequences to the livelihood of people and the economy both in the region and at the national scale (Anderson et al., 2019; CPCS, 2018; Ness et al., 2021, pp. 42–50).

In line with these considerations, the proposed framework seeks to assess risks from three perspectives: the impact on infrastructure, people, and broader economy (see Figure 1). The proposed framework will draw on an analysis of the most likely climate hazard risks that could affect the system based on the projected changes in weather patterns in the region over the coming decades due to climate change (Auld et al., 2016; Harris, S. et al., 2016). A version of the framework was presented at an expert workshop with participants from the Peel Region, CVC, and TRCA. Key suggestions and critical feedback have been integrated into the refinement of the framework. See Appendix A for a summary of workshop participants and highlights.

Figure 1

Proposed Assessment Framework



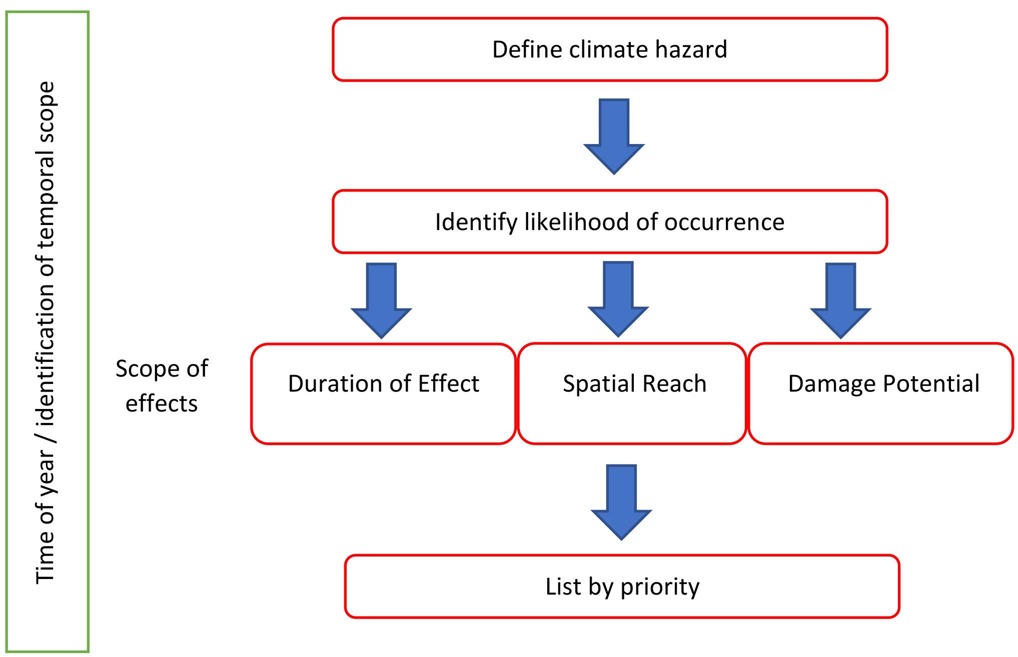
3.1 Overview of Climate Hazard Risk Identification

The prioritization of climate hazards depends on the likelihood of frequency and the potential severity of events (Chang, Ortega & Weidner, 2021). The changes in weather events of concern were identified in the literature, including previously published research and IPCC assessment reports. Based on Peel Region's site and context, the primary areas of concern include increased number of days with heatwaves, more extreme precipitation, and higher chances of flooding and erosion (Auld et al., 2016; IPCC, 2021, pp. 19–21, 41–43; Kwiatkowski et al., 2020; Region of Peel, 2018b, p. 13).

The first stage of the climate hazard risk identification is to identify potential climate change related scenarios. This assessment can be drawn from climate change weather patterns as projected by studies commissioned by the Peel Region and both the provincial and federal governments (Auld et al., 2016; Environment and Climate Change Canada, 2018). The next stage is the identification of priority climate hazards for the goods movement sector. Based on a 2014 assessment developed to examine the impact of extreme weather on European transportation networks, the hazard prioritization process is represented in Figure 2 (Molarius et al., 2014, p. 193).

Figure 2

Climate Hazard Prioritization Process



The process begins with listing potential climate hazards. The next stage is to analyze the likelihood of occurrence followed by an assessment of severity as measured by duration, spatial reach and damage potential under climate change scenarios versus a baseline year (Chang et al., 2021; Molarius et al., 2014). The steps to consider in defining these three aspects of key climate hazards are as follows:

- **Duration of Effect:** This refers to the duration, in days or hours, that each hazard under consideration may be present. The metric is the duration the resulting impact is expected to prevent immediate recovery and resumption of normal activity (Evans et al., 2020; Woudsma et al., 2017).
- **Spatial Reach:** The key outcome of this step is to enable the projection of the likely extent of areas affected by the climate hazard. This step will ultimately allow the identification of critical nodes along the road and/or rail system, and the infrastructure that should be assessed for resilience and adaptive capacity (Chang et al., 2021). Further study should investigate the consequences on the supply chain at both ends, as well as the impact on communities affected by disruption to the flow of goods and commodities (Becker et al., 2018; Ness et al., 2021).
- **Damage Potential:** The framework should be able to quantify damage in terms of the repair and replacement cost, and the potential economic damage due to disruption of movement which could divert and delay delivery. This draws from previously developed studies which stressed the importance of considering the impacts of climate change hazards on an entire system rather than focusing on individual aspects of infrastructure (Beheshtian et al., 2018; Molarius et al., 2014).

As stated, impacts and damage potential caused by changes in duration of a climate hazard event and spatial reach will vary by the infrastructure under consideration. While assessing the potential damage and duration of effect on the components of infrastructure, the time of year should also be included in considerations of the extent of damages, since this will have bearing on post-event remedial action (FCM, 2020; Ness et al., 2021; Region of Peel, 2018a). Once priority hazards are identified, the consequent cost of disruption can be assessed with greater accuracy (Molarius et al., 2014; Woudsma et al., 2017, pp. 160–164).

The data required for this assessment can be drawn from prior studies and existing government and private databases. For example, in 2021, Metrolinx published a Climate Change Informed Data standard to guide the use of available climate change data such as in the design of infrastructure assets to account for expected stresses caused by climate change (Metrolinx Design Standards, 2021). Based on the Representative Concentration Pathways (RCP) from the IPCC's Fifth Assessment Report that were available at the time of formulating the report, the standard suggested the use of the RCP 8.5 (high carbon) scenario, while other scenarios may be included as reference. These include:

- RCP 2.6: a very low emissions pathway with substantive reduction in greenhouse gases
- RCP 4.5: a low–intermediate emissions reduction with a peak by 2035 and stable concentrations at the end of the century
- RCP 6.0: a high–intermediate emissions pathway where the peak is attained by (approximately) 2060
- RCP 8.5: a high emissions pathway with increase in emissions with no substantive mitigation efforts

These scenarios were updated in 2021 with the sixth iteration of the assessment report by the IPCC as the Shared Socioeconomic Pathways which define the various approaches that could be taken in tackling climate change – from SSP 1 to SSP 5 ranging from a robust approach to tackling climate change to a fossil fuel focused economic development (IPCC, 2021). Each of these scenarios, alongside worldwide efforts in emissions reduction (or, in the case of RCP 8.5, no discernable effort) require different planning processes for the resulting impact on the goods movement system in the Peel Region (Ness et al., 2021, pp. 21–27). It is important to establish the select scenarios for analysis. As Ness et al. outline in the report on the expected costs of climate change and according to the Metrolinx data standard, it is then important for the planning process to establish the likely extremes of each possible hazard under different scenarios.

While historical data is readily available from the federal government's weather databases, other relevant projected data is available from these additional databases:

- Climate Atlas of Canada
- Climate Data for a Resilient Canada
- Ontario Climate Data Portal (York University)
- Ontario Climate Change Data Portal (University of Regina)

TRCA Flood Maps can be a critical part of the data collection process if the climate change projection leads to defining the increased extent of areas at risk is incorporated. The next step would be to extract data from the sources outlined and assess applicability to develop projections under the selected SSP-RCP scenarios. As stated in the outline of this initial stage of the framework, each hazard will then be assessed in terms of severity, which is determined based on duration, the projected area of effect, and intensity.

3.2 Vulnerability Assessment

The degree of impact from climate hazard events will depend on system vulnerability. The proposed framework identifies three key areas of potential vulnerability, infrastructure, people, and businesses. The priority climate hazards identified in stage 1 are examined in relation to these three areas. Vulnerability assessment as applied in this context requires an assessment of the condition of the intermodal transportation system and capacity of the system to fulfill the required functions during periods of increased stress (BCMOTI, 2020; Beheshtian et al., 2018; Kwiatkowski & Chinowsky, 2017).

Transportation Infrastructure

Transportation infrastructure refers to a collection of sub-systems that enable seamless movement of goods and people (Abulibdeh et al., 2015). Within the system there are critical nodes which are and will become increasingly vulnerable to climate change risks (Auld et al., 2016). The impact of a single event in one aspect of the system can result in cascading impacts on the overall stability and predictability of the region's economy (Ness et al., 2021; Schwartz et al., 2014; Schweikert et al., 2015).

As discussed, impact will be assessed based on the physical infrastructure, the people working in the system or benefiting from its function, and the businesses that rely on the goods transferred. Each of these three components will be represented by specific measures relating to significant risks for that component; for example, flood maps will be combined with road and rail pathways to extrapolate the points of greatest likelihood for disruption by flood to movement. The data to be collected and the prospective processes for the collection of data are expected to vary accordingly (Brinckerhoff, 2014; Schwartz et al., 2014). Costs to consider include direct damages due to adverse events and those associated with lost productivity, impacts on livelihoods, or business disruption. While more difficult to quantify, subsequent iterations of the framework should consider indirect costs and costs of cascading effects.

3.3 Assessment of Intermodal Transportation System Pathways

The primary transportation systems with which this framework is concerned are the road and rail systems, since the majority of goods movement in the Peel Region relies on these two modes (Region of Peel, 2017, pp. 10–17). As stated, the key exposures of the road and rail systems are to floods, heatwaves, and erosion. The consequences of these weather-related hazards could be compounded by the volume and nature of goods being moved (Chinowsky et al., 2019; Woudsma et al., 2017). The measurement of what could lead to higher levels of loss to the region also varies by the nature of the road or railway. For example, concerns have been raised about flooding on roads leading to Pearson airport (PIEVC, 2014; Woudsma et al., 2017) where various modes of a transportation system converge which must be monitored for cascading impacts on the region's economy (Meyer et al., 2014; Ness et al., 2021). The data collection for the proposed framework first examines the unique requirements of assessing road/railway corridor vulnerability and then examines how best to assess key facilities other than corridor infrastructure.

3.3.1 Assessment of Rail Corridors

The rail network in the Ontario corridor that passes through Peel Region is particularly important as it carries the bulk of vital commodities such as petroleum, coal and wheat to and from various markets in Northeastern North America (Anderson et al., 2019;

Region of Peel, 2017, p. 17). One key concern is flooding on stretches of track, causing short-term disruptions of movement and long-term degradation of the foundations of the track due to erosion (Wang et al., 2020; Woudsma et al., 2017, p. 163). As stated previously, this erosion can result from flooding due to high precipitation during various times of the year (Feltmate & Moudrak, 2021; IPCC, 2012; Ness et al., 2021). Another concern for the stability and longevity of rail pathways is the impact of increased high temperature days (Auld et al., 2016, pp. 42–50). As has been shown in various studies, hot temperatures can cause buckling of rail (Brinckerhoff, 2014, p. 4; Woudsma et al., 2017, p. 162).

Figure 33

Peel Region Rail Corridors

Source. Region of Peel Public Information Database (https://data.peelregion.ca/datasets/railway)

To assess the impact of climate change related stressors on the rail system in the region, the following mechanism for mapping and codifying knowledge related to vulnerabilities is proposed.

Table 1

Assessment of Rail Corridor Vulnerability

Step #	Activity to be undertaken	Expected Data Source
1	Map the primary cargo rail paths	CN Rail, Canadian Pacific Railway, Metrolinx
2	Identify highest density and risky cargo paths	Movement of Dangerous Goods Report; CN Rail, Canadian Pacific Railway
3	Map flood zones – related to waterbody overflow and under-capacity of storm dispersal systems	TRCA flood maps, GTHA
4	Assess frequency and intensity of flooding under selected climate change scenarios	
5	Combine flood maps with the cargo rail paths	
6	Assess frequency and duration of heatwaves under selected climate change scenarios	Climate Change focused data websites mentioned previously
7	Determine heat related vulnerability of track sections; identification of sections of track likely to undergo buckling under selected climate change scenarios	CN Rail, Metrolinx
8	Identify key junction points – track change points, road crossings, bridges; combine with assessment of stationary infrastructure	Peel Region, CN Rail, Metrolinx
9	Develop a composite map showing points of highest risk of degradation (erosion, physical damage) of rail pathway and disruption of movement across various seasons	

The final outline of the key risk points in the rail system should include key installations and components of the road system and the proposed analysis of stationary facilities.

3.3.2 Assessment of Roads

The hazards for road pathways are similar to the previously mentioned concerns for rail pathways. However, one slight advantage that roads have versus the rail system is the availability of alternative routes within the region which can be used to bypass adversely affected areas (CPCS, 2018). Nonetheless, certain routes, especially highways, are expected to be more densely used than others and it is unlikely that intermodal goods hauling trucks would be able to divert en masse at short notice (CPCS, 2018; Region of Peel, 2017, p. 16; Singh, 2018).

As with rail paths, the roads in Peel Region are vulnerable to the cumulative impact of increased precipitation causing floods and affecting safe movement, and erosion affecting the viability of the road structure (Brinckerhoff, 2014; Meyer et al., 2014; Schweikert et al., 2014). There is an expected increase in the frequency of flooding which will affect not just the movement of goods but also the consequent pressures on maintenance crews and equipment (Brinckerhoff, 2014, p. 5; Woudsma et al., 2017, p. 157). Erosion resulting from freeze-thaw cycles and increased precipitation and flooding is also a major consideration for any assessment process to monitor the health of the region's roads (Kwiatkowski & Chinowsky, 2017; Woudsma et al., 2017). A further issue to monitor is the potential impact of extended heatwaves during summer months on the road surfaces (Ness et al., 2021, p. 18; Woudsma et al., 2017, p. 157).

To assess the impact of climate change related stressors on the road system in the region, the following process is proposed. This process is also applicable to roads leading to critical stationary facilities such as Pearson and the CN Brampton Yard as well as critical commercial warehouse complexes in the region. The resilience of these key facilities also relies on the road system connecting them to the highways and local road systems (Anderson et al., 2019; CPCS, 2018, p. 17).

Table 2

Road Vulnerability Assessment

Step #	Activity to be undertaken	Expected Data Source
1	Map the road system	Peel Region Database

2	Identify key paths taken by intermodal cargo vehicles	Peel Commercial Vehicle Survey Report
3	Identify key facilities – parking and rest areas, airport, warehousing complexes, bridges both public run and private	Same as above
4	Map flood zones and combine with key cargo paths	TRCA flood maps
5	Assess frequency and intensity of flooding under selected climate change scenarios	
6	Collate and identify road maintenance reports: surface and foundation damage, culvert capacity	Emergency and service crews
7	Identify points of accidents by month of the year and list type and insured damage reported (Note: important to classify damage related to human error and damage related to road system)	Same as above; Insurance companies
8	Interpose damage and accident reports with map of key paths combined with flood mapping	
9	Project frequency and severity under various climate change scenarios	

A key part of the assessment process is to define the criticality and redundancy of the various roads in the region. This would need an assessment of the types of goods moved, traffic at specific intervals, and proximity to critical infrastructure. The contribution of this analysis is, with the assessment of the rail pathways, to identify key points of concern throughout the intermodal goods transportation network. This follows steps undertaken in other previous research studies and government reports that sought to identify the cost-benefit analysis mechanisms of reinforcing goods movement against expected impacts of climate change (Meyer et al., 2014; Schweikert et al., 2014). The assessment of corridor viability under varying climate change related scenarios is important especially considering the myriad of stationary components which are a key part of the intermodal goods transportation system in the region. The roads leading to such installations, especially Pearson International Airport and CN Brampton yard, are particularly critical (CPCS, 2018; Woudsma et al., 2017). The next stage of the framework seeks to understand the vulnerability of the stationary components themselves.

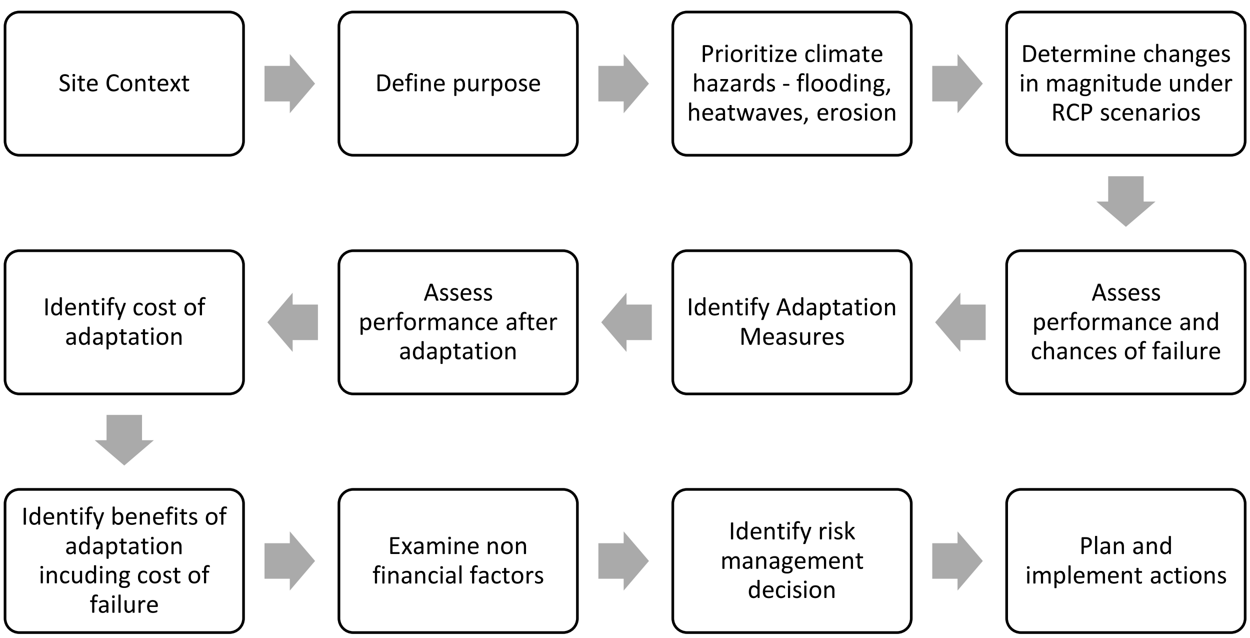
3.4 Assessment of Intermodal Goods Transportation System Installations

The installations related to the intermodal transportation system can be divided according to purpose: storage, transfer, and redistribution. Then there are facilities associated with the initiation of movement of goods as well as receipt of goods for local businesses of varying sizes (Anderson et al., 2019; CPCS, 2018; Singh, 2018). With Peel Region being such a critical part of the logistics of the whole of Eastern Canada (Region of Peel, 2017, p. 9) means that the region hosts critical stationary infrastructure points that warrant constant and dynamic vigilance in monitoring risk related to climate change (Anderson et al., 2019). The storage of goods is a particularly important aspect of the goods movement infrastructure in the region and includes both privately and publicly owned facilities such as large company warehouses and the Brampton Intermodal Terminal (Region of Peel, 2017, p. 9; Singh, 2018). The transfer of goods takes place at these storage points and also at key offloading points, including the airport. The directing of goods movement is also done through various junctions and intersections which connect the United States and international markets to key Canadian towns and cities (Anderson et al., 2019; CPCS, 2018). In addition to purpose-built facilities, each has attached facilities such as parking and access roads leading to the facilities that need to be part of any assessment. In addition to these facilities, there are 176 bridges and large culverts that need to be monitored for adaptation and resilience to adverse climate change related stressor events (Harris, S. et al., 2016; Ness et al., 2021; Region of Peel, 2018a).

Flooding affects both the facilities themselves and the pathways leading to them. Flooding could also affect the commodities stored and the specialized equipment needed for the functioning of facilities (Ness et al., 2021). Flooding and waterlogging could result in increased erosion and degradation of facilities, affecting optimal functionality, particularly of bridges at key intersection points along rail and road pathways (Ness et al., 2021).

The ability of key road and rail facilities to be able to tolerate sustained heatwaves is a further area of concern. Heatwaves could affect the energy costs of running these facilities and the people working in them. This section outlines a proposed framework to monitor the physical viability of facilities to withstand sustained heatwaves in terms of design limits and goods condition (Meyer et al., 2014, pp. 47–50; Woudsma et al., 2017). This framework is drawn from a previously published report on assessing infrastructure adaptation measures for the United States Department of Transportation and focused on the Gulf Coast of the United States (Brinckerhoff, 2014). A number of refinements are proposed for this framework that have been drawn from the Public Infrastructure Engineering Vulnerability Committee (PIEVC) model, which has been in use since 2008 for assessing key infrastructure facilities in Canada, such as the Pearson airport (PIEVC, 2014; Woudsma et al., 2017, pp. 168–169).

Figure 44



Note. *Assessment and risk management of stationary components of intermodal goods transportation*

The data needed for the above assessment can be collected from a variety of government, industry, and academic databases. Bridges and culverts which are part of the rail and road network are stationary components for which data can be collected from Peel Region's transportation department or other transport companies such as CN Rail. Loading and offloading facilities such as the CN Brampton Yard fall under CN rail. The problem with large facilities such as CN Brampton Yard and Pearson International Airport, as outlined in an assessment of Pearson International Airport, is the multi-jurisdictional nature of the actions needed to alleviate impacts: for example, worker training to deal with sudden flooding, additional electricity used to maintain passenger health during heatwaves. This means that data collection will be needed across functions and agencies. This will most likely require a centralized assessment team composed of representatives from various government departments for easier access to information (PIEVC, 2014, pp. 8–9). Another key part of the intermodal goods transportation system in the region is the presence of critical privately owned company warehouses such as Nestle, and Molson-Coors, which need to be evaluated in terms of access roads and any other barriers to operation as the impacts of climate change continue to manifest (CPCS, 2018, p. 83). Data collected for these commercial facilities will most likely involve significant outreach with company representatives who are aware of the benefits of developing sustainability, resilience, and adaptation measures (Bateman & Lee, 2021; Becker et al., 2018).

3.5 Key Output of Physical Infrastructure Assessment

The intermodal goods transportation system in the Peel Region is vital not just for the region but also for the Eastern Canadian economy as reflected by goods transferred per day, percentage contribution to national goods movement GDP, etc., and thus any disruption would be detrimental (Anderson et al., 2019; Region of Peel, 2017, pp. 10–11). One key impact that the outlined framework seeks to assess is related to the damage and repair costs for infrastructure. Another key impact is understanding potential reductions in the expected service life of a given component. The monetary consequences are compounded by how critical a particular node or corridor is within the region's intermodal transportation system, especially if alternatives are not available (Beheshtian et al., 2018; Ness et al., 2021, p. 9). This means that even beyond the calculation of frequency and severity of impact, there could be cascading consequences on the other two key foci of the framework: people who work in the goods movement sector and businesses that rely on its proper functioning (CPCS, 2018; Singh, 2018).

3.6 Assessment of Impact on People

Several researchers have investigated the welfare of people connected to an area that will undergo rapid changes in climate, affecting living conditions and economic growth. In this report, the focus is on monitoring the welfare of people who are connected to and work in the intermodal transportation system in the Peel Region. The goods movement industry is stated to account for 43% of jobs in the Peel Region with an estimated $29 billion in wages and salary income (Region of Peel, 2017, p. 10). The general impact of adverse climate change events will also affect the welfare of people dependent on the sector, ranging from shoppers in local supermarkets to workers in car manufacturing throughout the Great Lakes Basin (Anderson et al., 2019; Singh, 2018; Zeuli et al., 2018). For the purpose of this report, the data collection and consequent analysis will be restricted to workers and personnel directly involved in the intermodal transportation system.

People working in the goods movement sector include those involved in the direct transportation of goods including drivers, operators, and loaders and the varied supporting functions both in the private and in the public sector related to intermodal transportation, such as workers employed at storage warehouses and transit facilities (CPCS, 2018; Region of Peel, 2017; Singh, 2018). In addition, there are workers involved with the construction and maintenance of key transportation installations necessary for the operations of the transportation system (Meyer et al., 2014; Schwartz et al., 2014). To populate this component of the framework, the following data collection is proposed:

Table 3

Workforce Impact Assessment

Data	Purpose for collection	Potential sources
Transportation workers – rail	Identify workforce involved in direct transportation of goods	CN Rail, Metrolinx

(non-maintenance)		
Transportation workers – rail (maintenance and emergency crews)	Identify at risk workforce in case of adverse events	CN Rail, Metrolinx, Provincial services
Truck operators	Identify road intermodal transportation focused workforce	Company association, Peel Database
Goods handling facility (CN Brampton Yard, Pearson)	Identify workforce related to various publicly run road/rail paths and facilities	CN Rail, Metrolinx, Pearson Airport Authority
Warehouse staff and frontline workers	Identify workforce in warehousing – directly involved in logistics	Companies*NAICS data available up to 2018

The data collected needs to identify the demographic makeup and the ability to access community health and social services which will be critical to dealing with physical and mental health impacts of increased adverse events as a result of climate change (Paterson et al., 2012). Climate change related adverse events are expected to increase in frequency and severity leading to increased mortality, especially among emergency crews (Meyer, 2014) and among frontline staff working in the logistics sector due to infrastructure failure (Brinckerhoff, 2014; Ness et al., 2021). The workforce may also be impacted by productivity loss or travel disruptions which will inform the broader economic impact assessment.

3.7 Assessment of Impact on the Economy

The goods movement sector is critical not just for the region but also because of the consequences for the organizations that rely on timely transfer and delivery of goods. This ranges from the food sector to large car manufacturers in the Great Lakes Basin, many of which currently don't have sufficient capacity to withstand disruptions to the supply chain (Anderson et al., 2019; CPCS, 2018; Singh, 2018; Zeuli et al., 2018). This framework proposes to assess risks to regional economy by combining the hazard maps for assessing the physical risk to infrastructure with the site characteristics of sector related businesses in the region. This is important to analyze and identify the key nodes for the transfer of goods and services which could have an immediate impact due to disruptions in operations (Beheshtian et al., 2018; Region of Peel, 2017). An additional data consideration is the proportion of cargo passing through the region to other areas in the Great Lakes Basin. A previous examination of such cargo found that there is a concentration of movement through the Peel Region by virtue of its centralized location (Anderson et al., 2019, p. 79). This means that disruptions to movement in this location could result in backlogs affecting movement in jurisdictions well beyond the region. The proposed data collection process is as follows:

Table 4

Economic Impact Assessment

Step #	Activity to be undertaken	Expected Data Source
1	Layout of rail and road maps for high density cargo transfer	CN Rail, Commercial Vehicle Survey Report
2	Identify key goods transfer points in the region	CN Rail, Canada Pacific Railway
3	Identify critical warehouses in region	Industry association, NAICS data from Peel Region Database
4	Classify commodities transferred as for end use or for storage for later transfer	Survey of warehouses, companies
5	Integrate flood maps and assess changes in flood prevalence under varying climate change scenarios	TRCA
6	Assess frequency and severity of high temperature days	Peel Region Climate Projections
7	Identify preparedness for consistent high temperatures – commodities & workforce	Survey of warehouses and storage points
8	Map potential risks in terms of loss of goods and increased costs of maintenance	

9	Estimate potential delays due to adverse events by value of goods affected

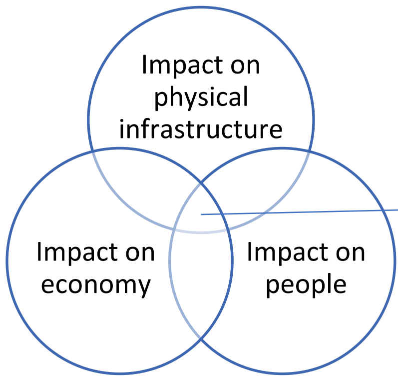
The primary data collection process is expected to lead to a significantly updated picture of two critical measures: expected average time delays of goods movement due to various climate hazards and the magnitude of lost value addition because of these hazards. This will enable the estimation of the potential impact of vulnerability to the consequences of climate change: disruption to businesses and loss of GDP in the Peel Region (Beheshtian et al., 2018; Schweikert et al., 2015).

3.8 Cascading Economic Impacts of Climate Change

The intersecting impacts of climate change related stressor events have a multiplying effect when any disruption or delay in one component of the system affects the timely transfer of goods and services. This is especially so considering the region is itself such a critical node in the movement of goods and services in the Great Lakes Basin and St. Lawrence region (Anderson et al., 2019; CPCS, 2018; Region of Peel, 2017; Singh, 2018). The importance of value chains, as they affect the viability of a region's economy as well as the welfare of the people living and working in the area, was an area of concern even before the current COVID-19 crisis. The primary concerns were availability and sustainability of the sourcing of consumer commodities as well as input for critical industries (Bateman & Lee, 2021; Becker et al., 2018). The data previously collected enables an assessment of an aggregate value at risk within the region's supply chains, supporting predictions around the larger value chain at stake as the climate change related adverse weather events begin to intensify (AECOM, 2017; Beheshtian et al., 2018).

Figure 55

Cascading Economic Impact Assessment



Cascading impact at intersection of 3 components of the framework results from:

i. Goods transferred at risk
ii. People's livelihood – income, health, family welfare at risk
iii. Value of further production / services at risk
iv. Consequences of reduced capacity of interconnecting transportation infrastructure
v. Remedial and replacement cost of equipment and infrastructure – public & private

An assessment of the cascading impacts can be derived from the data outlined above which should be collected as part of the impact analysis of each individual component. The estimation of the multiplied consequences can be made by identifying the portion of the sector that is directly connected to further economic activities after the goods move from the region to where they are expected (CPCS, 2018; Region of Peel, 2017). Should the goods be delayed or disrupted, the economies of other regions around the Great Lakes Basin will be affected (Anderson et al., 2019; Beheshtian et al., 2018). Added costs may be incurred due to the consequences of damage or loss in transit resulting from degraded infrastructure facilities which receive the transfer of goods (Ness et al., 2021; Woudsma et al., 2017). Another concern is the replacement and reinforcement of key infrastructure components whether under government or private ownership because of the climate change related degradation (BCMOTI, 2020; Ness et al., 2021; PIEVC, 2014; Woudsma et al., 2017). In summary, the economic impact is not simply related to the direct losses from disruption, but also the consequent economic impacts on supply chain entities - personnel, companies and physical infrastructure.

4 Recommendations for Future Consideration

4.1 Data and Research

- Consult and revise as appropriate Intensity-Duration-Frequency curves to reflect rapidly changing trends in rainfall events; consider opportunities to integrate future climate projections or different data sources (e.g. radar data to supplement rain gauges)

- Develop a plan to extend assessment of potential changes in rainfall events to Greater Toronto Hamilton Area to be able to assess system wide vulnerabilities
- Undertake scenario analysis to understand compound impacts of multiple events (e.g., flooding and extreme heat)
- Undertake scenario analysis to understand the potential cascading impacts of major climate hazard events
- Research benefits, risks, and potential impacts of emerging technologies that have potential to disrupt transportation sector including, for example, autonomous transportation, drones, and AI; an assessment of how climate change may affect these technologies should also be undertaken
- Explore the impacts of climate hazards on the increased likelihood of spills
- Investigate the risks of climate hazards and resiliency levels of existing infrastructure to industry attraction and/or potential loss; conversely, investigate leadership and growth opportunities as a result of climate action
- Develop a process to collate data assess the conditions of current road and rail bridges which are part of the intermodal transportation network as well as data need to enable specific key capacity increases in the design of new ones.

4.2 Model Considerations

- Integrate health impacts of higher temperatures and flooding
- Integrate impacts on EMS response, crime, and accidents associated with flood events
- Consider consequences of just-in-time delivery business models, especially for critical goods
- Integrate impacts on increasingly prevalent "gig economy"
- Integrate impacts on novel infrastructure nodes, such as EV charging stations
- Complete an inventory of economic costing studies and methodologies

4.3 Policy and Planning

- Disclose climate change risks affecting existing and proposed infrastructure

- Introduce infrastructure standards, such as low-impact development, informed by research into climate change and its risks; standards should reflect a minimum 30-year projection period of future climatic conditions
- Integrate a wide variety of urban nature-based climate solutions into mainstream practice and infrastructure planning for multiple co-benefits and greater resilience
- Advance 'climate lens' capital and a program spending budget tool which includes life cycle costing
- Advance circular economy efforts in the Peel Region with emphasis on the goods movement sector; look to regional examples including City of Toronto and Guelph as well as global examples in the Netherlands and South Korea
- Support relocalization of supply chains to reduce the need for long-haul transportation of goods
- Develop a cross jurisdictional and departmental governance structure to manage supply chain risks
- Investigate retrofitting and climate adaptation options for community buildings and goods movement infrastructure

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Appendix A

On November 25th, the project team convened a stakeholder focused workshop to review and provide input to a preliminary climate risk and vulnerability assessment framework. The meeting provided critical in person feedback as well as discussions that affirmed the importance of the framework in helping develop climate change related impact assessment for the intermodal goods movement sector. The workshop was held virtually. An online tool was used to present certain key questions to the attendees. Participation in the form of answers to the questions provided general feedback which could develop into potential avenues for further examination. These have been attached below as notes.

Attendees (position and organization)

- Jeffrey Wilson, Assistant Professor, School of Environment, Enterprise and Development, University of Waterloo
- Muhammed Ahsanur Rahim, Phd Student, School of Environment, Enterprise and Development, University of Waterloo
- Ryan Johnson, Phd Student, School of Environment, Enterprise and Development, University of Waterloo
- Mark Pajot, Advisor, Office of Climate Change and Energy Management, Region of Peel
- Jeremy Schembri, Manager, Office of Climate Change and Energy Management, Region of Peel
- Christine Tu, Director, Office of Climate Change and Energy Management, Region of Peel
- Meaghan Eastwood, Senior Research Scientist, Ecosystem and Climate Science, Toronto and Region Conservation Authority
- Sharon Lam, Research Analyst, Ecosystem and Climate Science, Toronto and Region Conservation Authority
- Gail Anderson, Principal Planner, Regional Planning and Growth Management, Region of Peel
- Judith McWhinney, Regional Economist, Region of Peel

- Sabbir Saiyed, Manager, Transportation System Planning, Region of Peel
- Sabrina Khan, Principal Planner, Transportation System Planning, Region of Peel
- Eleanor Gillon, Specialist, Road Operation Maintenance, Region of Peel
- Christine Zimmer, Senior Manager, Water and Climate Change Sciences, Credit Valley Conservation
- Rehana Rajabali, Associate Director, Engineering Services, Toronto and Region Conservation Authority
- Noah Gaetz, Senior Manager, Ecosystem and Climate Science, Toronto and Region Conservation Authority
- Jennifer Taves, Senior Manager, Partners in Project Green, Toronto and Region Conservation Authority

Question 1:

What climate or non-climate related risks or hazards are you most concerned about in the context of the transportation system?

Answers:

- Backup power and gasoline or diesel supply
- Impact on supply chain, especially in lighter goods moved by GTAA – Pearson International Airport
- Wear and tear on roads and rails due to more extreme temperatures
- Spills/source protection is something I think also needs to be considered – if there is a climate event (icy roads, erosion, flood), the risk of spills increases
- Compound events and interdependent systems
- Governance challenge – businesses and organizations having to manage supply chain risks individually and some without capacity to do so
- Flooding
- Higher temperatures and associated health impacts
- Low-probability, high impact events

- Federal government requires social VA analysis for infrastructure funding (DMAF/INF Climate Change Lens), so it is important to account for that when prioritizing investment. The Risk Tool provides a layer of SVA
- Heatwaves and health related consequences
- Some long-range plans (413) are not fully considering these types of impacts to future lifecycle costs and budgets
- Long term impacts on transportation sector, employment, and risks to Peel residents' livelihood
- Impacts to our transportation infrastructure and the financial needs to address the impacts
- Supply chain disruptions because of severe weather events. As we are observing now, there can be significant economic consequences
- Flooding and erosion
- Safety risks due to climate change to all modes of transportation
- Additional operating costs to respond to climate change impacts
- Washouts (flooding and erosion combined)
- Delivery of goods on time
- Reliance on just-in time delivery
- Human health and safety
- Temperature variability resulting in ice
- Disruption to supply chains – many large distribution centers are in Peel that serve the entirety of Canada e.g. Indigo or Nestle distribution centers

Question 2: What consequences are you most concerned about as a result of disruptions to the movement of goods? (e.g. healthcare systems, food security)

Answers:

- Long-term cascading impacts – think Evergiven (?)
- During the July 8 2013 storm, some major roads were flooded, requiring re-routing, impacting EMS response, in speaking with Municipalities, crime and traffic accidents also increased associating with flooded roads

- Combination of social and economic impacts – could be pivotal to bring resilience to the forefront to demonstrate that it makes business sense in terms of finances
- Disruption to essential services (health, food, water, electricity, etc)
- That we don't lead together (build the Barn) but rather over-invest too much to offset other risks not being addressed by others (e.g. CN rail)
- Peel has some of the largest distribution centers in Peel – disruptions to them can affect supply chain as well
- I am hoping we can look at ways to leverage PCCP initiatives, we have already started to gather good information
- Industry leaving the municipality if infrastructure is not resilient
- Inflation diminishing the quality of life over time
- Production disruptions
- Price surges
- Cost of goods due to disruptions
- Spills/source protection is a concern, as well as EMS considerations should a train/metrolinx track be undermined as was the case on July 8, 2013
- More focus on mitigation given demand up and down supply chain; still hurdle for businesses to recognize ROI of adaptation
- Inflation
- Unknown unknowns
- Pearson international airport – supply to hospitals and other healthcare systems (e.g. covid vaccines); disruption to air traffic would be a big issue for us all
- Same for CN

Question 3: Application of draft framework:

1. Does the framework present a logical flow of how to account for the potential impacts of climate change risks to the movement of goods in Peel Region?
2. Are we missing anything?
3. What data can be used to support this assessment?

Answers:

- What emission scenario and temporal scales are we considering?
- Flexibility to consider different hazard scenarios
- Ability to use the framework for stress-testing existing and new infrastructure
- Work with industries
- Consider three main stakeholders: CN, CP, Rail yard
- Traffic counts and traffic modelling
- Double check presumed data list and available data list
- Durham roads capacity project tweaked probability for future climate
- Disruption is a good metric – e.g. annual average disruption; network disruption; cost of lost trips or lost time
- Direct capital costs (e.g. based on past repair costs)
- Ability to inform infrastructure design and how we build infrastructure
- Consider upstream and downstream dependencies (e.g. transportation relies on electricity, gas, and diesel to operate)

Question 4: What stakeholders should be included in efforts to enhance the resilience of the movement of goods? How might we include them?

Answers:

- Economic Development offices – at both the Provincial and Municipal levels as well as FedDev Ontario – the Federal southern Ontario economic development organization
- Peel Data center
- GTAA
- Supply Chain Canada
- Canada-US stakeholders
- Statistics Canada
- US department of transportation
- Emergency Management
- MTO
- Retail Council of Canada
- Major employers

- Industry (logistics, warehouse)
- Key sectors (food, health)
- CN

  Other local municipalities
- Utilities
- Public Health
- Peel businesses
- Trucking/Shipping companies
- Economic Development Ontario
- Consider the three main stakeholders – CN, CP, Rail Yard
- Insurance industry
- SMEs

Question 5: Do you have any other suggestions moving forward?

No answers