

STANDARDS RESEARCH

# Climate Change Resilience and Adaptation for Public Transit

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# Author

**Nicholas Roberts, P. Eng, MSc.,** CPCS Transcom Ltd.

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# Executive Summary

Canada's climate is changing at an unprecedented pace, with rising temperatures and an increased prevalence of extreme weather events resulting in short – and long-term impacts across the country. Climate change has already caused catastrophic events that have impacted public transportation in Canada, including floods and severe winter storms that have stranded passenger trains, and melting permafrost that is degrading the quality of vital transportation links to northern Canada. Overall, climate change is expected to increase the costs of building, operating, and maintaining public transit systems.

Canada's public transportation sector is also changing in ways that may make it even more susceptible to climate change risks. The trend of decarbonizing public transit systems (e.g., electrification of passenger rail, and electric and hydrogen fuelled zero emission buses) is changing their risk profile. The sector will require increased investment and improved resiliency to manage risks related to electrical power supply and distribution systems, among others.

Transit agencies from across Canada have identified risks related to intense precipitation and extreme heat as the sector's most pressing concerns. These climate stressors can lead to infrastructure damage, operational disruptions, and in the case of extreme heat, health and safety concerns for people (e.g., transit operators, construction workers, maintenance personnel, and transit riders). Both of these climate stressors are Canada-wide concerns that are projected to continue intensifying.

This research report addresses four key questions:

1. What are the top challenges and issues resulting from climate change currently facing Canada's public transportation sector (focusing on passenger rail and bus systems)?
2. How are these challenges expected to evolve over the near – and long-term?
3. How are representatives in Canada's public transportation sector responding in the areas of climate adaptation and improving resiliency?
4. What areas of opportunity exist for the development of standards to help respond to climate adaptation and resiliency needs in Canada's public transportation sector?

The research included a literature review, meetings with representatives from public transit authorities, operators, and related entities across Canada, and two workshops with representatives to present and discuss key research findings.

This report identifies ten areas for further exploration in the context of standards development and climate adaptation, which encompass standardization opportunities throughout an asset or system lifecycle to potentially yield improvements in climate adaptation and resiliency (design and planning, construction, operations, and maintenance) for Canada's public transit sector.



**"Canada's warming trend is approximately double the global average. The observable changes resulting from climate change include ice melts and thawing permafrost in the north, a shorter duration of snow cover, and an increase in precipitation, most notably with more rainfall instead of snowfall [2]."**

# 1 Introduction

## 1.1 Canada's Changing Climate

Canada is experiencing the effects of climate change, with rising temperatures across all regions of the country. Since the 1950s, Canada's average annual temperature has increased by 1.7°C [1]. Temperature change has been particularly evident in northern regions, the Prairies, and British Columbia (BC), where the average annual temperature has increased by 2.3°C compared to 1948 [1].

Canada's warming trend is approximately double the global average. The observable changes resulting from climate change include ice melts and thawing permafrost in the north, a shorter duration of snow cover, and an increase in precipitation, most notably with more rainfall instead of snowfall [2]. Furthermore, warmer air carries a higher moisture content, so higher temperatures can lead to higher intensity rainfall. These changes also affect seasonal events, such as spring thaw and the nature of extreme weather events [2].

## 1.2 Implications of Climate Change to Public Transit

Climate change is a mounting concern across Canada's public transportation sector. There is a need for increased adaptation and resiliency to respond to the challenges of climate change, as highlighted by the following recent events:

- Flooding and landslides in BC leading to train derailments;
- Winter storms in Ontario cutting power to stations and facilities for regional passenger rail service;
- Melting permafrost in Manitoba leading to unstable track conditions along rail lines connecting to rural and remote northern communities; and
- Wildfires in northern Alberta leading to the emergency use of public transit vehicles to support evacuation.

Overall, climate change is expected to increase the costs of building, operating, and maintaining public transit systems, including passenger rail and urban bus systems.

## 1.3 Background and Objectives

In Canada and the United States, there is evidence of a gap in standards to address climate adaptation, as captured in part by the following quote:

> *"Amtrak adheres to standards defined by Federal entities, such as the US Army Corps of Engineers or FEMA floodplain management ordinances, which often do not include requirements for climate adaptation or future conditions." [3]*

The Standards Council of Canada (SCC) published the report, Standards in Action: Building a Climate-Resilient Future [4], which identified gaps in standards, codes, and practices that leave Canadians vulnerable to climate change. The report also identified a significant need for investments in standards to ensure that Canada's infrastructure is climate ready.

Between 2016 and 2021, with funding from Infrastructure Canada, the National Research Council (NRC) led the Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI), with the goal to "provide the knowledge needed to integrate climate resilience into building and infrastructure design, guides, standards, and codes" [5]. The CRBCPI report highlighted a lack of common guidance on resilience for transit agencies that is specific to the Canadian context [6].

With this background, this report addresses the following four key research questions:

1. What are the top challenges and issues resulting from climate change currently facing Canada's public transportation sector (focusing on passenger rail and bus systems)?
2. How are these challenges expected to evolve over the near – and long-term?
3. How are representatives in Canada's public transportation sector responding in the areas of climate adaptation and improving resiliency?
4. What areas of opportunity exist for the development of standards to help respond to climate adaptation and resiliency needs in Canada's public transportation sector?

# 2 Methods

## 2.1 Literature Review

The research conducted for this report included a literature review of publications from industry associations, government reports, and studies from public transit agencies. The literature review highlighted key trends and risks resulting from climate change across Canada, identified key priorities that need to be addressed, and provided information about types of response and risk mitigation efforts.

The literature review included publications from the Canadian Urban Transit Association, the American Public Transport Association, the Transportation Research Board, and the Railway Association of Canada, along with climate vulnerability and risk assessments from a variety of Canadian municipalities and transit agencies. All sources are cited throughout this report and listed in the References section.

Reports such as Canada in a Changing Climate: National Issues Report [7] and Metrolinx's Climate Adaptation Strategy [8] can help bring into focus the key climate-related risks and issues currently facing the public transportation sector, as well as mitigation efforts, particularly in the Canadian context. While Amtrak is the national inter-city passenger rail service provider of the United States, it also runs service into Canada, connecting into Toronto's Union Station and Vancouver's Pacific Central Station. Due to geographical proximity and similarities between Canada and the United States, there was merit to including climate-related passenger rail issues in the United States to better inform this study.

## 2.2 Interested Parties Engagement

The research also included meetings with a selection of representatives from public transit authorities, operators, and related entities across Canada. This engagement supplemented the information gathered from the literature review.

Engagement was prioritized with interested parties who could speak to a breadth of public transit modes under the scope of this study (e.g., transit authorities that have passenger rail and bus operations) and agencies that are leading the transition of their assets to meet zero emission mandates (e.g., leaders in fleet electrification) so the risks of new public transit assets and technologies could be discussed in the context of near – and long-term challenges. A mix of representatives from small, medium, and large transit agencies were also targeted.

**Table 1:** Representatives in the Engagement Process

| Representative Type | Number Engaged |
|---|---|
| City, municipality, transit agency | 7 |
| Provincial ministry, agency, Crown corporation | 3 |
| Federal agency, organization, Crown corporation, regulator | 2 |
| Standards development organization | 1 |

Engagement with provincial authorities was also targeted, in order to understand climate resilience and adaptation issues relevant to road infrastructure, and consequently, bus transportation. Passenger rail transportation generally has dedicated fixed infrastructure (e.g., rail, track) whereas bus transportation relies on the use of shared road infrastructure, which may be under the jurisdiction of municipal or provincial authorities.

A goal of 10 to 15 meetings were targeted, and a total of 13 one-on-one meetings were held. Table 1 lists the types and numbers of interested parties that were represented in the engagement process.

## 2.3 Validation Workshops

To validate the key research findings and the list of top climate-related risks to public transit systems across Canada, two workshops with interested parties were held, one virtually (by invitation) and the second as an in-person workshop organized as part of the Transit Rail Association for Canadian Contractors, Maintainers and Standards (TRACCS) conference held in 2023.

Both workshops followed the format of a presentation of the key research findings followed by a discussion period with poll questions, prompts, and an open discussion. Questions were organized into the following three themes of discussion:

1. What do you view as key climate change risks?
2. What are you doing to mitigate these risks?
3. How could standards support your efforts on climate adaptation?

Attendance at the virtual workshop mostly comprised transit agencies and members of government, whereas the TRACCS workshop included slightly different perspectives from interested parties, such as contractors, who are more involved in the design and construction stages of infrastructure projects.




# 3 Results

## 3.1 National Perspectives on Climate Change

The impacts of climate change do not affect all regions in Canada equally. Section 3.1.1 highlights the key challenges faced by different regions of Canada under specific climate stressors.

### 3.1.1 Climate Stressors across Canada

***Extreme heat.*** Extreme heat events, often called heat waves, are characterized by high temperatures and humidity. Extreme heat events have been increasing over time. Environment and Climate Change Canada (ECCC) works closely with provincial and territorial health authorities to issue extreme heat warnings, which can vary depending on the region. Typically, extreme heat alerts are activated when temperatures reach 30°C or higher for two or more consecutive days, and minimum overnight temperatures are expected to be at least 14°C [9].

Periods of extreme heat in Canada are projected to become more frequent and intense [2]. Extreme heat can impact infrastructure, the natural environment, and people's health and well-being. This has implications for the design of ventilation and air conditioning (A/C) systems (for buildings, vehicles, and equipment), demands on the electrical power grid (brownouts or blackouts due to the increased draw of power for A/C during heatwaves), and the health and safety of workers and the general public.

***Wildfire risk and air quality.*** Prolonged periods of extreme heat can create drought conditions with tinder-like brush and vegetation. This increases the risk of wildfires, which can be started by lightning strikes or human causes (e.g., campfires or vehicle exhausts). In Canada, wildfires are most common in two major areas: southern BC and the boreal forest, which extends from Alaska to Newfoundland and Labrador [10]. However, forested areas throughout the country, such as in northern Ontario and Quebec, also face wildfire risk. Not only do wildfires pose a risk to damaging infrastructure but their smoke also causes poor air quality, which can impact people's respiratory health and the ventilation and cooling systems of buildings, equipment, and vehicles. In recent years, wildfires in western Canada have negatively impacted air quality during the summer months. The City of Calgary reported that smoke hours observed at the Calgary International Airport have increased exponentially over the last 60 years [11]. Transit agencies in western Canada have also noted that the historical wildfire season (May to September) has been extended (April to November). The impacts of wildfire smoke in major metropolitan areas, such as Vancouver, have become an annual concern.

***Severe storm elements.*** Across Canada, the occurrence and severity of storms are projected to increase [12]. Convective storms (thunderstorms) bring the risk of high winds, short-duration high-intensity rainfall, lightning strikes, and hail.

Climate scientists have indicated that hail storms have relatively low predictability because they cannot be



captured in global and regional climate models due to limitations in resolution [12]. However, an increase in atmospheric energy and occurrence of severe weather are likely to increase the probability of large hail events. There is a heightened risk in Canada's hot spots for thunderstorms, particularly the Great Lakes region and southwestern Ontario, as well as some regions in western Canada and Atlantic Canada [13].

Lightning strikes and hail can cause severe damage to buildings and other infrastructure, particularly those that are not properly designed or electrically insulated. Furthermore, high-intensity rainfall can accompany these storms, which brings an increased risk of flooding.

***High winds.*** Atmospheric pressure gradients can form as low-pressure systems that move across the country and lead to high winds and severe storms. ECCC issues severe wind warnings when winds are sustained in the range of 70 km/h or greater, and a severe thunderstorm warning when wind gusts are 90 km/h or greater [9]. Strong winds have the potential to damage infrastructure, down trees and telegraph poles, and cause blackouts due to downed power lines. In addition, strong winds coupled with precipitation can cause poor visibility (e.g., whiteout blizzard conditions due to blowing snow).

There is also a risk of short-duration high-intensity winds storms (tornadoes) forming due to specific atmospheric and geographic conditions [14]. While

the science of tornado formation is not completely understood, tornadoes are most often the result of thunderstorms with persistent updrafts causing wind shear and leading to a rotating column of air. Canada is experiencing more severe windstorms with tornadoes in certain regions of Ontario (e.g., Barrie and Ottawa) and Quebec making news headlines in recent years. These tornadoes have been characterized by wind speeds in the range of 180 to 220 km/h [15].

***Intense or prolonged precipitation.*** Across Canada, annual precipitation has increased by an average of 20% since 1948 [2]. The most significant changes have been observed in northern Canada, Manitoba, Ontario, northern Quebec, and Atlantic Canada [16]. Precipitation is expected to increase in all regions, but at a faster rate in northern Canada [2]. Intense rainfall events are defined when 25 to 50 mm or more rain is expected to fall within one hour, although the downpour threshold varies by region [2]. Flooding is usually caused by short-duration high-intensity rainfall events, which are expected to become more frequent [2]. In addition to flooding, heavy or prolonged precipitation may cause mudslides and washouts [17].

Regionally, along Canada's west coast, the intensity and duration of precipitation can also be affected by atmospheric rivers, which are concentrated bands of moisture carried over from the Pacific Ocean [18]. This weather formation notably led to severe flooding in BC during 2021.

Other precipitation events such as heavy snow fall or freezing rain can also cause operational disruptions and damage to infrastructure [19].

***Intense cold snaps.*** Although seasonal temperatures are projected to increase across Canada, there is still a risk for cold snaps triggered by cold masses of Arctic air moving south [20]. In 2019, a polar vortex hit central Canada with wind chill temperatures in the range of minus 30°C to minus 40°C. An Alberta clipper or a chinook wind can also bring cold air across the Prairies and into central Canada [21]. The requirements that ECCC follows for issuing extreme cold weather alerts varies by region. For example, in southern Ontario, extreme cold warnings are issued when temperatures,





including wind chill, reach below minus 30°C for at least two hours [9]. In other regions of Canada, the wind chill threshold warning is set lower, such as minus 40°C in BC's central interior, northern Ontario, and the Prairies (i.e., Alberta, southern Saskatchewan, and southern Manitoba).

***Seasonal temperature variations.*** In recent decades, Canada has experienced an overall increase in mean seasonal temperatures, particularly during the winter months. As a result, winter, snow, and ice cover seasons have become shorter, affecting seasonal snow accumulation, which has decreased by 5 to 10% per decade since 1981 [2]. Moreover, thinner seasonal ice is replacing perennial sea ice in the Canadian Arctic, and seasonal lake ice coverage has declined across the country. Temperature changes in other seasons are causing drier conditions, increasing risks of drought and wildfires. Changing seasonal characteristics are also producing more extreme rainfall events, which affects the frequency and magnitude of floods [2].



***Melting permafrost.*** Permafrost refers to the thick subsurface layer of soil that remains frozen throughout the year. Warming seasonal temperatures are impacting geotechnical conditions and heightening the risk of seasonal flooding in Canada's northern regions due to melting permafrost. This is compromising ground stability, which has historically served as a solid foundation that supports various infrastructure, including roads and rail lines that offer connections into Canada's rural and remote northern communities. Notably, there is overlap between melting permafrost regions and transportation links to northern Manitoba, northern Ontario, and communities in northern Quebec.

***Storm surge and sea level rise.*** The rising sea levels projected along Canada's Atlantic and Pacific coasts are expected to cause an increase in flooding, leading to significant damage to infrastructure, ecosystems, and coastlines. Extreme high water level events are likely to become larger in magnitude and occur more frequently in areas along Canada's Arctic and Atlantic coasts. A decline in sea ice coverage will result in increased wave action and larger storm surges [2]. The impact of storm surge on Canada's three coasts has already been severe, resulting in significant damage to infrastructure and habitats, in addition to the erosion of coastlines. Canada faced ten storm surges between 1970 and 2013 with combined damage costs estimated higher than $27.5 million [22].

Atlantic Canada is projected to experience the largest sea level rise, on the order of 75 to 100 cm (mid-century vs. 2005 baseline), while Pacific coastal regions are projected to experience a 25 to 50 cm sea level rise [2].

### 3.1.2 Summary of Climate Change Stressors

As highlighted in Section 3.1.1, climate change stressors (or impacts) are expected to increase in severity and frequency, which in turn will increase the risks to Canada's built and natural environments, such as damage to infrastructure and ecosystems, disruptions to transportation systems, operations, economic activity, and safety concerns for the general public [23].

There is no standard definition of climate stressors, so for the purpose of this report, **a climate stressor** is a fundamental climate causation factor from the natural environment. For example, precipitation (rainfall) would be a climate stressor, whereas flooding would be a climate risk, developed as a second-order effect of the precipitation.

Most climate-related risks are expected to increase as global temperatures continue to rise [24]. Scientific models and projections suggest that these effects will intensify in the future regardless of whether global emissions are reduced [2]. Hence, adaptation and mitigation strategies are needed to reduce the magnitude of these effects. Climate adaptation is defined and discussed in detail in Section 3.5.1.

Table 2 summarizes key climate change stressors in Canada, their related geographic concerns, and projections in terms of their frequency and severity. Impacts of these stressors are also discussed in Section 3.7.

## 3.2 Examples of Climate Change Events and Impacts in Canada

This section highlights the impacts of climate change and extreme weather events triggered by a changing climate across Canada. These historical examples serve as an indication of the scope and severity of impacts, and draw linkages to the public transit sector.

**Table 2:** Summary of Climate Stressors and Their Projected Changes in Frequency and Severity

| Climate Stressor | Considerations and Geographic Concerns | Frequency | Severity |
|---|---|---|---|
| **Severe Storms (lightning, hail)** | Across Canada, the occurrence and severity of storms are projected to increase due to higher atmospheric energy from warming temperatures [12]. There is a heightened risk in Canada's hot spots for thunderstorms, notably in southern Ontario [12]. | Increase | Increase |
| **High Winds** | There is limited data and research on the mechanisms and causes of observed and projected changes to wind speeds in Canada [2]. However, high winds often accompany severe convective storms for which there is an expected increase in both frequency and severity (refer to considerations for severe storms) [12]. | Increase | Increase |
| **Heavy Precipitation (rain)** | More intense rainfall events are projected, which will increase the risk of flooding, notably in urban areas (due to an increased reliance on stormwater management systems) and areas in proximity to water sources. There is also a risk of landslides and washout in areas with large changes in elevation [2]. | Increase | Increase |
| **Heavy Precipitation (snow)** | Across Canada, there is a projection for less snowfall and accumulation during winter months as warming temperatures transition snowfall to more rainfall. Less snowfall accumulation may decrease the impact of seasonal spring flooding in some areas [2]. | Decrease | Decrease |
| **Extreme Heat** | Periods of extreme heat are projected to become more frequent and more intense across all parts of Canada [2]. Dense urban environments can act as heat sinks and further raise the risks associated with heat waves. Extreme heat also increases the risk of drought, wildfires, and poor air quality resulting from wildfire smoke [2]. | Increase | Increase |
| **Intense Cold** | Extreme winter temperatures are projected to become less cold due to an overall warming mean temperature [2]. However, there is still a risk of intense cold snaps and irregular weather patterns bringing cold Arctic air south and across into central Canada. | Decrease | Decrease |
| **Seasonal Temperature Variations** | Warming temperatures are projected across all seasons in Canada [2]. This will lead to continued thawing of permafrost and increase the risk of spring flooding, avalanches, landslides, and other geotechnical instabilities, particularly in northern Canada [2]. | Increase | Increase |
| **Storm Surge** | Coastal flooding risk is expected to increase in many areas of Canada due to local sea level rise [2]. In particular, Atlantic and Pacific Canada will have greater flooding risks in low-lying areas adjacent to the coast. | Increase | Increase |
| **Sea Level Rise** | The loss of sea ice in the Arctic and Atlantic Canada further increases the risk of damage to coastal infrastructure and ecosystems as a result of larger storm surges and waves [2]. | Increase | Increase |

### 3.2.1 Storm Surge, Winds, and Coastal Flooding in Atlantic Canada (2022)

Atlantic Canada continues to face the impacts of climate change from coastal storms, including powerful nor'easters [25], which typically bring severe winds and intense precipitation as they approach land, and can cause storm surge, coastal flooding, and erosion. A nor'easter is a large-scale storm that develops in the Atlantic Ocean and travels up the northeastern coast of the United States and Canada. These storms commonly develop during the hurricane season (September to April). In addition to nor'easters, storm remnants of hurricanes striking the east coast of the United States often travel up the coast and impact Atlantic Canada.

In September 2022, hurricane Fiona made landfall in Atlantic Canada and knocked out power to more than 400,000 customers across New Brunswick, Nova Scotia, and Prince Edward Island [26]. The storm surge caused flooding which resulted in closure of roadways and damaged infrastructure. High winds, recorded between 100 to 150 km/h, also contributed to the destruction [26]. The cumulative expected cost projected for wind damage over the period from 2015 to 2040 for the Halifax Regional Municipality is estimated to be between $60 to $140 million [7].

In 2022, the Province of New Brunswick launched a predictive flood modelling tool, which is available to the public, to highlight the potential impact of storm surge and coastal flooding caused by 1-in-20-year or 1-in-100-year events, such as hurricane Fiona. The tool brings to attention that major population centres, such as downtown Fredericton, risk being entirely covered by flood water [27].

### 3.2.2 Intense Rainfall in Ontario (2013)

On July 8, 2013, public transit service in the Greater Toronto Area was severely disrupted by a summer storm and an intense downpour, as the equivalent of one month's worth of rain fell during the evening rush hour [28]. This led to track washouts in low-lying areas along some of Metrolinx's busiest passenger rail corridors (Lakeshore West and Richmond Hill). In the Lower Don Lands, flooding stranded approximately 1,400 passengers on a partially submerged GO train for more than five hours as they awaited evacuation by emergency response personnel [29]. An absence of high water level detection systems along the right-of-way contributed to the passenger train becoming trapped in the valley and unable to reverse course.

Although flood waters began to recede later in the evening, there was still notable damage to infrastructure and rolling stock. This event was one of several triggered by climate change that prompted Metrolinx to begin developing plans for climate adaptation and resiliency (discussed in Section 3.6).

### 3.2.3 Winter Storms in Central Canada (1998, 2013, and 2022)

Canada has faced a long history of dealing with severe winter storms. This section provides a summary of some climate-related impacts of severe winter storms in the provinces of Ontario and Quebec.

In December 2022, a winter storm crossing Ontario and Quebec with severe winds caused a tree to fall onto Canadian National (CN) tracks, obstructing the tracks and halting a VIA Rail passenger train along the Toronto–Montreal rail corridor near Coburg, Ontario. Passengers were stranded on-board for more than 18 hours [30]. The storm also caused power outages and road closures across both Ontario and Quebec due to fallen debris damaging power lines and blizzard-like conditions impacting road conditions and visibility.

In 2013, an ice storm in southern Ontario caused widespread damage and prolonged power outages that affected approximately 300,000 households and caused delays across the public transit system. Metrolinx has noted that this ice storm emphasized the interdependencies between transit service and electricity infrastructure, as the power outages impacted the functionality of rail signals, switches, traffic lights, stations, facilities, power supply to overhead catenary for Toronto Transit Commission (TTC) streetcars, and a variety of other critical components in the transit system [28].



**"In June 2013, southern Alberta experienced a 1-in-100-year flood that resulted in $6 billion in damages across the province."**

The January 1998 ice storm was one of the biggest natural disasters in Canadian history, triggered by low-pressure warm air carrying moisture from the Gulf of Mexico colliding with a cold Arctic air mass above Ontario and Quebec [31]. Over the span of one week, nearly double the annual amount of precipitation fell in the form of freezing rain and ice pellets across regions from Kingston, Ontario to the Eastern Townships in Quebec. Widespread power outages and road closures halted travel and public transit across the affected regions in both provinces. Approximately 2.6 million people (19% of all Canadians) were impeded or prevented from commuting during the storm and its aftermath. The storm also cut power to 1.4 million hydro customers in Quebec and 230,000 in eastern Ontario. The financial cost of the 1998 ice storm was estimated at around $5.4 billion [31].

### 3.2.4 Flooding in the Prairies (2013)

On April 28, 2013, a VIA Rail train passing through Togo, Saskatchewan en route to Churchill, Manitoba had a partial derailment. The locomotives and two leading passenger railcars derailed as they passed over a segment of washed out track. The diesel fuel tanks on both locomotives also ruptured and ignited a fire [32]. The Transportation Safety Board investigation determined that the cause of the derailment was due to a collapse of the subgrade (i.e., the ground beneath the track). Heavy rainfall coupled with an obstructed culvert caused by ice blockage led to washout of the subgrade and track instability [33].

Greater variability in seasonal temperatures can lead to irregular and more frequent freeze–thaw cycles, which can compromise subgrade conditions and increase the vulnerability of infrastructure to floods. The Prairies are projected to experience increasing frequency of seasonal freeze–thaw cycles leading up to 2050 [34].

### 3.2.5 Flooding in Central and Southern Alberta (2013)

In June 2013, southern Alberta experienced a 1-in-100-year flood that resulted in $6 billion in damages across the province. A record year of snowfall in the 2012–2013 winter season coupled with a heavy rainfall event in June 2013, where communities saw levels of rainfall that were equivalent to half the annual average rainfall in two days, caused rapid snowpack melt and the rise of water levels, which could not be contained by the Bow, Elbow, and South Saskatchewan rivers and their tributaries. Between June 19 and 21, 32 communities declared a state of emergency and 80,000 Calgary residents were evacuated [35].

A significant amount of critical infrastructure was damaged as a result of the flood, including washed out bridges and closure of major infrastructure, such as bridges and the Trans-Canada Highway and Highway 1A. The flooding was also determined to be the cause of the Bonnybrook Bridge collapse on June 27, 2013, which derailed six Canadian Pacific (CP) freight tanker cars carrying petroleum dilutant [36].

### 3.2.6 Wildfires in Northern Alberta (2016)

In 2016, Alberta dealt with the largest wildfire evacuation in the province's history, forcing over 80,000 people to evacuate from the town of Fort McMurray and surrounding areas. The socioeconomic impact of the wildfire has been estimated at around $10 billion, with $3.8 billion in insurable losses [37].

A variety of vehicles, including urban transit buses, were used to assist with the mass evacuation [38], which caused gridlock on Highway 63 as motorists risked their safety to escape along the only major highway in and out of Fort McMurray. This event called into question the resiliency of Alberta's road transportation links to the north and prompted proposals for a secondary highway route to alleviate the dependency on Highway 63 [39].

### 3.2.7 Landslides in British Columbia (2021)

Over a three-week period in November and December 2021, heavy rains from an atmospheric river that formed over BC caused landslides, major outages, and washout on the CP and CN rail networks. These outages also impacted passenger rail as VIA Rail has track access agreements to operate service on CN track. A landslide triggered by this heavy rain also caused a VIA train derailment near Hope, BC and the evacuation of 200 stranded passengers [40].

Flooding also washed out sections of major roadways, which impacted inter-city bus service. The cost of rebuilding the transportation infrastructure was estimated at around $9 billion and is likely to be revised upwards [41].

### 3.2.8 Winter Storms and Melting Permafrost in Northern Manitoba (2017)

In northern Manitoba, the Hudson Bay Railway connects The Pas to Churchill and to Flin Flon via two major branches. The railway provides essential transportation services, including freight and year-round local passenger traffic, for communities in northern Manitoba that have limited alternative transportation options and no year-round road access.

Severe winter storms and subsequent spring flooding have led to washout of track in the past, which cut off the primary ground transportation link for many rural and remote northern communities [42]. In 2017 and 2018, the railway was closed for 18 months due to the cumulative effects of flooding and permafrost degradation beneath the track [7]. The loss of this ground transportation link has also raised the cost of living for northern communities as less cost-effective means of freight transportation had to be used to deliver essential goods such as food and medicine.

Melting permafrost and ballast continually seeping into the muskeg (grassy bog) are deteriorating the subgrade conditions of the Hudson Bay Railway. Significant capital and maintenance expenditures will continue to be required to maintain even very limited operations for the Hudson Bay Railway. Further expenditures will be required to adapt the track to the changing climate conditions in Canada's north.

### 3.2.9 Wildfires and Heat Waves in Western Canada (2022)

Weather conditions in recent years have produced unusually dry winter seasons and high seasonal temperatures, resulting in extreme heat and wildfires. Historically, the North American fire seasons lasted from July through October, but fire seasons now extend into December and January, and start as early as March [43], [44]. This has a major impact on communities spanning the western United States up through northern Canada as they are challenged with larger and more intense wildfires and increased smoke days [45]. Hotter and smokier summers have a significant impact on health of populations, and increasingly impact infrastructure that is not built and designed for prolonged extreme heat and smoky conditions, including buckling of road pavement, damage to streetcar and passenger rail infrastructure [46], [47], cancellation of flights due to extreme heat [48], and intense power drawdowns from the grid resulting in rolling blackouts and calls for reduction in heating, ventilation, and air conditioning (HVAC) and electric vehicle charging usage [49].

## 3.3 Overview of Canada's Public Transit Sector

In addition to the impacts of climate change, the public transit sector itself is undergoing a number of changes and trends that are relevant in terms of climate change adaptation and resilience considerations.

Public transit services can be found in all major cities and most towns across Canada. Depending on the nature of a service, Canadians leverage public transit for daily commuting, pleasure, tourism, or other one-off uses to meet their transportation needs. Table 3 presents a general overview of the types of public transit services offered in Canadian cities and towns.

**Table 3:** Types of Public Transit in Canadian Cities and Towns

| Transit Type | Typical Metrics | Examples |
|---|---|---|
| **Conventional Bus** | **Land use context:** Low to medium density<br>**Capacity:** 55 per bus<br>**Operating right-of-way:** Mixed traffic | Edmonton Transit Route 201<br>Winnipeg Transit Route 95<br>Barrie Transit Route 1A |
| **Para-Transit Bus** | **Land use context:** Low to high density<br>**Capacity:** 10–15 per bus<br>**Operating right-of-way:** Mixed traffic | Halifax Access-A-Bus<br>TTC Wheel-Trans<br>TransLink HandyDART |
| **Regional Bus** | **Land use context:** Low to medium density, suburban to urban<br>**Capacity:** 55 (single level), 80 (double decker) per bus<br>**Operating right-of-way:** Mixed traffic | GO Transit Route 25<br>Ontario Northland<br>(Toronto–North Bay) |
| **Bus Rapid Transit (BRT)** | **Land use context:** Medium to high density<br>**Capacity:** 55 (single), 77 (articulated) per bus<br>**Operating right-of-way:** Mixed traffic or dedicated BRT lanes (painted or separate lanes) | Mississauga MiWay Route 100 (Airport Express)<br>York Region Transit Viva<br>Brampton Transit Züm |
| **Streetcar** | **Land use context:** Medium to high density<br>**Capacity:** 100–130 per streetcar<br>Operating right-of-way: Mixed traffic | TTC Route 501 (Queen St.) |
| **Light Rail Transit (LRT)** | **Land use context:** Medium to high density<br>**Capacity:** 250–300 per LRT<br>**Operating right-of-way:** Partially or fully separated operating environment | OC Transpo O-Train<br>Grand River Transit ION |
| **Subway/Metro** | **Land use context:** High density<br>**Capacity:** 400–500 per train (up to 1,100 standing)**Operating right-of-way:** Dedicated rail corridor | TTC Line 1 (Yonge–University)<br>TransLink Canada Line |
| **Commuter Rail** | **Land use context:** Low to medium density, suburban to urban<br>C**apacity:** 160 (per train car), 1,900 (per trainset)<br>**Operating right-of-way:** Dedicated or shared railway corridor (shared with freight traffic) | GO Train Lakeshore Line<br>Montreal Exo (exo1) |
| **Inter-City Passenger Rail** | **Land use context:** Varied<br>**Capacity**: 40–60 per train car<br>**Operating right-of-way:** Dedicated or shared railway corridor (shared with freight traffic) | VIA Rail (Ottawa–Montreal)<br>VIA Rail (Vancouver–Calgary) |

Note that passenger and vehicle ferries (e.g., BC Ferries) were not included in the scope of this study.

From a physical infrastructure and assets perspective, a number of components are considered in the design, construction, operation, and maintenance of transit systems. Table 4 outlines the typical components that may be impacted by the effects of climate change.

Urban or regional transit services are typically planned and operated by dedicated transit agencies overseen by dedicated arms of municipal or regional governments focused on transit service planning and provision. Some examples of the organizational structures apparent in Canadian cities or regional areas include:

- **City or municipal department model.** Edmonton Transit Service is the branch of Edmonton's City Operations department that is responsible for the city's transit services. Here, transit services are planned, designed, and operated by city resources. Other similar examples include Calgary Transit within the City of Calgary's Operational Services department and Halifax Transit within the City of Halifax's Transportation department.

**Table 4:** Typical Components of Canadian Public Transit Systems

| Public Transit System Components | |
|---|---|
| **Buildings** | ▪ Buildings (administration offices)<br>▪ Maintenance facilities<br>▪ Stations (platform, complex, underground)<br>▪ Electrical equipment housings<br>▪ Storage facilities (bus garages and depots)<br>▪ Signage (static and dynamic) |
| **Linear Infrastructure** | ▪ Road system<br>▪ Track and guideway (rails, ballast, etc.)<br>▪ Culverts and drainage infrastructure<br>▪ Bridges<br>▪ Catenary (electrical) |
| **Rolling Stock** | ▪ Buses<br>▪ Trains, LRTs, and subways |
| **Electrical/Communications** | ▪ Switches, signals, traffic lights<br>▪ Substations<br>▪ Fare collection systems<br>▪ Traveller information systems |
| **Human Resources** | ▪ Drivers and operators<br>▪ Maintenance and construction workers<br>▪ Corporate resources<br>▪ Customer relations<br>▪ Ticketing |



**"... the federal government is planning to implement a $3 billion per year stream of permanent funding for public transit by 2026–2027 through Infrastructure Canada [50]."**

- **Transit agency model.** The TTC is responsible for the City of Toronto's transit services and management of all fleet and assets, with the exception of the roads, where their vehicles operate on a shared right-of-way. In this case, the city is responsible for road maintenance. Other similar examples include MiWay for the City of Mississauga, Grand River Transit for the Region of Waterloo, and OC Transpo for the City of Ottawa.
- **Crown corporations.** TransLink is Metro Vancouver's agency responsible for the region's transportation services, including the planning, design, and delivery of public transit in most cases. TransLink is a Crown corporation with a number of subsidiaries responsible for service provision of specific lines or management of assets (e.g., Coast Mountain Bus Company and BC Rapid Transit Company). Other similar examples include Metrolinx for transit services in the Greater Toronto Area and Ontario Northland for transit services connecting to northern Ontario. In addition, VIA Rail Canada is responsible for operating national passenger rail services across Canada on behalf of the federal government.

There is no national transit policy framework at the federal level in Canada nor is there a continuous funding source to cover transit operational costs, leaving much of the responsibility to plan, design, construct, fund, and operate transit services to the operators themselves. However, the federal government is planning to implement a $3 billion per year stream of permanent funding for public transit by 2026–2027 through Infrastructure Canada [50].

Infrastructure can be owned by either public or private entities. The segregation of ownership and authority over track and road infrastructure can determine the entity responsible for implementing climate adaptation measures to make infrastructure more resilient. Two notable examples in the Canadian context include:

- **Track infrastructure for commuter and inter-city passenger rail,** which may be owned by private freight railways, who handle physical enhancements and maintenance. For example, VIA Rail and Metrolinx both have track access agreements with CN, under which they pay a fee to the freight railway for the right to operate passenger trains on CN-owned track [51].
- **Road infrastructure in urban areas,** on which public transit buses operate, generally falls under the responsibility of the city or regional municipality (e.g., maintenance, repair, snow clearing, etc.). Highways fall under the jurisdiction of the provincial government ministry, such as the Ontario Ministry of Transportation, and the BC Ministry of Transportation and Infrastructure. Highways may be used by urban city buses or by inter-city coaches.

## 3.4 Emerging Developments

To assess climate risk and adaptation with a forward-looking perspective, it is important to understand not only climate change but also fundamental changes in Canada's public transportation sector. This section explores the major changes to Canada's public transportation sector, including decarbonization and electrification of public transit systems, implementation of higher order (capacity) public transportation, and inter-city passenger rail connectivity.

### 3.4.1 Decarbonization and Electrification of Public Transit Systems

#### 3.4.1.1 Urban Buses

Public transit agencies in municipalities across Canada are seeing a significant shift in planning for and implementation of alternative fuels and propulsion systems in their fleets. Agencies are taking their own approaches to fleet transition and are heavily influenced by local policies mandating greenhouse gas emissions reductions in conjunction with the Government of Canada's 2030 Emissions Reduction Plan [52] and Transport Canada's zero emission vehicle sales target of 100% by 2035 [53], and by low-interest loan programs and zero emission bus funding offered through the Canada Infrastructure Bank [54] and Infrastructure Canada's Zero Emission Transit Fund [55].

With public transit fleets rapidly adopting zero emission technologies, public transit agencies will require significant infrastructure investments, such as electrical power supply and distribution facilities, electric bus charging infrastructure, fuel – or technology-specific infrastructure design considerations, and alternative fuel fuelling stations. These investments could expose agencies to different planning and operational risks.

Furthermore, battery electric buses are generally heavier than internal combustion engine buses [56]. The operation of these heavier buses will have a direct impact on the cost of road maintenance, which increases by a power of four (x4) as a function of vehicle weight [57]. This could increase the risk of pothole formation, road wear, and the need for street closures as repairs are made to the road surface. Opportunities for new pavement compounds and maintenance practices to minimize road wear could arise as a result.

#### 3.4.1.2 Regional Express Rail in the Greater Toronto and Hamilton Area

The Metrolinx GO eExpansion Program is a $20 billion program that will transform the existing GO rail network into a two-way all-day regional rapid rail service with frequencies of 15 minutes or better on core lines [58].

In addition, Metrolinx plans to convert several rail corridors from diesel to electric propulsion. The electrified passenger rail system will include an overhead contact system (catenary), electrical feeder routes, and a number of electrical power supply and distribution facilities (traction power facilities) located in proximity and adjacent to the rail corridors [59].






**Table 5:** Major Passenger Rail Projects in Canada

| Project | Location | Phase |
|---|---|---|
| **Eglington Crosstown LRT** | Toronto | Under construction |
| **Finch West LRT** | Toronto | Under construction |
| **Hurontario LRT (Hazel McCallion Line)** | Mississauga and Brampton | Under construction |
| **Eglington Crosstown West Extension** | Toronto and Mississauga | Under construction |
| **Ontario Line** | Toronto | Under construction |
| **Scarborough Subway Extension** | Toronto | Under construction |
| **Hamilton LRT** | Hamilton | Planning; construction scheduled for 2024 |
| **On-Corridor Works (GO Expansion Program)** | Greater Toronto and Hamilton Area | Planning |
| **Stage 2 ION LRT** | Waterloo | Planning |
| **O-Train LRT Stage 2** | Ottawa | Under construction; target completion in stages from 2024 through 2026 |
| **Réseau Express Métropolitain (REM)** | Montreal | Phase 1 open; Phases 2 and 3 under construction; target completion in stages until 2027 |
| **Le Tramway de Québec** | Quebec City | Planning; construction scheduled for 2024 |
| **VIA High Frequency Rail** | Toronto to Quebec City | Planning |
| **Green Line LRT Stage 1** | Calgary | Under construction |
| **Capital Line South Extension** | Edmonton | Planning; construction scheduled for 2024 |
| **Metro Line Northwest Extension (Phase 1)** | Edmonton | Under construction; target completion in 2024 |
| **Valley Line West** | Edmonton | Under construction; target completion in 2027 |
| **Broadway Subway Project** | Vancouver | Under construction; target completion in 2026 |
| **Broadway Subway Project UBC Extension** | Vancouver | Planning; identified as a 10-year priority by the Mayor's Council and TransLink |

### 3.4.2 Higher Order Public Transportation

#### 3.4.2.1 Light Rail Transit in Growing Population Centres

To provide improved public transit service for growing communities and population centres across Canada, many regions are moving toward higher capacity public transit modes. Higher order public transit can refer to surface level LRT, streetcars, and subways.

Table 5 provides a sample of major passenger rail projects that are underway across Canada, in various stages (e.g., planning, design, and construction). Most are concentrated in Ontario's Greater Golden Horseshoe region around Toronto and Lake Ontario.

The expansion of public transit systems in heavily urbanized areas to include LRT and subways could expose the overall transit system to different climate risks compared to smaller transit services that operate only bus service. Some notable vulnerabilities of higher capacity transit systems to climate change include a greater reliance on electrical infrastructure that is exposed to risks of power outages in periods of extreme heat, flooding in tunnels and underground structures during intense rainfall, and heavy snow or ice obstructing guideways during winter storms. With many transit projects underway across Canada, it is also important to study how climate-related risks can be mitigated through the planning, design, and construction stages. This topic is explored further in Section 3.8.

#### 3.4.2.2 High Speed Rail for Inter-City Connectivity

High frequency rail (HFR) for inter-city passenger travel between southern Ontario and Quebec is currently being studied. VIA HFR would connect Quebec City–Montreal–Ottawa–Toronto with passenger rail service running on dedicated tracks (separate from freight traffic) [60]. The dedicated HFR infrastructure would enable electrification of the passenger rail service [61]. This change from conventional diesel locomotives to electric propulsion would also introduce new climate vulnerabilities to the inter-city passenger rail service, such as risk of power outages disrupting operations.

#### 3.4.2.3 Public–Private Partnerships

Private sector involvement is also becoming more prominent in the delivery of public transit service, whether through contracts for the design and construction of new systems (e.g., LRTs and subways) or through operations and maintenance agreements. Understanding climate risks is particularly important in public–private partnership contracts because the parties need to agree on acceptable terms of risk sharing. Furthermore, these contracts are often set for long periods (e.g., 25 years), during which significant environmental changes could impact the cost and risk profile of the agreement.

## 3.5 Linking Climate Change Issues to the Public Transit Sector

### 3.5.1 Climate Change Adaptation

This section explores definitions of climate risk and adaptation and their relevance to public transit service and assets.

Transport Canada uses the following definition in their Climate Change Adaptation Plan:

> *"**Climate change adaptation** involves taking action to reduce the **vulnerability** of natural and human systems to actual or expected changes to the climate (e.g., impacts of the environment on transportation). **Adaptation** is a form of risk management which can include adjusting activities, decisions and thinking in response to anticipated changes in climate, in order to moderate harm and take advantage of new opportunities. In other words, adaptation is a form of weather and climate risk management. In the context of transportation, adaptation addresses the impact of the environment on transportation." [62]*

As depicted in Figure 1, the need for climate adaptation can arise from changes in either or both of the following two primary factors:

1. **Transit assets and operations.** Changes to the underlying assets or operations of a public transit system can increase climate vulnerabilities. Currently, there is a significant shift toward transit decarbonization, as discussed in Section 3.4.1. This policy direction could result in new technologies being introduced, which could bring new or increased exposure to climate risk (e.g., bus operations becoming more vulnerable to power outages due to fleet electrification). In addition, aging infrastructure could also be more vulnerable to climate change as the intensity of weather increases (e.g., foundation cracking of old bridges).
2. **Environmental conditions.** Changes to the environment in which a transit system operates can also expose climate vulnerabilities. Changes in seasonal temperatures and increased likelihood or severity of extreme weather can affect the risk profile of the public transit system. For example, warmer weather and melting permafrost in parts of northern Canada could destabilize segments of passenger rail, leading to an increased risk of train derailment or track washout during floods.

Changes in the public transit system, environmental conditions, or a combination of the two can heighten existing risks or create new risks. Figure 2 presents a framework for assessing climate risk and adaptation that is used by several leading North American transit agencies in their climate adaptation plans, including the LA Metro [63], and the Massachusetts Bay Transportation Authority [64].

***Climate vulnerability*** comprises the following three elements:

1. ***Exposure,*** which reflects the likelihood that an asset or service will be exposed to a climate stressor. For example, rail track running along a coastal region might have higher exposure to the risks of storm surge and coastal erosion compared to a track located further inland.
2. ***Sensitivity,*** which refers to the magnitude of impact resulting from exposure of an asset to a climate stressor or hazard. For example, traction power systems for electrified passenger rail could have a greater sensitivity to power

**Figure 1:** Drivers of change necessitating climate adaptation.

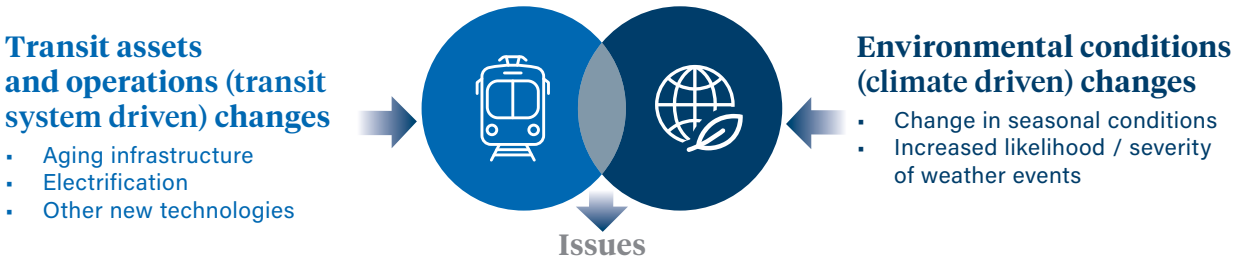



**Figure 2:** The composition of climate risk .





**"The resiliency triangle can be used to communicate the quality of infrastructure degradation and the corresponding time to recover in response to a disruption."**

outages triggered by extreme heat compared to road infrastructure for which there is no direct linkage between electrical power supply risk and pavement.

3. ***Adaptive capacity,*** which refers to the ability of a transit system or a particular asset to respond to a climate hazard or event. For example, during a flooding event, a bus route would have high adaptive capacity because buses could be re-routed to avoid the affected area(s). However, a subway line would have low adaptive capacity because flooding (even to a single station on the line) would impact operations along its entirety due to a greater reliance on fixed infrastructure (track) that cannot be easily adapted.

***Criticality*** can have varying definitions depending on each transit agency or authority. In a broad sense, criticality refers to the importance of an asset to the functioning of the overall transit system. Criticality can be assessed based on a variety of factors, including the asset's connection and reliance to other transportation assets, location of the served population, demographic groups, and various socioeconomic factors. For example, a rail line serving a remote northern community with limited transit alternatives could be viewed as a highly critical asset, whereas a single urban bus would have lower criticality as spare vehicles are often available in the fleet of a transit operator.

***Risk*** is the combined impact of climate vulnerability and criticality on infrastructure (i.e., capital assets), the natural environment, and the human users of the asset over its lifetime. Risk can be assessed on an asset-by-asset basis and rolled up to a global perspective of the public transit system and its performance.

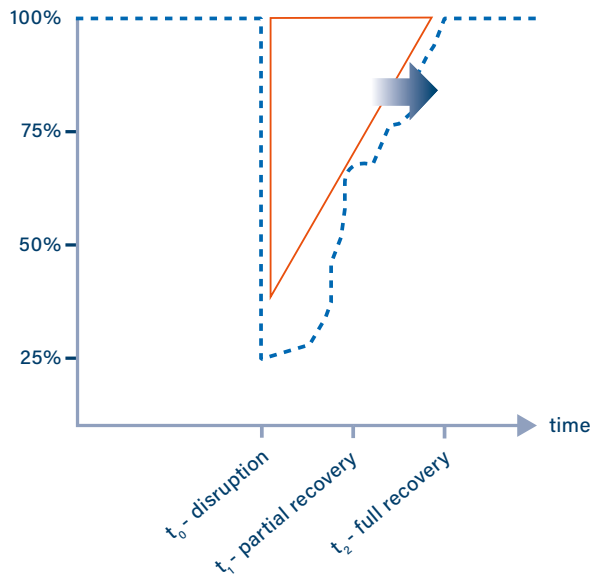
### 3.5.2 Resiliency of Infrastructure

***Resiliency to climate change*** is distinct from adaptation. It is the ability of social, economic, and environmental systems to maintain performance in response to climate-driven stressors, trends, or disturbances. Systems may respond or reorganize in ways that maintain their essential function, identity, and structure while also maintaining the capacity for adaptation and transformation.

An extensive review of the literature on resiliency concluded that "resilience is a commonly used, however ill-defined term" that "lacks a widely accepted, standardized definition and agreed-on measures" [65].

The resiliency triangle concept, depicted in Figure 3, draws attention to the temporal element of disruption response [66]. The resiliency triangle can be used to communicate the quality of infrastructure degradation and the corresponding time to recover in response to a disruption. For example, the time for a rail line to be rebuilt and become operational again after a flood

**Figure 3:** Resiliency triangle concept (adopted from [66] with authors' permission).




and track washout event. However, in the conversation on climate adaptation, there is an argument that infrastructure should be rebuilt to a higher standard, so it is more resilient to future extreme weather and climate disruptions.

In general, resiliency tends to incorporate common themes such as disruption, unexpected incidents, recovery, adaptability, minimizing impacts, and redundancy. The conceptualization of resiliency can vary depending on the interested party, which may reflect different elements of control.

### 3.5.3 Community Resiliency and Continuity Management

The concept of resiliency extends beyond public transit due to its interconnected nature with other essential services, such as health care and medical services. The preservation of transit service at a minimum threshold during emergency situations is a critical component of business continuity and emergency management. For example, there should be planning and coordination between the city or municipal authorities and the local transit agency to ensure service on essential routes is maintained during extreme weather events, such as priority of snow clearing on transit routes serving hospitals and backup power provisions during power outages.

In addition, public transit assets can provide support in emergency management. For example, transit buses can be used to evacuate residents from areas impacted by flooding or fires, or to shuttle vulnerable populations to cooling centres during summer heat waves. According to the consultations with interested parties, several transit agencies have already recognized the role of public transit in emergency response and have departments dedicated to developing integrated regional emergency and disaster response plans.

Existing standards, such as ISO 22301 [67], provide guidance on developing emergency response protocols and business continuity management.

## 3.6 Current Approaches to Identifying Climate Risks in Public Transit

### 3.6.1 Municipal Approaches

Many of Canada's larger municipalities, and some of the larger transit authorities, have started to formally identify and assess climate change risks to municipal infrastructure, and in some cases to transportation infrastructure. Based on a review of existing approaches, municipalities typically begin with an overall climate change strategy for all sectors, which some then follow with a specific assessment of climate change impacts and vulnerabilities for the transportation sector.

According to the consultations with interested parties, climate risk and vulnerability assessments can vary in depth and scope, and there is no consistently used assessment methodology. However, a number of these assessments reference ISO 31000 [68] and ISO 14091 [69], which are used to evaluate climate change impacts on assets, systems, and operations. Assessments can also be informed by Infrastructure Canada's Climate Lens Resilience Assessment tool [70] and the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol [71].

Appendix A lists some of the climate change risk assessment approaches and documents in the public transit sector, drawing on regional examples from transit agencies, cities, and municipalities. While most of the larger municipalities have prepared overarching, multi-sector climate risk assessments, few have developed targeted action plans for climate change adaptation and resilience in the passenger transit sector specifically. Furthermore, transit agencies have expressed a need for connecting climate adaptation measures and emergency management, as public transit can provide vital service during crises triggered by extreme weather.

### 3.6.2 Federal and Provincial Approaches

With the exception of VIA Rail, the federal government does not have oversight or ownership of public passenger rail or bus transit systems in Canada. However, the federal government does have a number of agencies and programs that support the identification and assessment of climate change risks. *These key programs are highlighted in Appendix B.*

In general, federal programs are more targeted (i.e., specific to climate adaptation and public transit) than provincial programs, which tend to have a broader scope on public infrastructure projects and funding streams related to adaptation measures.

Provinces and territories that are not included in Appendix B (Newfoundland and Labrador, Prince Edward Island, Ontario, and Alberta) do not have targeted funding programs for climate adaptation at the time of writing this report. However, several of them have funding for greenhouse gas reduction, such as Newfoundland and Labrador's Climate Change Challenge Fund [72], Prince Edward Island's Climate Challenge Fund [73], and Ontario's Green Investment Fund [74]. Territories are captured under the federal Climate Change Preparedness in the North Program [75].

In addition to funding programs, the federal government also supports research and analysis in the area of climate change resiliency and standards development through a number of federal entities, including the SCC and the NRC.

## 3.7 Summary of Climate Risks to Canada's Public Transit Systems

### 3.7.1 Inventory of Current Climate Risks

Table 6 provides a summary of known climate risks to Canada's public transit system, triggered by the climate stressors described in Section 3.1.2, as identified through the literature review and consultations with interested parties. This list may not be comprehensive because climate adaptation is an evolving area of study and several interested parties indicated that they are still in the early stages of identifying climate risks and mapping them to their public transit systems.

### 3.7.2 Short – and Long-Term Factors

The trends in the climate stressors described in Section 3.1.2 can be referenced to see how the resultant climate risks may evolve over time. In general, the only climate-related risks that are expected to decrease in frequency and severity over time are those related to snow and cold weather. As the climate continues to warm, it is expected that heavy snowfalls will transition to rain and there will be fewer severe cold snaps [2].

In the SCC's Standards in Action: Building a Climate-Resilient Future report, experts from across Canada identified the following top climate-related risks [4]:

- Extreme precipitation and flooding;
- Slow environmental degradation processes (e.g., melting permafrost, freeze–thaw cycles);
- Extreme heat and drought;
- Sea level rise and coastal hazards (e.g., erosion, storm surge);
- Extreme winds; and
- Wildfire and related interactions at urban interfaces.

As public transit systems move toward decarbonization, there might be greater reliance on electrical infrastructure (e.g., substations, transmission lines, etc.), which is likely to raise the vulnerability of public transit systems to certain climate-related risks or increase the severity of their impacts.

**Table 6:** Summary of Climate Risks to the Public Transit Sector

| Risk ID | Risk Description | Additional Considerations |
|---|---|---|
| **Climate Stressor: Intense Precipitation (IP)** | | |
| **IP-1** | Flooding and washout of roads, bridges, rail lines, and other infrastructure. | Canada-wide concern, particularly in low-lying areas (flood plains) adjacent to water sources (e.g., rivers and lakes) and in urban areas with limited stormwater management capacity. |
| **IP-2** | Water ingress to tunnels and other subterranean structures (e.g., underground stations) causing damage to infrastructure. | Canada-wide concern, particularly in dense urban environments where there are many underground transit systems providing higher order transit services (e.g., subways in Toronto and Montreal). |
| **IP-3** | Water ingress to housings of electrical systems, leading to short-circuits, power supply interruption, and possible system failures. | Canada-wide concern, particularly in low-lying areas (flood plains) adjacent to water sources (e.g., rivers and lakes) and in urban areas with limited stormwater management capacity. |
| **IP-4** | Impaired visibility to transit vehicle operators. | Canada-wide concern. |
| **IP-5** | Loss of traction on roadways or track guideways and physical obstructions (e.g., snow and ice build-up). | Canada-wide concern, particularly in regions with a history of severe winter weather and heavy snowfall. |
| **IP-6** | Freezing rain causing an accumulation of ice on overhead catenary, leading to loss of power supply for transit vehicles. | Canada-wide concern, particularly in regions with a history of severe winter weather and freezing rain. |
| **Climate Stressor: Extreme Heat (EH)** | | |
| **EH-1** | Buckling of track due to thermal expansion and increased derailment risk. | Canada-wide concern, particularly in dense urban environments, which act as heat sinks. |
| **EH-2** | Buckling or cracking of pavement due to thermal expansion. | Canada-wide concern, particularly in dense urban environments, which act as heat sinks. |
| **EH-3** | Sagging overhead catenary due to excessive heat and thermal expansion. | A concern for urban areas with electrified passenger rail. |
| **EH-4** | Failure of electrical systems, such as passenger rail signals, switches, and electric bus chargers, due to a lack of ventilation and/or increased load on A/C systems. | Risk is further increased if wildfire smoke or poor air quality inhibit or impede the use of ventilation systems. |
| **EH-5** | Failure of electrical systems due to an increased load on the electrical grid (blackouts or brownouts). | Canada-wide concern, particularly in dense urban environments, which act as heat sinks. |
| **EH-6** | Occupational health and safety risks to workers (heat fatigue). | Canada-wide concern, particularly in dense urban environments, which act as heat sinks. |
| **EH-7** | Drought and increased risk of wildfire sparking, leading to damage of infrastructure. | Risk is heightened if paired with high winds, which can accelerate the spread of wildfire. |
| **EH-8** | Drought and increased risk of poor air quality caused by wildfire smoke, potentially leading to failure of HVAC systems in buildings, equipment, and vehicles. | Canada-wide concern, although historically this risk has been more prominent in western Canada (e.g., Alberta and BC). |

| Risk ID | Risk Description | Additional Considerations |
|---|---|---|
| **Climate Stressor: Intense Cold (IC)** | | |
| **IC-1** | Formation of brittle cracks and structural failure of track infrastructure. | Canada-wide concern, particularly in regions with colder winters (e.g., Edmonton and Winnipeg). |
| **IC-2** | Seizure of track switches and other mechanical components. | Canada-wide concern, particularly in regions with colder winters (e.g., Edmonton and Winnipeg). |
| **IC-3** | Ice accumulation on overhead catenary. | Canada-wide concern, particularly in regions with colder winters (e.g., Edmonton and Winnipeg). |
| **IC-4** | Reduced operating range of battery electric transit vehicles. | Canada-wide concern, particularly in regions with colder winters (e.g., Edmonton and Winnipeg). |
| **Climate Stressor: Seasonal Temperature Variations (STV)** | | |
| **STV-1** | Melting permafrost causing degradation of subgrade and instability of geotechnical conditions. | A particular concern in northern Canada, the territories, and provincial regions with historically continuous permafrost. |
| **STV-2** | Increased frequency or severity of freeze–thaw cycles leading to road damage (pothole formation). | Canada-wide concern, particularly in regions with milder winters, where there is a higher likelihood for temperature fluctuation around freezing. |
| **Climate Stressor: High Winds (HW)** | | |
| **HW-1** | Structural damage to infrastructure. | Canada-wide concern. |
| **HW-2** | Debris obstructing roads and track or guideways. | Canada-wide concern. |
| **HW-3** | Impaired visibility to transit vehicle operators, if paired with intense precipitation. | Canada-wide concern. |
| **HW-4** | Increased risk of rapid wildfire spread. | Canada-wide concern, particularly in western Canada (e.g., Alberta and BC). |
| **HW-5** | Downed trees or telegraph poles causing power outages. | Canada-wide concern |
| **Climate Stressor: Severe Storms (SS)** | | |
| **SS-1** | Increased risk of lightning strikes causing damage to infrastructure or power outages. | Canada-wide concern, heightened risk in the Great Lakes region. Roof-mounted equipment may be more vulnerable to lightning strikes (e.g., charging cabinets for electric bus garages and HVAC equipment). |
| **SS-2** | Increased risk of hail damage to infrastructure. | Canada-wide concern, heightened risk in the Great Lakes region. |
| **Climate Stressors: Storm Surge/Sea Level Rise (SS/SL)** | | |
| **SS/SL-1** | Storm surge causing flooding in coastal areas. | A particular concern in low-lying coastal regions in Atlantic Canada (maritime provinces), along the St. Lawrence, and in western Canada (BC). |
| **SS/SL-2** | Corrosion of metallic infrastructure (e.g., track and electrical connectors) due to standing sea water. | A particular concern in low-lying coastal regions in Atlantic Canada (maritime provinces), along the St. Lawrence, and in western Canada (BC). |
| **SS/SL-3** | Coastal erosion and instability of geotechnical conditions leading to road or track washout. | A particular concern in low-lying coastal regions in Atlantic Canada (maritime provinces), along the St. Lawrence, and in western Canada (BC). |



**"In general, the only climate-related risks that are expected to decrease in frequency and severity over time are those related to snow and cold weather."**

The ranking of specific climate-related risks is challenging because exposure and sensitivity characteristics can vary greatly by transit system and region. Furthermore, assets are often part of an interconnected system, thereby making it difficult to assess risk on an individual basis [4].

## 3.8 Response to Climate Change

### 3.8.1 Mitigation and Adaptation Actions for Climate Risks

Previous sections identified the causes of climate change risks and the approaches being used to identify specific risks for public transit. This section summarizes current or considered climate adaptation measures or actions performed by Canada's public transit sector to respond to climate risks. This summary of adaptation actions may help to inform areas of interest for standards development.

Overall, there are three different approaches to address climate risk and resiliency through adaptation:

1. ***Hardening and protecting infrastructure.*** This approach comprises engineering solutions for assets so they are better able to withstand the impacts of climate change and weather events. Examples include sizing drainage systems to accommodate 1-in-100-year flooding events rather than 1-in-50-year events, and the use of permeable pavement to pass stormwater into underlying soil during heavy downpours.
2. ***Operational and maintenance adjustments.*** This approach comprises actions to adapt existing operations, procedures, or behaviour to mitigate or eliminate climate risk. Examples include the use of tensioners on overhead catenary wires to absorb extra slack during hot weather operating conditions, and frequent cleaning of culverts or installation of drainage systems to prevent obstructions to water flow.
3. ***Relocation of infrastructure or services.*** This approach aims to permanently move an asset or service element out of the impacted or high-risk area. Examples include elevating segments of track, road, or stations in low-lying flood plains, and moving roads inland to avoid coastal erosion.

It is common for interested parties to assess climate adaptation actions through a lifecycle analysis perspective. As illustrated in Table 7, each climate adaptation approach can be mapped to one or more of the stages in an asset's lifecycle: a) planning, design, and procurement; b) construction, including rehabilitation; and c) operations and maintenance.

Table 8 summarizes the various climate adaptation actions developed by transit agencies, regulatory agencies, various levels of government, and other interested parties in response to the climate risks profiled in Section 3.7. Each risk is linked to one of three mitigations (i.e., adaptation actions), along with the applicable climate adaptation approaches and lifecycle intervention stages.

**Table 7:** Climate Adaptation Approaches and Lifecycle Intervention Stages

| Adaptation Approach | Lifecycle Intervention Stage | | |
|---|---|---|---|
| | A. Planning, design, and procurement | B. Construction, rehabilitation | C. Operations and maintenance |
| 1. Hardening and protecting infrastructure | ✓ | ✓ | |
| 2. Operational and maintenance adjustments | | | ✓ |
| 3. Relocation of infrastructure or services | ✓ | ✓ | |

### 3.8.2 Actions to Harden and Protect Road and Rail Infrastructure

Several innovative adaptation measures have been implemented to protect road and rail infrastructure against the impacts of climate change. This section highlights examples of such adaptation measures in response to risks triggered by intense precipitation and extreme heat.

***Permeable compounds and hardscape designs to mitigate flooding.*** Permeable hardscape allows rainfall to pass through to underlying soils or a stormwater reservoir. The hardscape design can include interlocking paving blocks (for parking lots or walkways) and permeable asphalt or concrete mixtures.

Due to their mixture of coarse aggregates and bonding material, specialty mixes of asphalt and concrete can be more porous at a micro level, allowing water to pass through an absorbing subgrade (e.g., soil). Permeable concrete mixtures have little to no sand, which increases the void content in the hardened concrete (voids in the range of 15 to 25%) [78]. Porous concrete has been used on highways to reduce water pooling during intense rainfall events and the risk of vehicles hydroplaning [79].

***Specialized pavement compounds to mitigate buckling in heat.*** Since 1997, the Ontario Ministry of Transportation and larger Ontario municipalities have used a specialized asphalt mixture, based on Ontario Provincial Standard Specifications [80]. The mixture considers high – and low-temperature performance for extending pavement lifecycles. Asphalt mixtures are specified based on different locations within the province, according to their seasonal temperature variations.

Other provinces have also published pavement design guidelines that specify materials and thicknesses on different roadway designations (typically classified based on traffic volume), including BC's Pavement Structure Design Guidelines [81].

***Monitoring subgrade conditions for track infrastructure in relation to flooding and permafrost melt.*** Railways have a variety of methods at their disposal to actively monitor track and subgrade conditions. Inspection methods that can support identification of track segments at high risk of washout or collapse due to deteriorating subgrade from intense rainfall events or melting permafrost include:

- ***High water detection systems.*** Sensors along the right-of-way and in nearby drainage systems can monitor water levels and inform the risk assessment of potential flooding.
- ***Track geometry inspections.*** Railways conduct regular track geometry lasering inspections to assess any changes in track curvature or elevation, which may indicate changes in the subgrade conditions and the need for maintenance intervention (e.g., re-ballasting or track replacement).
- ***Instrumentation cars.*** Railways also run specialized railcars outfitted with lasers and video cameras to record data on track geometry and condition.

**Table 8:** Climate Risks and Associated Mitigation Approaches and Intervention Stages

| Risk ID | Climate Risk | Mitigation(s) | Adaptation Approach(es) | Intervention Stage(s) |
|---|---|---|---|---|
| **IP-1**<br>**IP-2**<br>**IP-3** | ***Intense precipitation*** leading to flooding obstructions or damage to transit assets or infrastructure. | Improve drainage system designs for more severe flooding events (e.g., 1-in-100-year vs. 1-in-50-year events). | **1** | **A** |
| | | Elevate and/or relocate infrastructure. | **3** | **A and B** |
| | | Replace under-sized culverts and outdated drainage systems. | **1** | **B** |
| | | Clear debris and obstructions from culverts and other components of the drainage system. | **2** | **C** |
| | | Reroute transit service to avoid impacted flood areas. | **3** | **C** |
| | | Update design specifications for waterproofing of encasements that house vulnerable electrical equipment. | **1** | **A** |
| | | Install high water level detection systems to improve response time and utility of other flood mitigation efforts. | **2** | **C** |
| **IP-4** | ***Intense precipitation*** impairing visibility for transit vehicle operators. | Issue speed restrictions on operations and implement use of sensors and other driver-assist technologies. | **2** | **C** |
| **IP-5** | ***Intense precipitation (snow or freezing rain)*** causing loss of traction on roadways or track guideways, and physical obstructions (snow and ice build-up). | Improve road and guideway cold weather maintenance standards, which may include the frequency and method of snow and ice clearing (e.g., plows, chemical compounds, etc.). Improved coordination between municipal services (e.g., snow clearing) and transit agencies can also help to ensure transit service can function on priority routes (e.g., links to hospitals). | **2** | **C** |
| **IP-6** | ***Intense precipitation (freezing rain)*** causing an accumulation of ice on overhead catenary, leading to a loss of power supply to transit vehicles. | Update operations and maintenance practices to keep catenary clear of ice (e.g., Region of Waterloo continually running ION LRT service to prevent ice build-up [76]). | **2** | **C** |
| **EH-1** | ***Extreme heat*** causing thermal expansion and buckling of track. | Lay track in warmer temperatures and apply low-solar absorption coatings to rail. | **1** | **B** |
| | | Issue speed restrictions on operations. | **2** | **C** |
| **EH-2** | ***Extreme heat*** causing thermal expansion and buckling and cracking of pavement. | Design and use specialized pavement compounds. | **1** | **B** |

| Risk ID | Climate Risk | Mitigation(s) | Adaptation Approach(es) | Intervention Stage(s) |
|---|---|---|---|---|
| **EH-3** | ***Extreme heat*** leading to sagging of overhead catenary. | Use tensioning mechanisms on catenary during hot operating conditions. | **2** | **C** |
| **EH-4** | **Extreme heat** causing overheating and failure of electrical systems. | Improve A/C ventilation in electrical equipment housings, select colour to reflect solar radiation, use solar absorption coatings, provide shade (trees) or relocate electrical systems to cooler areas. | **1 and 3** | **B** |
| **EH-5** | ***Extreme heat*** causing failure of electrical systems due to an increased load on the electrical grid (blackouts or brownouts). | Design the electrical power generation, transmission, and distribution system to be more resilient, and design transit operations with backup emergency power provisions. | **1** | **A** |
| **EH-6** | ***Extreme heat*** causing occupational health and safety risks to workers (heat fatigue). | Update occupational health and safety standards for the use of personal protective equipment, more frequent breaks and hydration, and heat exposure monitoring. | **2** | **C** |
| **EH-7** | ***Extreme heat*** causing drought conditions and heightening the risk of wildfires sparking (e.g., from rolling stock steel wheels or engine exhausts). | Increase vegetative clearance in areas adjacent to track and increase stringency on locomotive exhaust cleaning. | **2** | **C** |
| **EH-8** | ***Extreme heat*** leading to poor air quality caused by wildfire smoke, potentially leading to failure of HVAC systems in buildings, equipment, and vehicles. | Design ventilation systems with high efficiency particulate air (HEPA) filters. | **1** | **A** |
| **IC-1** | ***Intense cold*** causing brittle failure or structural cracks in track infrastructure. | Select appropriate material for track design (e.g., cold formed steel grades). | **1** | **A** |
| | | Issue speed restrictions for operations in cold weather conditions (more appropriate for freight). | **2** | **C** |
| **IC-2** | ***Intense cold*** causing seizure of track switches and other mechanical components. | Use gas-fed heaters for de-icing switches (e.g., used by Chicago Transit Authority [77]) | **2** | **C** |
| **IC-3** | ***Intense cold*** causing reduced operating range of battery electric vehicles. | Draft vehicle performance specifications with larger battery sizes and/or diesel auxiliary heaters to compensate for reduced operating range in cold weather. | **2** | **A and C** |
| **STV-1** | ***Seasonal temperature variations*** melting permafrost and causing degradation of subgrade and instability of geotechnical conditions. | Rehabilitate subgrade with improved construction techniques. | **1** | **B** |

| Risk ID | Climate Risk | Mitigation(s) | Adaptation Approach(es) | Intervention Stage(s) |
|---|---|---|---|---|
| **STV-2** | ***Seasonal temperature variations*** impacting freeze–thaw cycles and damage to roads (pothole formation). | Improve drainage to avoid standing water damage and apply pavement waterproofing (sealant). | **1** | **B** |
| **HW-1**<br>**HW-2** | ***Severe winds*** causing damage to infrastructure and risk of debris obstructing roads and track guideways. | Improve the design of infrastructure to withstand stronger wind forces (e.g., aerodynamics to protect against wind shear). | **1** | **A** |
| | | Temporarily suspend transit operations during high winds. | **2** | **C** |
| **HW-3** | ***Severe winds*** impairing visibility to transit vehicle operators, if paired with intense precipitation. | Issue speed restrictions on operations and implement use of sensors and other driver-assist technologies. | **2** | **C** |
| **HW-4** | ***Severe winds*** leading to increased risk of rapid wildfire spread. | Update vegetation management-related standards along rail or road corridors and prepare emergency response protocols. | **2** | **C** |
| **HW-5** | ***Severe winds*** knocking down trees or telegraph poles causing power outages. | Plan provisions for backup power supply (e.g., generators or batteries). | **1** | **A** |
| **SS-1** | ***Severe storms*** causing lightning strikes and power outages. | Design buildings with lightning protection and grounds for electrical equipment. | **1** | **B** |
| | | Plan provisions for backup power supply (e.g., generators or batteries). | **2** | **A** |
| **SS-2** | ***Severe storms*** causing hail damage. | Design modular structures to protect against hail damage (e.g., overhead canopies and roofing). | **1** | **B** |
| **SS/SL-1** | ***Storm surge*** causing flooding in coastal areas. | Improve design and construction in low-lying coastal areas by elevating vulnerable assets (segments of infrastructure) and constructing protective structures (e.g., dykes and break walls). | **1 and 3** | **B** |
| **SS/SL-2** | ***Storm surge*** causing corrosion risk of metallic infrastructure (e.g., track and electrical connectors) due to standing sea water. | Design and select material to mitigate corrosion (e.g., galvanic pairings, coatings, anodizing). | **1** | **A** |
| | | Plan provisions for the use of backup drainage systems (e.g., pumps). | **2** | **C** |
| **SS/SL-3** | ***Storm surge*** causing coastal erosion. | Improve design and construction in low-lying coastal areas and relocate vulnerable assets inland. | **1 and 3** | **B** |
| **N/A** | Several climate stressors interacting to reduce the operational lifespan of an infrastructure asset. | Conduct periodic inspections and improve maintenance practices and lifecycle rehabilitation. | **2** | **C** |

Detecting track washout and other obstructions. Railways also use the following methods for detecting segments of track impacted by washout, rockfall, and avalanches:

- ***Slide detection fences.*** In high-risk areas, railways have wires strung along hillsides that trip the signalling system if broken by an obstruction (e.g., rockfall in the Rocky Mountains) [82].
- ***Monitoring of signalling system.*** Most track is electrified at low voltage for operation of the signalling system. A track washout could create a break in the low voltage circuitry and signal that there is an obstruction to that segment of track.

## 3.9 State of Response in Canada

### 3.9.1 Response by Regulators and Government

Transport Canada has implemented several new regulatory measures to mitigate risks associated with climate change. Two notable actions taken by Transport Canada include mitigating structural damage to rail infrastructure in cold weather operations and new wildfire prevention regulations.

#### 3.9.1.1 Mitigating Structural Damage to Rail Infrastructure in Cold Weather

In 2020, Canada's Minister of Transport issued a Ministerial Order under the Railway Safety Act [83] to reduce the risk of train derailments during cold weather through railway companies developing a Winter Operation Risk Mitigation Plan [84]. This approach refers to a range of temperatures for restricting train speeds rather than relying on a specified period of calendar days during the winter months, which recognizes the rise in abnormal seasonal temperature fluctuations that may occur outside of the traditional November 15 to March 15 dates. In addition, the Ministerial Order includes measures to:

- Improve track inspection and track maintenance practices;
- Require further speed restrictions if warranted due to inspection results;
- Require risk mitigation measures to account for rapid temperature fluctuations;
- Require new technology to detect a rail break; and
- Require approval of the plan by a professional engineer [85].

#### 3.9.1.2 Mitigating the Risk of Wildfires from Rail Operations

In 2022, Transport Canada published new rules on railway fire prevention and mitigation during the fire season, which runs from April 1 to October 31 [86]. The scope of these rules include:

- Establishing temperature thresholds at which train speed restrictions are issued and supplemental track inspections are required;
- Increasing stringency on locomotive exhaust cleaning and inspection; and
- Requirements for transportation operators to develop an Extreme Weather Fire Risk Mitigation Plan, which must be submitted to Transport Canada and reviewed every 5 years [87].

At a minimum, an Extreme Weather Fire Risk Mitigation Plan should include the following measures to:

- Monitor fire risk levels;
- Detect and report fires along track right-of-way;
- Manage vegetation and the removal of combustible materials or debris from and adjacent to the right-of-way;
- Mitigate fire hazards during line work maintenance activities and respond to any fires resulting from such activities;
- Assess conditions and implement appropriate mitigations during active fire events on or encroaching on the right-of-way to maintain safe railway operations, including adjustments to train operations; and
- Respond to detected or reported fires, including immediate action to suppress the fire, communication with and/or deployment of appropriate emergency response resources [87].

### 3.9.2 Response by Transit Agencies

As noted in Section 3.6.1, several large Canadian transit agencies have already started responding to the need for climate adaptation, similar to leading transit agencies in the United States, by preparing climate vulnerability assessments (or risk assessments). This involves understanding the environmental conditions in which their transit systems operate, identifying long-term climate projections, and mapping climate stressors and risks to individual assets of their transit systems (e.g., mapping flood-prone areas to the location of stations and track).

Transit agencies have noted a correlation between developing climate risk and resiliency plans and being successful in competitive federal funding applications. Federal programs often have tight application timelines, and transit agencies that have already completed climate vulnerability assessments are in a better position to respond to funding criteria.

As a result of climate vulnerability assessments, some transit agencies are adapting their best practices for climate adaptation. For example, Metrolinx has revised its track laying temperature to mitigate the effects of track buckling during extreme heat. Traditionally, Metrolinx's track laying temperature was 32.2°C. The climate-induced increase in the average summertime daily temperature has prompted Metrolinx to adopt a higher temperature for rail laying of 37.7°C for all new track. Metrolinx assessed this preferred rail laying temperature by comparing it to future maximum temperatures from ClimateData.ca projections [88].

Some transit agencies are also starting to incorporate climate risk assessment into the formal design review process of new infrastructure, while other agencies are doing this assessment on a case-by-case basis, notably for major infrastructure projects.

Canadian transit agencies are also forming working groups via industry associations to promote knowledge sharing on transit decarbonization and climate adaptation. For example:

- The Ontario Public Transit Association (OPTA) has established the Zero Emission Bus (ZEB) Committee. One of its key topics is the need to better understand the risks associated with new low or zero emission technologies and how they interface with change climate conditions (e.g., how electric bus fleets will operate in extreme heat or extreme cold conditions, and their risk of exposure to power outages) [89].
- The SCC has formed a Hydrogen Codes and Standards Working Group that has three task forces that focus on: a) production, b) transportation and storage, and c) end-use applications, including transportation [90].

Other working groups focus on topics such as reviewing technologies to monitor flooding risks along track rights-of-way, and revisions to operating and maintenance procedures. Industry associations include OPTA, the Canadian Urban Transit Association, and the Railway Association of Canada, which have relevant working groups established.

According to the consultations with transit agencies, the constant technological advancement of low and zero emission technologies poses a challenge for the formation of standards. However, transit agencies are sharing within working groups their best practices and lessons learned from the deployment of new transit vehicles (e.g., battery electric and hydrogen buses).

### 3.9.3 Response by Federal Research and Standardization Organizations

#### 3.9.3.1 Standards Council of Canada

In the area of climate change sustainability, the SCC launched a Standards to Support Resilience in Infrastructure Program in 2016, which supports projects ranging from publishing reports that identify priorities and best practices for climate change adaptation to supporting the work of national and international standards committees to funding the development of new standards and updating existing ones [91].

The SCC's report Standards in Action: Building a Climate-Resilient Future [4] identified gaps in standards, codes, and practices that leave Canadians vulnerable to climate change. The report also identified a significant need for investments in standards to ensure Canada's infrastructure is climate ready, and emphasized that more than 100 standards are out-of-

date and require updates to reflect Canada's current environmental conditions [4]. The report acknowledged that Canada's responses to climate change are maturing, but there are still gaps to be addressed [4]. Furthermore, it noted that standardization could aid the development of cost-effective solutions for responding to climate change but indicated that more effort will be required to promote awareness of standards and to build capacity to understand how standards can be applied [4]. Overall, Canada's standardization efforts need to be more inclusive of diverse perspectives and must understand that the urgency and type of response to hazards triggered by climate change can vary greatly across Canada's vast geography [4].

In 2021, the SCC also commissioned a Guide for Integrating Climate Change Adaptation Considerations into Canadian Standards [92], which is specifically relevant to standards development organizations. In 2022, the federal government announced an additional $11.7 million over 5 years for the Standards to Support Resilience in Infrastructure Program [91].

#### 3.9.3.2 National Research Council

The NRC is a federal agency reporting through the Minister of Innovation, Science and Industry, and is Canada's largest federal research and development organization. Among other areas, the NRC carries out research and provides guidance to support the federal government's climate change resilience agenda (as laid out in the Pan-Canadian Framework on Clean Growth and Climate Change [93]).

As previously mentioned, the NRC led the CRBCPI with the goal to "provide the knowledge needed to integrate climate resilience into building and infrastructure design, guides, standards, and codes" [5]. In 2019, the CRBCPI program published a detailed report on the state of practice and knowledge gaps on climate change adaptation, with a wide range of observations related to the public transit sector, among other sectors [6].

The CRBCPI report noted that bridges are generally designed to the Canadian Highway Bridge Design Code, which is managed by CSA Group. However, there is no standard approach for determining the impact of future climate loads or the stresses of simultaneous extreme weather events on bridge performance. In addition, despite relatively standardized methods for road design and construction, there are still possibilities for improving pavement materials, road condition monitoring, and repair methods. Futhermore, railway engineering in Canada typically relies on standards published by the American Railway Engineering and Maintenance-of-Way Association (AREMA), which may not be fully applicable to Canada's environmental conditions. Climate issues and weather events, such as flooding, are addressed in some aspects of AREMA standards but often in a static reference, so they may not reflect the dynamic nature of a changing climate and environmental conditions.

The CRBCPI report also stated that:

> *"A complicating factor in providing guidance on climate change adaptation is that there is no single standard for rail transit infrastructure in use across Canada. The different systems were installed at very different times and have different legacy equipment and standards. Climate change resilience guidance will therefore need to be in the form of best practices, rather than codes or standards." [6]*

In 2022, the Canadian Government announced a new Climate Resilient Built Environment initiative, led by the NRC, which will provide knowledge to adapt public infrastructure where necessary, inform changes to building and infrastructure codes, and create guidelines, standards, and technical solutions for climate resilience. The initiative has been provided with $35 million in funding over five years [91].

Under the Climate Resilient Built Environment initiative, the NRC has a 4-year working program within their Automotive and Surface Transportation Research Centre that is focused on safety, efficiency, and resilience of road, rail, and off-road modes [94]. As part of this program, there is a monthly meeting with transit agencies across Canada to discuss and share information on resilience concerns in their operations.



**"NRC led the CRBCPI with the goal to "provide the knowledge needed to integrate climate resilience into building and infrastructure design, guides, standards, and codes" [5]."**

One of key themes emerging from the NRC meetings is a lack of common guidance on resilience for rail transit agencies that is specific to the Canadian context [6]. As noted, most agencies use AREMA standards or guidance from the American Public Transport Association, which may not always be suited to the Canadian climate. For example, Canadian rail operators typically face more challenges with ice and snow build-up than their American collagues. These increasing challenges could potentially affect operations and safety at crossings and switches, as well as overhead catenary and other power system sources.

# 4 Discussion and Recommendations

## 4.1 Key Climate Risks

The findings indicate that climate risks related to intense precipitation and extreme heat, as shown in Table 9, are the most pressing concerns for the Canadian public transit sector. Both of these climate stressors are Canada-wide concerns that are projected to continue worsening, which suggests that the benefits of developing or improving standards to account for these risks would be wide-reaching. In addition, freezing rain events resulting from a combination of higher precipitation and longer periods of near freezing temperatures in winter could also become more problematic in the future [16].

Certain climate risks, namely IP-3, IP-6, EH-3, EH-4 and EH-5, are further highlighted as an important consideration in resilience planning due to the continued decarbonization of the public transit sector and the emergence of higher order transit systems, such as LRT. These trends are changing the risk profile of public transit systems by creating a greater reliance on the resiliency of electrical systems for powering transit operations.

In addition, some of the other climate-related risks listed in Table 8 may require special consideration, as their climate adaptation measures may be of higher priority for certain regions. For example, addressing storm surge and coastal flooding in Atlantic and Pacific Canada, permafrost degradation in northern Canada, and severe thunderstorms with high winds in the Great Lakes region.

## 4.2 Opportunities for Standardization

The research conducted for this report identified the key climate risks and potential mitigation measures for Canada's public transit systems. These findings informed the identification of the following ten areas for further exploration in the context of standardization efforts and climate adaptation:

1. Design for stormwater management systems to increase capacity and efficiency to address high-intensity rainfall events, which are likely to cause flooding.

2. Design and planning for high water level monitoring systems along track right-of-way to detect flood risk and enable appropriate changes to operations and emergency plans to a) uphold safety, and b) mitigate disruptions to transit operations.
3. Design for waterproofing vulnerable electrical equipment (e.g., power, signals, and communications), particularly in subterranean structures (e.g., underground stations and tunnels), to address the risk of water and moisture ingress during heavy rain, and possible short-circuits, corrosion, and other modes of equipment failure.
4. Operations and maintenance for overhead catenary systems to address the issues of catenary sag during hot temperatures and ice build-up during freezing rain events.
5. Operations and maintenance for roads and guideways to address the risk of traction loss for transit vehicles due to the build-up of snow and ice on roads and guideways.
6. Design for building, equipment, and vehicle ventilation systems to increase cooling capacity and air filtration to address the risk of extreme heat causing equipment failures, heat-related health issues to workers and the public, and the risk of poor air quality from disasters, such as wildfires, impeding traditional approaches to cooling and ventilation (e.g., opening depot overhead doors for ventilation on a hot day).
7. Fire safety of transit maintenance and storage facilities to address the fire hazard of new technologies being stored indoors, namely thermal exposure of battery electric buses and flammability risk of alternative fuels, such as hydrogen.
8. Construction methods for laying track to address the risk of buckling and train derailment during periods of extreme heat.
9. Materials for pavement compounds to address the issues of pavement buckling during hot temperatures and permeability to assist with stormwater management during intense rainfall events.
10. Design and planning for backup power provisions to address the risk of brownouts and blackouts impacting transit operations, and the ability to provide an essential service in emergency situations (e.g., transportation of vulnerable populations to cooling centres during heat waves).

# 5 Conclusions

There is a growing need to address climate adaptation and resiliency of public transit systems across Canada. Extreme weather events are becoming more frequent and more severe, which is resulting in costly system level distruptions.

Intense precipitation and extreme heat are the two most pressing Canada-wide climate stressors, for which there is a range of risk identification and adaptation opportunities where standardization can play a role in mitigation efforts. This report identifies ten areas for further exploration in the context of standards development and climate adaptation, which encompass standardization opportunities throughout an asset or system lifecycle to potentially yield improvements in climate adaptation and resiliency for Canada's public transit sector.

The SCC and ISO have developed guidelines for incorporating climate adaptation into standards development. The NRC is also actively involved in identifying climate change risk and resilience considerations. However, gaps remain on how to apply this guidance to assets and systems in the public transit sector. Furthermore, trends such as the electrification of public transit systems are increasing the vulnerability of systems to existing climate stressors and creating exposure to new risks.

There are opportunities for standards development agencies to engage with industry associations and their working groups to continue advancing the integration of climate adaptation into standards for Canada's public transit sector.

**Table 9:** Summary of Key Climate-Related Precipitation and Heat Risks for Public Transit Systems

| Climate Stressor | Risk ID | Description |
|---|---|---|
| **Intense Precipitation** | IP-1 | Flooding and washout of roads, bridges, rail lines, and other infrastructure. |
| | IP-2 | Water ingress to tunnels and other subterranean structures (e.g., underground stations) causing damage to infrastructure. |
| | IP-3 | Water ingress to housings of electrical systems leading to short-circuits, power supply interruption, and possible system failures. |
| | IP-5 | Loss of traction on roadways or track guideways and physical obstructions (e.g., snow and ice build-up). |
| | IP-6 | Freezing rain causing an accumulation of ice on overhead catenary, leading to loss of power supply for transit vehicles. |
| **Extreme Heat** | EH-1 | Buckling of track due to thermal expansion and increased derailment risk. |
| | EH-2 | Buckling/cracking of pavement due to thermal expansion. |
| | EH-3 | Sagging overhead catenary due to excessive heat/thermal expansion. |
| | EH-4 | Failure of electrical systems due to a lack of ventilation and/or increased load on A/C systems. |
| | EH-5 | Failure of electrical systems due to an increased load on the electrical grid (blackouts or brownouts). |
| | EH-6 | Occupational health and safety risks to workers (heat fatigue). |
| | EH-7 | Drought and increased risk of poor air quality caused by wildfire smoke, potentially leading to failure of HVAC systems (buildings and vehicles). |

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# Appendix A—Regional Efforts to Identify Climate Risks to Public Transit across Canada

**Table A:** Regional Efforts to Identify Climate Risks to Public Transit across Canada

| Region and City (Transit Agency) | Climate Risk Identification and Adaptation Approaches |
|---|---|
| **Atlantic Canada**<br>**Halifax Regional Municipality**<br>**(Halifax Transit)** | ▪ The Halifax Regional Municipality has prepared a climate action plan, HalifACT 2050 [95], which identifies projected climate changes for Halifax and a strategic vision for reducing greenhouse gas emissions at the municipal level. The need for high level risk assessments with internal and external representatives for utilities, transportation, water, health facilities, and telecoms are identified as strategic actions [95].<br>▪ The City of Halifax has perfomed LiDAR mapping of sea level risk to inform the potential risks of climate change, notably to the Halifax harbour [96].<br>▪ Halifax Transit has not yet completed a climate vulnerability or risk assessment. However, several public transit projects have started incorporating design aspects for climate resiliency. Consultations with interested parties provided the following examples:<br>  ▪ Increasing the horizontal setback distance and elevation of a new ferry terminal to accommodate future sea level rise and mitigate flooding risk; and<br>  ▪ Adding specifications for backup power provisions at the Burnside Transit Centre. |
| **Central Canada**<br>**City of Montreal**<br>**(ARTM and STM)** | ▪ The City of Montreal has prepared a Climate Plan 2020–2030 [97], which includes strategic priorities to adopt an investment target for climate change adaptation and to establish thresholds for climate resiliency that are integral to decision-making for infrastructure projects [97].<br>▪ The City of Montreal has also developed a climate adaptation plan that provides a broad assessment of climate change and risks across various types of municipal infrastructure, including a cursory mention of public transit. It has also published a summary of adaptation actions, detailed in Climate change adaptation plan for the Montreal urban agglomeration 2015–2020 [98].<br>▪ Consultations with interested parties indicated that L'autorité régionale de transport métropolitain (ARTM) is still in the early stages of developing a guide for the design of infrastructure and an asset management system that incorporates climate risk.<br>▪ The Société de transport de Montréal (STM) has a Sustainable Development Plan 2030 [99], which includes (under Priority 2) a proposed action to develop and implement a climate change adaptation plan for STM buildings and infrastructure. |
| **Central Canada**<br>**City of Ottawa**<br>**(OC Transpo)** | ▪ The City of Ottawa developed an overall Climate Change Master Plan [100], followed by a Climate Change Vulnerability and Risk Assessment [101], which assessed potential climate impacts on health, community well-being, infrastructure, natural environment, and the economy. The results of the vulnerability/risk assessment will inform the development of a Climate Resiliency Strategy, which is currently underway [102]. |

| Region and City (Transit Agency) | Climate Risk Identification and Adaptation Approaches |
|---|---|
| **Southern Ontario**<br>**City of Toronto (TTC and Metrolinx)** | ▪ The City of Toronto has a net zero strategy, TransformTO [103], focused on emissions reduction, as well as a Resilience Strategy [104]. Both strategies reference transportation needs in addition to other areas.<br>▪ Metrolinx has a Climate Adaptation Strategy [8] that contains 40 actions to mitigate the impacts of climate change on Metrolinx's transit service. These include considering climate resiliency within technical standards, manuals, and project agreements as new transportation infrastructure is built.<br>▪ Consultations with interested parties indicated that the TTC is expanding its in-house resources specialized in climate resiliency and adaptation through its Innovation and Sustainability program to embed climate resiliency into organizational best practices.<br>▪ The TTC has also worked with the University of Toronto on research that maps climate risks (notably flooding impacts) to the public transit service [105].<br>▪ Consultations with interested parties also indicated that the TTC has completed some climate risk and vulnerability assessments for specific assets (e.g., Greenwood Yard), but a system-wide climate vulnerability assessment has yet to be completed, and climate resiliency is not formalized in the various design, planning, procurement, and other processes for capital projects. |
| **Northern Ontario**<br>**North Bay, Cochrane, Moosonee**<br>**(Ontario Northland)** | ▪ Ontario Northland has recognized sustainability in its Business Plan 2021–2022, along with the need for a better understanding of climate hazards and mapping short- and long-term risks to their transportation assets and service [106].<br>▪ Ontario Northland has applied and received funding from Transport Canada's Rail Climate Change Adaptation Program to fund the installation and use of high water level detection systems along the track right-of-way to monitor flood risk [107]. In addition, Ontario Northland uses a combination of satellite imagery, on-ground inspectors, helicopters, and drones to assess the condition of drainage infrastructure, and to identify, map, and monitor areas prone to flooding risk (before the spring thaw).<br>▪ Consultations with interested parties indicated that Ontario Northland is a member of the Railway Association of Canada's environment and sustainability committee. |
| **Prairies/Western Canada**<br>**City of Calgary**<br>**(Calgary Transit)** | ▪ The City of Calgary has developed a Climate Risk Assessment Framework and Process Guide for all public infrastructure projects [108]. The guide identifies nine climate hazards (stressors): extreme heat, increased air temperature, wildfires, drought, short-duration high-intensity rainfall, severe storms, high winds, river flooding, and heavy snowfall. Public transit is captured under this scope.<br>▪ Calgary Transit applied this framework to conduct a Fleet Electrification Planning Study: Climate Risk and Resilience Assessment [109] to evaluate potential impacts from climate change on built and charging infrastructure, fleet assets, the environment, and people. The assessment, which was informaed by the PIEVC High Level Screening Guide, also contains recommendations and strategies to reduce risk and improve resilience to climate change. |

| Region and City (Transit Agency) | Climate Risk Identification and Adaptation Approaches |
|---|---|
| **Pacific Canada**<br>**City of Vancouver**<br>**(TransLink)** | ▪ The City of Vancouver has developed a Climate Change Adaptation Strategy [110], which includes research on climate stressors and trends, a vulnerability and risk assessment, and evaluation of adaptation actions. The strategy covers impacts to municipal infrastructure, services, and the general population, but does not go into detail about specific public transit assets or risks.<br>▪ TransLink has prepared a Climate Action Plan [111] to focus on mapping climate-related issues to risks specific to the public transit service, including passenger rail, bus, and ferries. The assessment that informed TransLink's plan was based on the PIEVC High Level Screening Guide. TransLink's plan also includes actions to embed climate-related responsibilities and knowledge across the organization.<br>▪ Consultations with interested parties indicated that climate vulnerability and risk assessments are done on a project specific basis, notably for large infrastructure projects. However, TransLink is working toward integrating climate risk assessment into standard practice for all projects, addressing resiliency and adaptation in design requirements.<br>▪ Consultations with interested parties also indicated that TransLink works in close collaboration with municipalities on emergency response plans (referencing CSA Z1600, Emergency and Continuity Management Program). Transit is seen as an essential service in emergency response planning (e.g., transporting evacuees, ensuring the elderly and other vulnerable populations can get to cooling centres during heat waves, and coordinating with municipal snow clearing priorities to ensure transit access on routes serving hospitals and other care centres). |

# Appendix B—Federal and Provincial Funding Programs Supporting Identification and Assessment of Climate Risks to Public Transit

**Table B:** Federal and Provincial Funding Programs Supporting Identification and Assessment of Climate Risks to Public Transit

| Program and Funder | Purpose |
|---|---|
| **Rail Climate Change Adaptation Program (R-CCAP)**<br>**Transport Canada** | To provide funding to Class I, II, or III railways for research and development on innovative tools, technologies, and approaches to address climate risk [107].<br>A major focus of the R-CCAP, as evident by the projects funded, is flood monitoring and mitigation measures. For example, Ontario Northland received $300,000 for the installation of high water level sensors along rail right-of-way and for the use of drones and satellite imagery to monitor regional water levels and assess flooding risk along its passenger rail corridor into northern Ontario. Projects to monitor geotechnical hazards (e.g., landslides, rockfalls, sinking, and erosion) have also received funding.<br>**Total funding:** $5.4 million (closed) |
| **Disaster Mitigation and Adaptation Fund (DMAF)**<br>**Infrastructure Canada** | To provide funding to harden public infrastructure (including transit) against the impacts of climate change [112].<br>Project types include new construction of public infrastructure, reinforcement or modification of existing infrastructure, and use of natural infrastructure to prevent, mitigate, or protect against extreme weather and climate change.<br>**Total funding:** $3.375 billion (closed) |
| **Rail Safety Improvement Program (RSIP)**<br>**Transport Canada** | To provide funding directed at a range of activities, including research and analysis on how to adapt Canada's critical rail infrastructure against the impacts of climate change [113].<br>**Total funding:** $100 million (closed) |
| **Natural Infrastructure Fund (NIF)**<br>**Infrastructure Canada** | To provide funding for natural infrastructure projects to make communities more sustainable and resilient to climate change [114].<br>Projects may include hybrid infrastructure (a combination of built and natural), such as green roofs and naturalized stormwater ponds. Other project examples include living dykes and natural coastal restoration.<br>**Total funding:** $200 million (closed) |

| Program and Funder | Purpose |
|---|---|
| **Northern Transportation Adaptation Initiative (NTAI)**<br>**Transport Canada** | To provide funding to communities in Canada's northern territories to support projects that [115]:<br>▪ Develop new knowledge about how climate change is affecting transportation systems in northern Canada;<br>▪ Develop tools and practices to respond to these effects; and<br>▪ Provide education and training to help manage transportation systems affected by climate change.<br>To date, funded projects include measuring permafrost thaw and climate change impacts on the cost of maintaining roads and highways in northern Canada [116].<br>**Total funding:** $7 million (closed) |
| **Investing in Canada Infrastructure Program (ICIP)**<br>**Infrastructure Canada** | To deliver the Investing in Canada Plan funding through a cost-sharing model between federal, provincial, and territorial governments [117]. There are four funding streams:<br>▪ Public transit infrastructure<br>▪ Green infrastructure (including climate adaptation projects)<br>▪ Community, culture, and recreation infrastructure (not relevant to the scope of this research)<br>▪ Rural and northern communities infrastructure<br>**Total funding:** $33 billion (closing 2027/28) |
| **Climate Change Preparedness in the North Program**<br>**Crown–Indigenous Relations and Northern Affairs Canada** | To provide funding to climate change adaptation projects in Yukon, the Northwest Territories, Nunavut, Nunavik, and Nunatsiavut [75]. This program provides support for the following project types:<br>▪ Vulnerability and risk assessment of climate change impacts;<br>▪ Development of hazard maps and adaptation plans;<br>▪ Development of adaptation options; and<br>▪ Implementation of non-structural and structural adaptation measures<br>**Total funding:** $5 million per year (open) |
| **Sustainable Communities Challenge Fund**<br>**Nova Scotia** | To support Nova Scotia communities with climate change mitigation and adaptation, including projects to address flooding and the impacts of extreme heat. The Nova Scotia Federation of Municipalities developed and administers the fund on behalf of the province [118].<br>**Total funding:** $15 million (closing 2025) |
| **Climate Impact Fund**<br>**New Brunswick Innovation Foundation and Opportunities New Brunswick** | To fund research and development of innovative solutions to help address climate change and adaptation measures [119]. There are two funding streams:<br>▪ Climate mitigation and cleantech development<br>▪ Climate adaptation, environmental, and social impacts<br>**Total funding:** $1.5 million (open) |
| **Climate Municipalities Program**<br>**Government of Québec** | The Government of Quebec allocated $40 million in funding to support research and analysis ($5 million) and pilot demonstrations ($35 million) for municipal projects that reduce greenhouse gas emissions or support climate adaptation [120].<br>**Total funding:** $40 million (closed) |

| Program and Funder | Purpose |
|---|---|
| **Electrification and Climate Change Fund and Green Economy Plan**<br>**Government of Québec [121]** | To promote electrification and adaptation to climate change, this program is funded by revenue from Quebec's carbon pricing market (carbon tax) [121]. Since 2021, all new projects have been funded through the 2030 Green Economy Plan [122].<br>Of note, the Ministry of Transport has a tracking database of projects to increase knowledge on climate hazards (stressors) and adaptation solutions for transport infrastructure. In addition, there are several streams tracking municipal infrastructure climate adaptation projects, such as support for integration of climate change into municipal planning, adaptation of stormwater management systems, adaptation for heat waves, and monitoring permafrost degradation in northern Quebec [123].<br>**Total funding:** Variable amount, funded from carbon tax revenue (open) |
| **Conservation and Climate Fund**<br>**Manitoba** | To provide financial support to projects that deliver on one or more of the following priorities [124], [125]:<br>▪ Reducing greenhouse gas emissions;<br>▪ Addressing the effects of climate change, including measures to adapt to climate change; and<br>▪ Promoting sustainable development while ensuring natural resources are managed in a way that ensures availability for future generations.<br>**Total funding:** $1.5 million (closed) |
| **Adapting to Climate Change**<br>**British Columbia** | To make highways safer by increasing the resiliency of BC highway networks and roads to the threats of climate change [126].<br>As part of BC's Economic Plan [127] and its Climate Preparedness and Adaptation Strategy [128], the provincial government has committed funding for a variety of projects, including riverbank erosion protection, creek channel training, culvert upsizing, flood protection works, slope erosion protection and avalanche system maintenance [129]. The Climate Preparedness and Adaptation Strategy has $500 million invested across a broad range of sectors and industries [130].<br>**Total funding:** $21 million |

## CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

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