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CHAPTER 2: SYNTHESIS

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Transportation plays a critical role in the movement of goods and people in Canada, supporting all sectors of the economy and Canadians' quality of life. The effects of a changing climate and extreme weather present both risks and opportunities to transportation infrastructure and operations. How Canadians adapt to these changes will be important to ensure the continued prosperity of our nation.

This Synthesis summarizes findings from the seven core chapters of the report *Climate Risks and Adaptation Practices for the Canadian Transportation Sector 2016*, and presents examples of regional climate impacts, specific modal impacts (e.g., road, rail, marine, air and urban systems), and adaptation approaches being undertaken across Canada. (References for the examples presented in this chapter appear throughout the report.)

The following present high-level conclusions from the report:

- **Transportation infrastructure, essential to Canada's domestic and international trade, is vulnerable to damage and disruptions from a changing climate and extreme weather, and this can pose risks to other sectors of the economy.** Studies are underway to better understand these vulnerabilities, and adaptive practices are being undertaken to reduce future impacts. Regional chapters provide further details on initiatives related to the Great Lakes-St. Lawrence Seaway, the Chignecto Isthmus (highway and rail), Port Metro Vancouver, Port Saint John, and other trade infrastructure.

- **Climate and weather-related delays and disruptions to passenger travel could become more frequent in future.** These events can temporarily isolate remote communities in northern regions, which may rely on a single highway or airport for connectivity, and lead to costly damages and travel disruptions for large urban areas. Redundancies in transportation systems (allowing multiple methods of travel) are one method to reduce these impacts.

- **Northern transportation systems are experiencing some of the greatest impacts from warming, and temperatures will continue to increase at a faster rate than any other region in Canada.** Degrading (thawing) permafrost has caused damage to roads, railways, and airport taxiways and runways, and will continue to pose risks to transportation safety, efficiency, and maintenance budgets in the North. The operating windows and capacities of some winter (ice) roads have also shortened in recent years, resulting in the need for alternative methods of shipping.

- **A changing climate is expected to result in some opportunities for Canadian transportation.** Potential benefits include longer marine navigation and construction seasons, reduced winter maintenance, greater operating efficiency for rail, and improved fuel efficiency for all modes. Melting sea ice is also slowly opening up arctic waters to new navigation routes, however, the increased mobility of summer sea ice, as well as increased coastal erosion and storm surge flooding, present ongoing difficulties for shipping, exploration, and associated coastal infrastructure.

- **Reactive approaches to managing climate risks (e.g., responding to past impacts or events), remain common in Canada's transportation sector. At the same time, examples can be found in all regions, and for all transportation modes, of actions being taken in anticipation of future climate conditions.** Many owners and operators, both public and private, have adapted their operations based on investigations and lessons learned from past weather-related events. Transportation decision-makers are also more frequently engaging in pro-active planning.

- **Transportation decision-makers are increasingly adopting a risk management approach to reduce climate risks to their infrastructure and operations.** A variety of specific practices are being used to enhance climate resilience of transportation systems, including integration of climate considerations into organizational planning, policy and design changes, risk and vulnerability assessments, structural and physical adaptations, smart technologies and operational and maintenance changes.

REGIONAL CLIMATE RISKS

While there is considerable variation in Canada's climate, transportation systems across the nation share many of the same climate risks; practitioners can therefore learn from each other's experiences. Risks common to all regions include extreme weather events (particularly heavy precipitation) and extreme and fluctuating temperatures. Extreme events have affected communities across the country, including large urban centres, costing billions in disaster-related losses. Provinces and territories with marine coasts face common risks associated with storm surge flooding, sea-level changes, and coastal erosion. Canada's northern regions, including the three territories and the northern parts of several provinces, all face risks associated with thawing permafrost.

Examples of past impacts to each region's transportation system from climate change and extreme events are depicted in Figure 1. These impacts are characteristic of many, though not all, of the future risks these regions face.

Figure 1. Examples of past impacts to each region's transportation system from climate change and extreme events. (Sources: Ontario – The Arthur M. Anderson unloading at Huron, Ohio, November 29, 2008, By Zars[2]/CC BY- SA 3.0, from Wikimedia Commons; Urban Canada – Frank Frigo, City of Calgary; sources of other photos can be found in other chapters)

2 https://commons.wikimedia.org/wiki/File:AMAnderson.jpg

MODE-SPECIFIC IMPACTS

Similar to regional climate risks, Canada's four major modes of transportation – road, rail, marine, and air – share many common risks to their infrastructure and operations. Furthermore, due to the integration of transportation modes and their physical proximity to one another, weather impacts that adversely affect one mode of transportation tend to have negative impacts on others. An example is the history of simultaneous and sequential failure of highways and rail lines in British Columbia, which often run in parallel along mountain corridors and rivers.

Each transportation mode also faces unique risks. The sections below depict some of the ways that climate and weather can affect road, rail, marine, air, and urban transport systems in Canada, based on the findings in this report. (Note: Drawings are for illustration purposes only and not intended to be technically accurate).

ROAD TRANSPORT

Climate and weather-related impacts on road transportation (Figure 2) can compromise safety and efficiency, disrupt operations, and increase maintenance and operational costs. Anticipated changes to some climate variables can also provide benefits to road transport. For example, warmer winter temperatures can lead to greater fuel efficiency for vehicles, longer construction seasons, and reduced winter maintenance requirements.

Figure 2: How climate and weather can affect road transport. (Illustration created by www.soaringtortoise.ca)

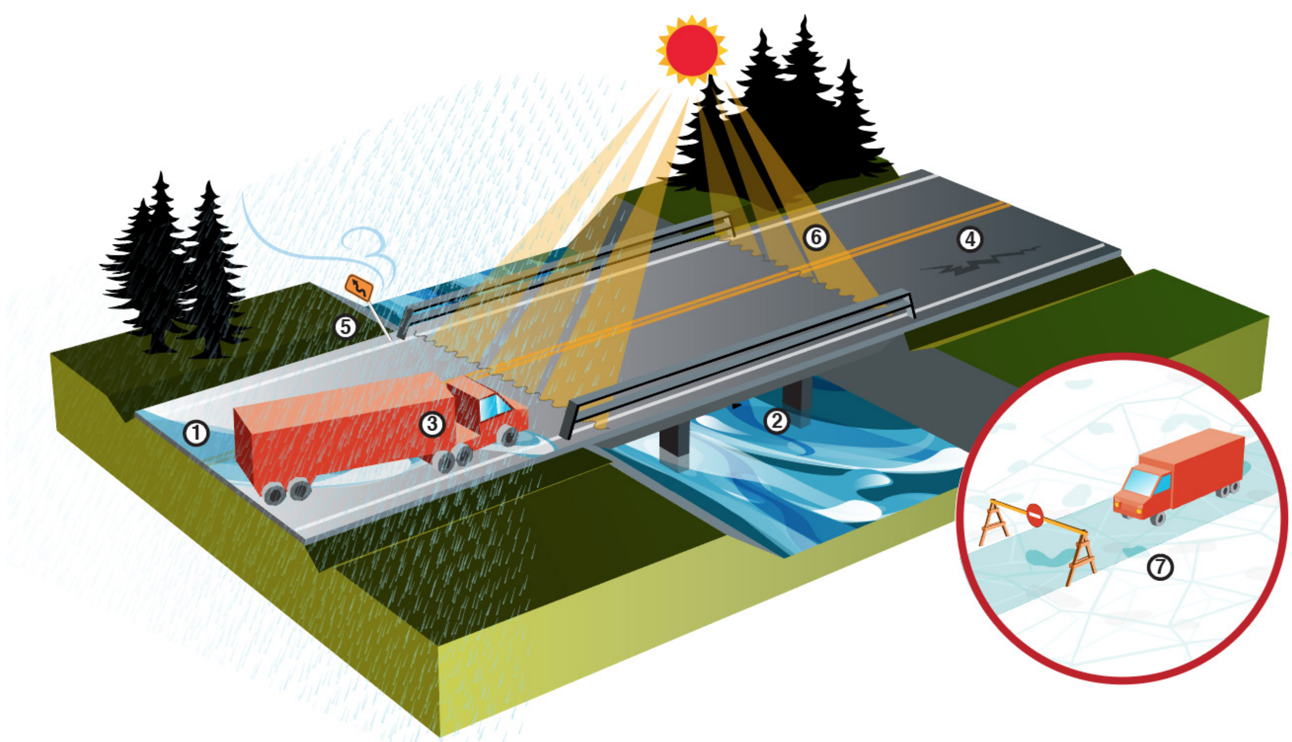


Table 1: Examples of direct impacts on road transportation from various climate factors.

	EXAMPLES OF CLIMATE IMPACTS ON ROAD TRANSPORT	CLIMATE FACTOR(S)
①	**Flooding, damage, and wash-outs of roads and bridges**	• Extreme precipitation (heavy rainfall) and associated standing water, landslides, mudslides, ice-jam flooding, debris floods • Storm surges/sea level rise in coastal areas
②	**Bridge scour**[1]	• Extreme precipitation (heavy rainfall, flood-induced erosion)
③	**Reduced vehicle traction / stability, visibility issues**	• Extreme precipitation • Freezing rain • High winds (including blowing snow)
④	**Damage and deterioration of roads**	• High temperatures (pavement softening, rutting, flushing, bleeding) • Freeze-thaw cycles (pavement deformation, shearing, deterioration) • Warming and thawing of permafrost (ground settlement, slope instability, drainage issues, cracking) • Extreme precipitation (weakened embankments, depressions)
⑤	**Damage to road structures (including signage and traffic signals), obstructions (i.e. fallen power lines/ trees), bridge closures**	• High winds • Extreme precipitation • Freezing rain
⑥	**Thermal expansion of bridge joints, potentially resulting in "blow ups"**	• High temperatures
⑦	**Reduced integrity of winter roads, shortened operating season**	• Warming temperatures

[1] Scour refers to the erosion of sediment at the base of bridge piers, abutments and other underwater structures

RAIL TRANSPORT

Similar to road transportation, the safety, efficiency, and reliability of rail transportation can be compromised by the climate impacts illustrated in Figure 3. Extreme precipitation and coastal storm surges can cause washouts, while both permafrost degradation and temperature extremes can necessitate slower train speeds and potentially cause derailments. At the same time, warming winter temperatures, which are projected throughout Canada, may reduce track and mechanical issues caused by extreme cold.

Figure 3: How climate and weather can affect rail transport. (Illustration created by www.soaringtortoise.ca)

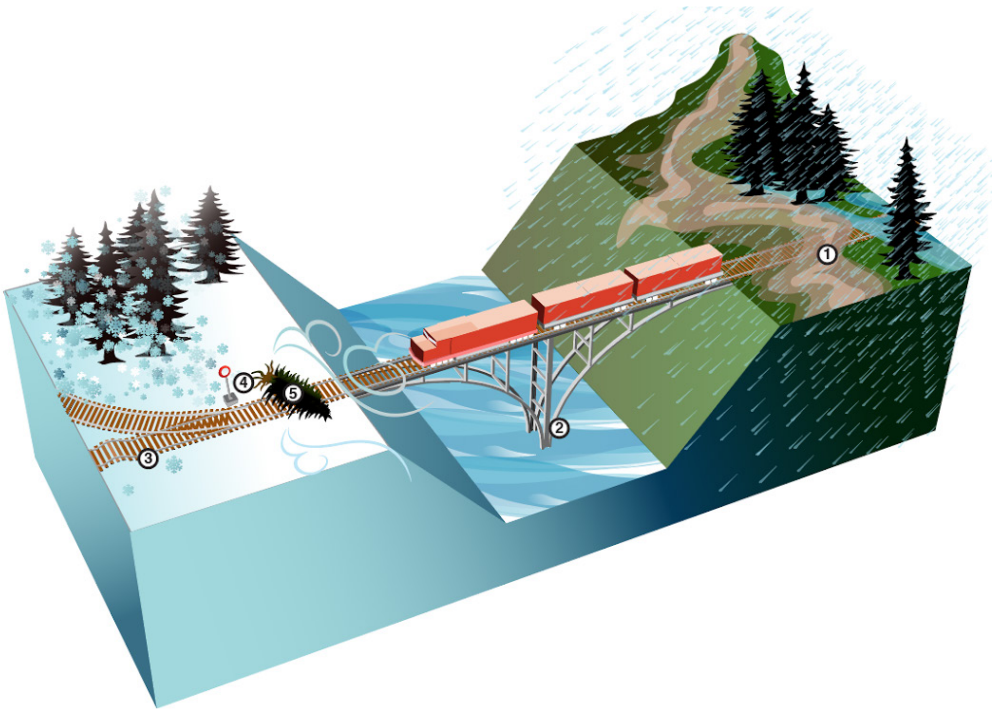


Table 2: Examples of direct impacts on rail transportation from various climate factors.

	EXAMPLES OF IMPACTS ON RAIL TRANSPORT	CLIMATE FACTOR(S)
①	**Flooding, wash-outs, and obstructions of railway tracks and embankments, bridges, and culverts, flooding of below-grade tunnels**	• Extreme precipitation (heavy rainfall) and associated standing water, landslides, mudslides, rock slides, debris floods, ice-jam flooding • Storm surges/sea level rise in coastal areas
②	**Rail bridge scour and damage to bridge structures from ice jams**	• Extreme precipitation (heavy rainfall, flood-induced erosion)
③	**Buckling of rail tracks**	• Permafrost thaw • Extreme heat or large temperature fluctuations
④	**Broken rail tracks and equipment malfunctions and failures (may include broken wheels, reduced effectiveness of brakes, frozen switches)**	• Extreme cold
⑤	**Damage to signalization equipment, rail line obstruction (i.e. fallen power lines/trees), railcar blow-over**	• High winds • Extreme precipitation • Freezing rain

AIR TRANSPORT

Many of the impacts to air transport illustrated in Figure 4 can lead to flight delays, diversions and cancellations. Few accidents are caused by weather conditions in the absence of other contributing factors. Instrument landing systems and other innovations allow aircraft to fly safely in difficult weather conditions, and aircraft are grounded in conditions considered unsafe for flight. Climate risks to airport infrastructure tend to present greater challenges for smaller airports in Canada, which lack the same technologies and resources as larger airports.

Figure 4: How climate and weather can affect air transportation. (Illustration created by www.soaringtortoise.ca)

Table 3: Examples of direct impacts on air transportation from various climate factors.

	EXAMPLES OF IMPACTS ON AIR TRANSPORT	CLIMATE FACTOR(S)
①	**Flooding of airport runways/taxiways, and damage to airport structures and equipment**	• Extreme precipitation (heavy rainfall) and associated standing water • Storm surges/sea level rise in coastal areas
②	**Damage to runways, taxiways**	• High temperatures (pavement softening, rutting, flushing, bleeding) • Freeze-thaw cycles (pavement deformation, shearing, deterioration) • Warming and thawing of permafrost (ground settlement, slope instability, drainage issues, cracking) • Extreme precipitation (weakened embankments, depressions)
③	**Damage to terminals and navigation equipment**	• High winds • Extreme precipitation
④	**Decreased traction on runways**	• Extreme precipitation • Freezing rain
⑤	**Reduced "lift" in aircraft during take-off (plane requires more fuel or must carry less weight)**	• Extreme high temperatures
⑥	**Aircraft not able to take-off or land**	• Extreme fog (low visibility) • Wind (strong cross-winds/tailwinds affect some runways)
⑦	**Operational impacts (equipment malfunction and failure, occupational health and safety issues)**	• Extreme temperatures (heat and cold)
⑧	**Increased use of pavement de-icers (runways) Increased use of aircraft de-icing and anti-icing**	• Changing precipitation conditions

MARINE TRANSPORT

The impacts illustrated in Figure 5 can disrupt marine transportation and compromise the efficiency of port and shipping activities. For example, lower water levels on inland waterways can reduce the cost-effectiveness of marine shipping by decreasing the capacity of vessels, and result in a shift to other ports or other modes of transportation. Hazards to marine navigation from changing ice conditions and storm events can pose safety risks. Ports along Canada's Atlantic and Pacific coasts are subject to impacts from sea level rise and storm surges, and some may also be vulnerable to coastal erosion. Warming temperatures can result in opportunities for marine transport, including a longer operating season and potentially open up shipping routes in Arctic waters, however, this is tempered by continuing challenges to navigation and safety posed by mobile summer sea ice and older, thicker ice.

Figure 5: How climate and weather can affect marine transportation. (Illustration created by www.soaringtortoise.ca)

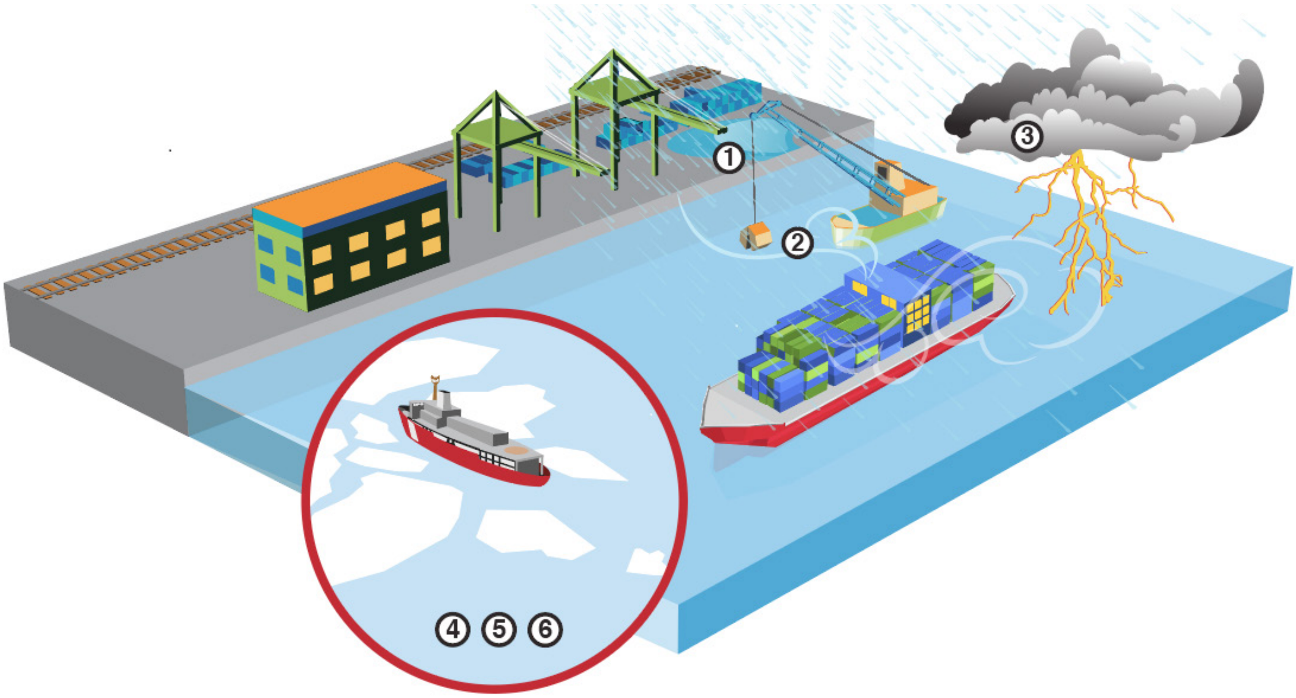


Table 4: Examples of direct impacts on marine transportation from various climate factors.

	EXAMPLES OF IMPACTS ON MARINE TRANSPORT	CLIMATE FACTOR(S)
①	**Flooding and/or damage to port facilities**	• Extreme precipitation (heavy rainfall) and associated standing water • Storm surges/sea level rise, erosion in coastal areas • Freezing rain (ice-scour damage on dock structures and visual navigational aids) • Low water levels (damage and accelerated decay of exposed infrastructure)
②	**Increased or reduced access to ports, dredging requirements**	• Increasing sea levels (e.g., Atlantic Canada and British Columbia) permitting entry of heavier vessels (deeper drafts) • High water levels inhibiting passage of vessels under bridges • Decreasing sea levels (e.g., Hudson Bay) and lower freshwater levels (e.g., Great Lakes) inhibiting access by heavier vessels
③	**Hazards to vessel navigation – storms and wind events (waves)**	• Wave action (difficulty maneuvering vessels) • Melting sea ice (open water worsening the impact of storms and wind events)
④	**Hazards to vessel navigation – detached sea ice**	• Melting ice (detached sea ice moving into unexpected areas)
⑤	**Longer or shorter shipping season**	• Earlier ice break-up/later freeze-up (longer navigation season), later ice break-up/earlier freeze-up (shorter season)
⑥	**New navigation opportunities**	• Melting sea ice (creating open water where navigation was previously not possible)

URBAN TRANSPORT

Impacts to urban transportation systems (Figure 6) include many of the same issues and opportunities identified for road and rail systems in the sections above. Risks more unique to urban systems are associated with underground transit systems and electrical systems. Weather-induced shifts between modes of passenger transport are also more relevant in an urban context. For example, extreme temperatures, precipitation, and strong winds all reduce the percentage of trips taken by walking or cycling.

Figure 6: How climate and weather can affect urban transportation. (Illustration created by www.soaringtortoise.ca)

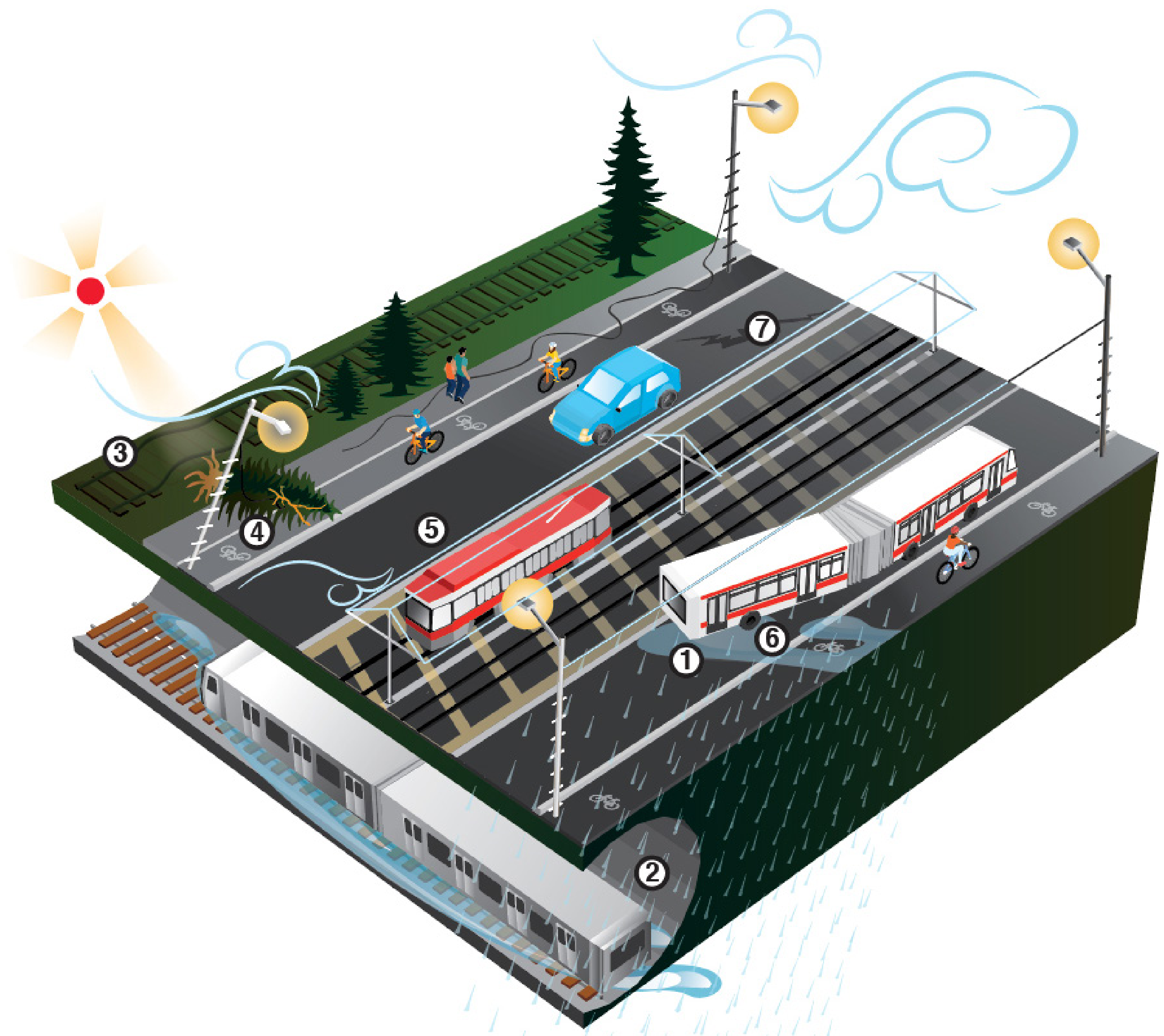


Table 5: Examples of direct impacts on urban transportation from various climate factors.

	EXAMPLES OF IMPACTS ON URBAN TRANSPORT	CLIMATE FACTOR(S)
①	**Flooding, damage, and wash-outs of surface infrastructure (e.g., culverts, roads, sidewalks, bicycle paths)**	• Extreme precipitation (heavy rainfall) and associated drainage issues, ice-jam flooding • Storm surges/sea level rise in coastal areas
②	**Flooding of underground transit systems (e.g., subway tunnels)**	• Extreme precipitation (overloading drainage systems) • Extreme cold (cracking water mains)
③	**Buckling of rail transit lines**	• Extreme heat or large temperature fluctuations
④	**Damage to traffic signals, signage, fallen power lines, trees obstructing routes**	• High winds • Extreme precipitation • Freezing rain
⑤	**Loss of power (overhead electricity for streetcars/trolleybuses, traffic signals)**	• Extreme precipitation • High winds • Freezing rain • Extreme heat
⑥	**Reduced traction/stability of vehicle, visibility issues**	• Extreme precipitation • Freezing rain • High winds (including blowing snow)
⑦	**Damage to and deterioration of roads and bridges**	• High temperatures (pavement softening, rutting, flushing, bleeding) • Freeze-thaw cycles (pavement deformation, shearing, deterioration) • Warming and thawing of permafrost (ground settlement, slope instability, drainage issues, cracking) • Extreme precipitation (weakened embankments, depressions, bridge scour)

ADAPTATION APPROACHES

Transportation owners and operators are using a variety of different approaches to reduce climate risks, including:

- **Integrating climate considerations into organizational planning, policies and designs** - known as "mainstreaming", this refers to the practice of systematically considering climate risks in broader organizational plans and requirements.
- **Undertaking risk and vulnerability assessments -** processes that assess the vulnerability of transportation infrastructure and operations to climate change and associated risks. Results can inform investments and operational decisions.
- **Implementing structural and physical (engineering) adaptations** - solutions that enhance the physical resiliency of transportation networks or infrastructure components. In some cases, structural adaptations are part of broader climate adaptation strategies and programs.
- **Integrating smart technologies** - monitoring and communications technologies and tools, these can provide climate and weather data to support adaptation decision-making, and allow real-time monitoring of asset conditions.
- **Changing operations and maintenance practices** - this category of approaches is often the most cost-effective to implement.

Examples of each of these adaptation approaches are identified below (Table 6) based on chapter findings. This list provides concrete examples of adaptation actions being implemented across Canada.

Table 6: Examples of adaptation approaches identified in this report.

Adaptation Activities	Chapter Reference(s)
Organizational planning, policies and designs	
The BC Ministry of Transportation and Infrastructure requires infrastructure design work to consider climate change adaptation, and has developed a set of notional best-practices.	British Columbia
TransLink, Vancouver's regional transportation authority, has integrated responsibility for climate change risks into its financial management processes.	Urban
Port Saint John's long-term port modernization plans are accounting for sea level rise.	Atlantic
Jurisdictions, such as the City of Sept-Îles are using zoning requirements to control coastal land use and are undertaking cost-benefit analysis for threatened structures.	Quebec
Several jurisdictions are updating design flows and return periods for stormwater management networks, including culverts, to account for an increased frequency and/or magnitude of heavy precipitation events in the future.	Prairies Ontario Atlantic
Structural and physical (engineering) adaptations	
The New Brunswick Department of Transportation rebuilt and raised a bridge on the main road into Pointe-du-Chêne to accommodate future sea level rise scenarios.	Atlantic
The Quebec Ministry of Transportation has oversized the diameter of culverts by 10% to help manage heavy precipitation events.	Quebec
Norman Wells Airport and Ottawa International Airport have grooved their runways to improve traction and drainage during heavy precipitation.	Northern Ontario
Transportation practitioners are implementing and testing engineering techniques, such as thermosyphons, to reduce permafrost thaw under infrastructure, and are using fiber optic technologies to monitor permafrost degradation.	Northern Quebec
Roads in Ontario are using the "SuperPave" system to determine optimal pavement mixtures for local temperature conditions.	Ontario
GO Train engineers are increasing the preferred rail-laying and rail-distressing temperatures for track, in order to reduce buckling risks to rail lines from high temperatures.	Ontario
Risk and vulnerability assessments	
The Greater Toronto Airport Authority (GTAA), the BC Ministry of Transportation and Infrastructure, municipalities, and others have used the Public Infrastructure Engineering Vulnerability Committee's (PIEVC) Engineering Protocol to assess transportation infrastructure (see Box).	British Columbia Prairies Ontario Atlantic
Marine transportation companies have conducted winter-operation risk assessments and ship-specific winterization procedures to reduce risks posed by changing ice conditions in Arctic waters.	Northern
Railway companies are undertaking vulnerability assessments and GIS mapping of areas at risk from landslides, washouts, and other natural hazards.	British Columbia Prairies

Adaptation Activities	Chapter Reference(s)
Smart technologies	
Provinces are using Road Weather Information Systems (RWIS) to inform operations and maintenance, trucking firms are monitoring real-time weather events in their networks to enable efficient re-routing.	Prairies Ontario
Wind sensors are being installed on some rail bridges, allowing rail operators to delay passage or adjust speeds, in the Greater Toronto Area, Metrolinx and GO Transit have installed flood sensors in transit corridors.	Prairies Urban
Railway companies are actively monitoring weather events, climate risks, and asset health by installing washout detectors and laser movement detection systems, using fiber optics to detect slope movements, measuring track stability with radar interferometer, and installing warning systems for extreme weather.	British Columbia
Marine ports, such as Port Saint John, are using real-time weather and wave forecasting tools, including the "SmartAtlantic" inshore weather buoy, to support planning and navigation.	Atlantic
Vessel operators in the Great Lakes-St. Lawrence Seaway System are using Onboard Draft Information systems and other electronic navigation services to support operations in low water conditions, in Arctic waters, vessels are using radar and satellite technology to provide near real-time ice charts, images and forecasts.	Northern Ontario
The Quebec Geomatics Centre and the Ministry of Public Security have implemented an online interactive mapping tool (GéoRISC portal) for the Saguenay-Lac-Saint-Jean region, to allow decision-makers to limit and reduce flooding impacts and ultimately plan for alternative road routes.	Quebec
Operations and maintenance requirements and practices	
To maintain the integrity of winter roads in Northern Canada, operators are spraying roads and bridges and are constructing snow caches at key points along the winter roads, for repair purposes.	Northern Ontario
The City of Toronto is more regularly monitoring and clearing drainage culverts to prevent issues during extreme precipitation events.	Urban
The Quebec Ministry of Transportation has introduced a thermal monitoring program for 13 airport runways in Nunavik. They are built on land sensitive to permafrost thaw.	Quebec
Some jurisdictions are using combination ploughing and salting vehicles to better react to freezing rain conditions.	Urban
Carriers at northern airports have developed portable de-icing mechanisms to more flexibly address aircraft icing requirements.	Northern Prairies
Trucking firms are using technologies to reduce fuel consumption that also enhance climate resilience. Aerodynamic devices (fairings and trailer skirts) can improve the stability of trucks during wind events, and auxiliary power units (APUs) can help truckers respond to increased frequency of cold snaps or heat waves.	Prairies

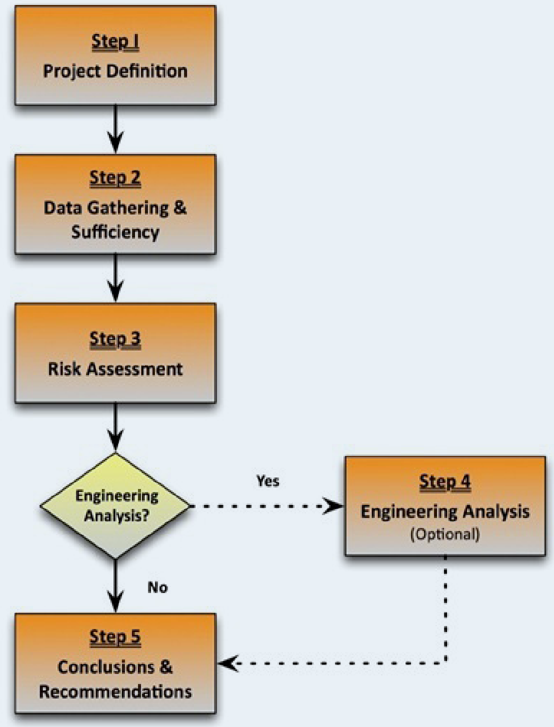
ADAPTING ENGINEERING PRACTICES TO CLIMATE CHANGE

While engineers have long considered climate parameters in engineering design work, this has usually meant looking back at historic trends. Given the current rate of climate change, this is no longer a reliable approach. Provincial Professional Engineering Associations are responding by adding new professional requirements to ensure that potential climate change impacts are taken into account in the design process for the service life expected of the infrastructure. This is a cultural change for agencies responsible for infrastructure, consultants carrying out engineering design work and clients commissioning the work. It is expected that future engineering work related to new infrastructure design and rehabilitation will reflect such action and progress.

The **Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol**, led by Engineers Canada, was developed as a 5-step process to analyze the engineering vulnerability of individual infrastructure systems based on current climate and future climate projections. Since 2012, the Protocol has been applied to a wide variety of infrastructure types, including roads and airports.

For more information, see http://pievc.ca/

Figure 7: Engineers Canada PIEVC Protocol Process. (Source: Engineers Canada)



CONCLUSION

The research conducted for this report suggests that a changing climate and extreme weather are affecting all modes of transportation in every region of Canada, and that many climate risks are increasing. The adaptive efforts being undertaken to date speak to the willingness of Canada's governments, agencies, and private sector to confront the risks to transportation safety, efficiency and reliability posed by a changing climate. At the same time, gaps and barriers remain, including limitations in localized climate projections, and resource and capacity constraints, particularly in Canada's North. Advancements in science and technology, along with training, tools and guidance for practitioners, have the potential to help the sector respond to these challenges. Coordination across jurisdictional boundaries, and with industry and researchers, will be important to advance adaptation solutions and enhance the resilience of the sector in the face of these growing risks.