1 · Introduction

CHAPTER 1: INTRODUCTION

LEAD AUTHORS:

JEAN ANDREY[1]
KATHY PALKO[2]

RECOMMENDED CITATION:

Andrey, J., and Palko, K. (2017). Introduction. In K. Palko and D.S. Lemmen (Eds.), *Climate risks and adaptation practices for the Canadian transportation sector 2016* (pp. 2-10). Ottawa, ON: Government of Canada.

1 Geography and Environmental Management, University of Waterloo, Waterloo, ON
2 Transport Canada, Ottawa, ON

The Earth's climate is changing, and Canada is warming at a faster rate than most regions in the world. From 1950 to 2010, the average annual temperature in Canada has increased by close to 1.5°C, which is approximately double the global average (Bush et al., 2014). This warming trend has been associated with changes to other important climatic variables, including precipitation, sea level, inland water levels, sea ice, permafrost, and extreme weather events (Table 1).

In the coming decades, anthropogenic emissions of greenhouse gases will result in further changes to global and regional climates. These changes have implications for the transportation sector, and the Canadian economy and society more broadly.

The Government of Canada has produced a series of climate change assessments at the national level, which identify observed and expected impacts to Canada's economy, society, and environment; and practices to adapt to these impacts. These include:

- Canada's Marine Coasts in a Changing Climate (2016);
- Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation (2014);
- From Impacts to Adaptation: Canada in a Changing Climate (2007);
- Climate Change Impacts and Adaptation: A Canadian Perspective (2004); and,
- Canada Country Study: Climate Impacts and Adaptation (1997-98).

While these reports indicate that some aspects of transportation are highly vulnerable to changing climatic conditions, adapting infrastructure and operations to a changing climate and emerging environmental conditions remains a relatively new area of focus for the transportation sector.

PURPOSE AND FORMAT OF REPORT

This report is a snap-shot in time, presenting the state of knowledge about climate risks to the Canadian transportation sector, and identifying existing or potential adaptation practices that may be applied to reduce them. It is intended to serve as an accessible source of information that can inform decision-making and policy development, without making recommendations or prescribing specific actions which can vary based on different situations. This report provides transportation decision-makers and practitioners with information intended to support enhanced resilience to climate risks, while also serving as a knowledge foundation for future research.

The report is organized into six regional and one urban chapter to reflect the different climate vulnerabilities, priorities, practices and opportunities across Canada's national transportation system. Each chapter includes a profile of the region's population, economy, climate and transportation networks, in addition to examining observed climate impacts, future risks, opportunities, and adaptation approaches for road, rail, air, and marine transportation.

Climate risks considered within the framework of this report include both changing climate conditions ("slow onset" changes, such as permafrost thaw and sea level changes) and extreme weather events. While it is difficult to attribute a single weather event to climate change, there is growing confidence that some types of extreme events will increase in frequency and/or intensity as the climate continues to warm, and these events represent significant risks to transportation infrastructure and operations.

The development of this report represents a significant and collaborative effort in bringing together the knowledge, expertise and perspectives of the chapter authors and reviewers. Based on available literature, each chapter includes an assessment of peer-reviewed (academic) and grey literature relevant to the transportation-climate nexus in the given region. Furthermore, to round out the knowledge base in cases where existing literature was limited, several chapters also integrate perspectives from transportation practitioners, and are cited as personal communications.

Content that has been deemed out of scope for the purposes of this report includes:

- Impacts on pipelines and power transmission infrastructure;
- Indirect impacts on transportation associated with climate change impacts on other sectors (e.g., agriculture, tourism and recreation, fisheries), and other nations. Interdependencies among municipal sectors are considered in Chapter 9;
- Disaster and emergency management practices; and
- The impact of transportation on the climate (e.g., greenhouse gas emissions) and climate change mitigation activities.

Collectively, these features have shaped the unique content found in the chapters. For example, the Urban Chapter emphasizes transportation planning approaches; the British Columbia and Northern chapters provide greater detail on engineering practices and extreme precipitation risks; and the Prairies Chapter incorporates content on practitioner experiences and adaptations within the trucking industry. The Synthesis chapter attempts to bring these regional and urban perspectives together to capture the state of knowledge at the national level on climate risks and adaptation practices for Canada's transportation system.

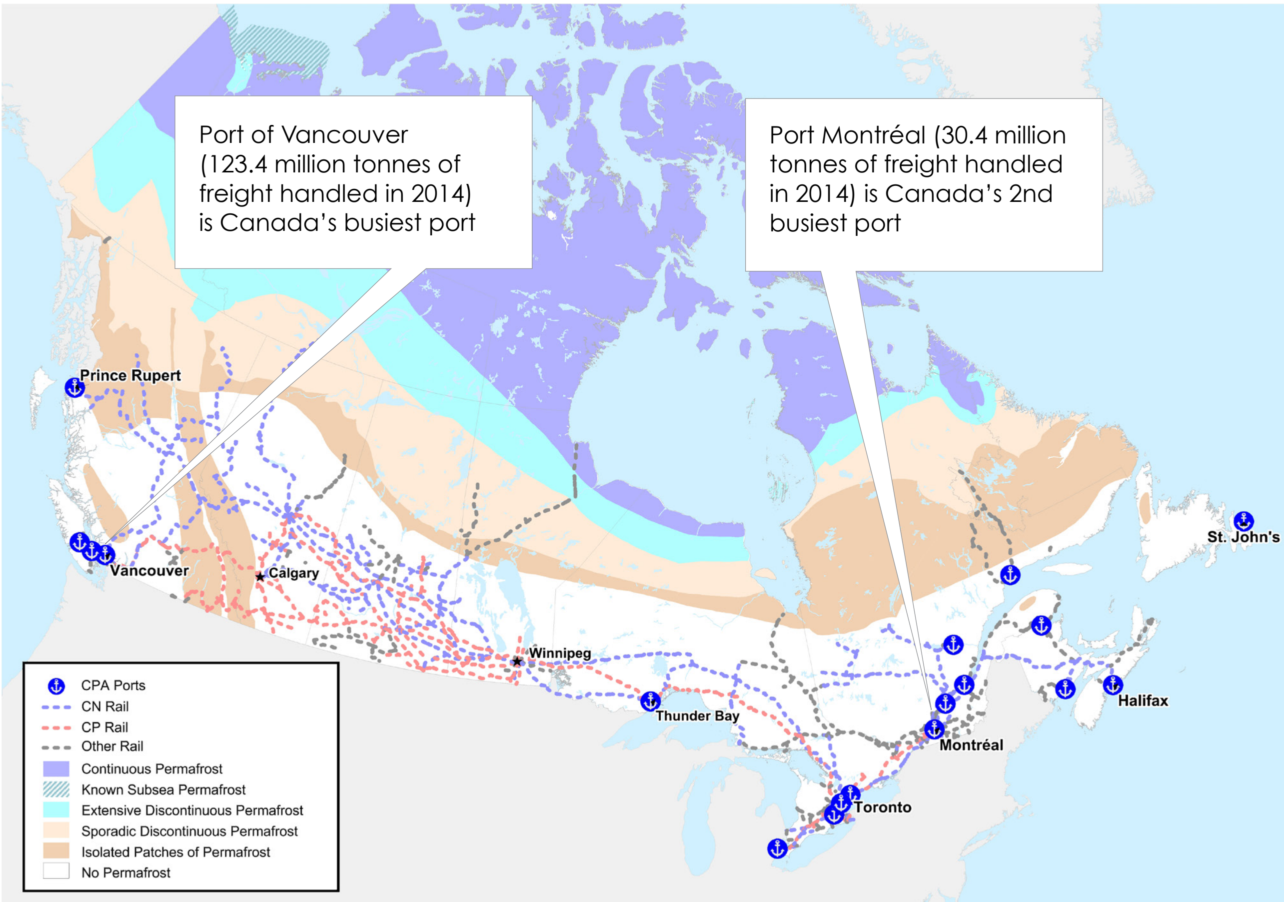
CANADA'S TRANSPORTATION SYSTEM

Canadians depend on transportation services for day-to-day travel, and for the movement of resources and goods vital to the economy. Canada's communities and markets are widely dispersed, spanning a distance of more than 5,000 km from east to west and 4,500 km from north to south. Industries such as manufacturing, energy, mining and agriculture, as well as services such as healthcare and retail trade, all depend on the reliable functioning of the transportation system.

All modes of transportation, each with its own unique characteristics, play specific roles in local, national, and international movements (Figure 1 and Figure 2). As a whole, the Canadian transportation system (including highways, railways, airports, ports, and associated facilities) moved over $1.04 trillion of merchandise trade in 2014 (Transport Canada, 2015).

Transportation is jointly governed by Canada's federal, provincial, and municipal governments. Generally, the federal government oversees international and interprovincial transportation (including aviation, marine, and rail); provincial governments are responsible for intra-provincial transportation (including highways); and municipal governments are responsible for managing urban transportation (including transit and local roads). The private sector also plays an important role as owners, operators, and managers of infrastructure and assets, including rail infrastructure, vehicles, ships, and aircraft.

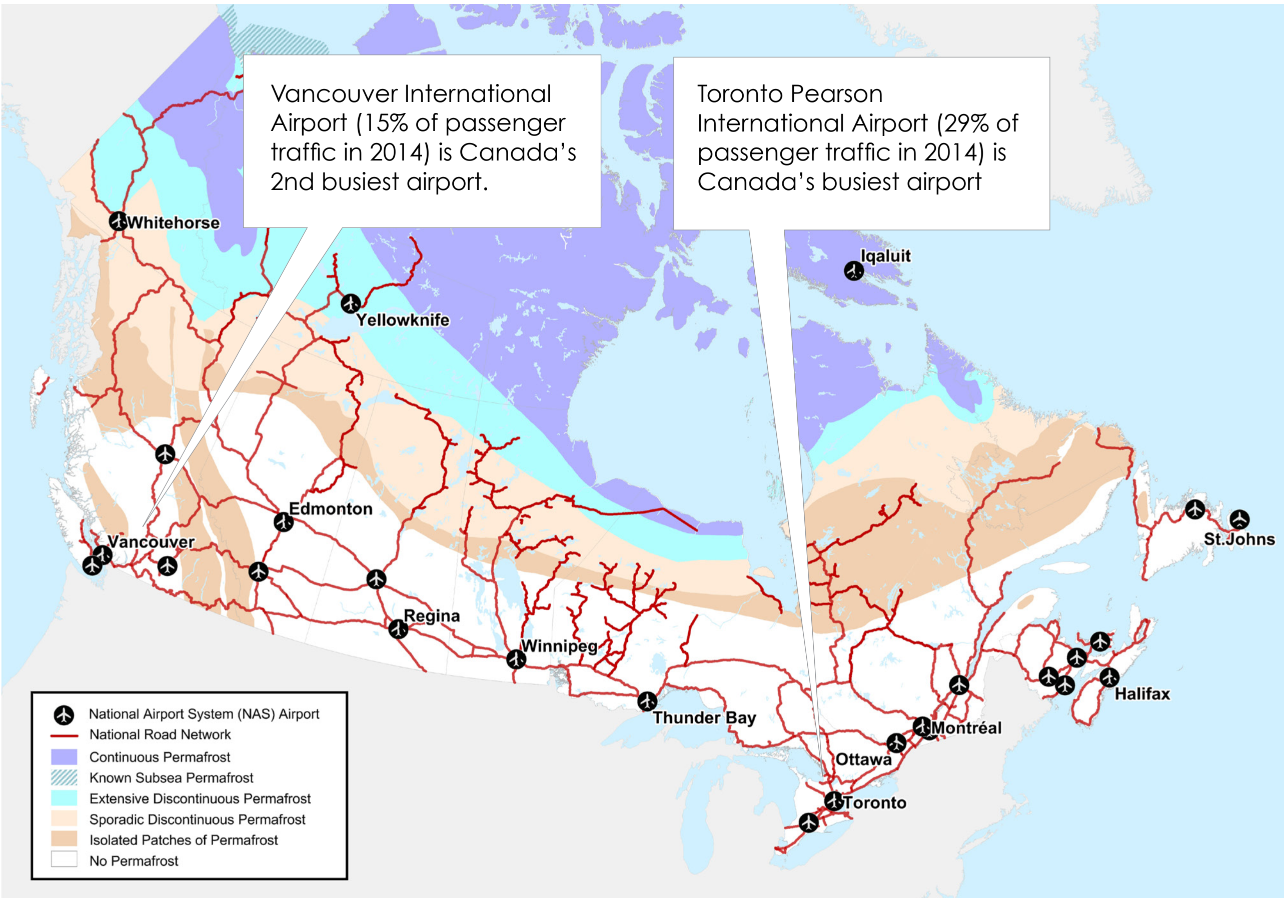
Figure 1: System overview of the Canadian Port Authorities, Great Lakes and National Rail Network, including key trade and passenger statistics for marine and rail transport.



Canada's Rail System
- 320.2 million tonnes of freight shipped by rail (2014)
- $126.2 billion in rail international trade traffic (2014)
- 45,742 route-kilometres (km) of track:
  - CN owns 49.2% (22,517 km)
  - CP owns 26.1% (11,927 km)
- VIA Rail moved 3.77 million passengers (2014)

Canada's Port System
- 567 port facilities, 902 fishing harbours and 202 recreational harbours
- 62% of total tonnage handled by the 18 Canadian Port Authorities
- Great Lakes/St. Lawrence Seaway System serves 15 major international ports and 50 regional ports that connect to 40 provincial/interstate highways and 30 rail lines

Figure 2: System overview of the National Airport System and National Highway System, including key trade and passenger statistics for aviation and road transport.



Canada's Aviation System
- 647 Canadian air carriers
- 26 NAS airports handled around 90% of total air passenger traffic (2014)
- 1.1 million tonnes of freight unloaded at Canadian airports (2014)

Canada's Road System
- > 1.3 million kilometres of public road in Canada
  - 34% is paved
- Canada's largest transportation sector
  - > 62,000 trucking businesses in operation
- $371 billion in trucking traffic between Canada and the U.S. (2014)

OBSERVED AND PROJECTED CHANGES TO CANADA'S CLIMATE AND HYDROLOGY

Canada has experienced a number of changes to climate variables affecting the transportation sector, including temperature, precipitation, permafrost, relative sea level, sea, lake and river ice, inland water levels, and extreme weather events; and further changes to these variables are projected (Table 1).

Table 1: Summary of observed and projected changes to climate and hydrological variables relevant to the Canadian transportation system. (Source: Warren and Lemmen, 2014; other sources as indicated)

Variable	Observed Changes	Projected Changes
Temperature	**Canada has become warmer.** • The average air temperature has increased by 1.5°C during the period from 1950 to 2010. • Hot summer days have become more frequent since 1950, while the frequency of cold nights has decreased, nationally.	**Canada will continue to warm.** • Warming will be greatest in winter, with the largest temperature increases projected in northern Canada. • The magnitude of projected warming varies substantially with the emission scenario. • Unusually warm days are projected to occur more often throughout the 21st century, while unusually cold days and nights will become less frequent. • Heat waves are projected to become longer, more frequent and more intense. By mid-century, a one-in-20-year extreme hot day is projected to become about a one-in-5 year event over most of Canada.
Precipitation & Snow Cover	**Canada has generally become wetter.** • Annual average precipitation has increased in recent decades. • Annual snowfall has declined over most of southern Canada and increased in the north over the last 6 decades.	**Most of Canada will continue to get wetter, with regional differences in seasonal patterns.** • Precipitation may decline in summer and fall in parts of southern Canada. **Most of Canada will see less snow cover.** • Snow cover is projected to decrease in southern Canada (especially the west coast mountains), while it is projected to increase in northern Canada due to increased precipitation. **Heavy precipitation events are projected to occur more often.** • Rare extreme precipitation events are projected to occur about twice as often by mid-century over most of Canada, relative to the period from 1950 to 2010.
Permafrost	**Permafrost has warmed.** • Permafrost temperatures at many sites across Canada have increased over the past two to three decades.	**Permafrost is projected to continue to warm at higher rates than those observed to date.** • It will take many decades to centuries for colder permafrost to completely thaw.

Variable	Observed Changes	Projected Changes
Relative Sea Level	**Sea levels have changed in Canada.** • Relative sea level has been rising in Atlantic Canada and the Beaufort Sea (over 3 mm/year), and on the Pacific coast to a lesser extent. (Average global sea level rose 1.6 mm/year between 1880 and 2012). • Where sea level has risen, storm surges and coastal erosion have been amplified (Atkinson et al., 2016). • Relative sea level has been falling in areas where land has been rising due to post-glacial rebound. Relative sea level has declined about 10 mm/year around Hudson Bay.	**Sea levels will continue to change.** • Estimates of future changes in global sea level by the year 2100 range from a few tens of centimetres to more than a metre. • Projected changes in Canada range from increases of up to 100 cm on the Atlantic, Pacific, and Beaufort coasts, to decreases of almost 100 cm in the central Arctic.
Sea Ice	**Arctic sea ice extent has decreased significantly.** • Minimum ice extent at the end of summer has declined by 13% per decade over 1979-2012. Maximum winter sea ice extent has declined by 2.6% per decade. • Ice cover has become increasingly dominated by thin first-year ice, with significant reduction in the extent of thick multi-year ice. • Winter sea ice has also declined in the Labrador-Newfoundland and Gulf of St. Lawrence region.	**The extent and thickness of sea ice in the Canadian Arctic will continue to decrease.** • Some models project a nearly ice-free summer before mid-century in the Arctic Ocean. Summer sea ice may persist longer in the Canadian Arctic Archipelago region.
Lake and River Ice	**Ice cover duration has been decreasing.** • Most of Canada has seen trends towards earlier ice-free dates (lakes) and ice break-up dates (rivers) since the mid-20th century, and this trend is particularly evident in Western Canada.	**Duration of ice cover is projected to continue to decrease.** • Earlier break-up dates and later freeze up dates are projected to decrease ice cover duration by up to a month by mid-century.
Inland water levels	**Inland water levels have been highly variable with episodes of lower than normal levels.** • Great Lakes Water levels were below long-term averages from 1997 to 2012 (Shlozberg et al, 2014) but higher than normal in 2013 and 2014. (Dorling and Hanniman, 2016; Great Lakes Environmental Research Laboratory, 2015).	**Inland water levels are expected to continue to fluctuate, with a projected trend towards lower water levels.** • Episodes of low water levels are projected to occur more frequently in some freshwater bodies (e.g., the Great Lakes and Mackenzie River). • Some models project decreases in water levels of 0.5 to 1 m in the Great Lakes and St. Lawrence River by 2055 (Shlozberg et al, 2014; Brown et al., 2012).

SENSITIVITIES OF CANADIAN TRANSPORTATION TO CLIMATE

All transportation systems are climate-sensitive. These sensitivities can translate into infrastructure damage and deterioration, disruptions to transport operations, and unsafe conditions. Some of the most vulnerable components of Canada's transport system are integral to remote and resource-based communities in the North. However, a changing climate and extreme weather will affect all modes of transportation in every Canadian region.

Transportation's sensitivities to climate and extreme weather are illustrated by the impacts of acute weather events in recent years. For example, Canada's costliest disaster – the June 2013 floods in Alberta – resulted in an estimated $6 billion in damages and recovery costs, and saw 1,000 km of roads destroyed and hundreds of bridges and culverts washed out. Similarly, the July 2013 flash flood in the Greater Toronto Area, which is considered to be the most expensive natural disaster in Ontario, caused major transit delays, road closures, and flight cancellations (Environment Canada, 2014).

EXTREME WEATHER TRENDS

Trends in extreme precipitation events have been difficult to identify from climate data, due to spatial variability in precipitation patterns. However, insurance data demonstrates that natural disasters have been increasing in Canada, including events associated with flooding, wind, and wildfires (Institute for Catastrophic Loss Reduction, 2012).

While many factors, other than climate change, contribute to rising insurance losses (including exposure of property, increasing wealth, and aging infrastructure), this trend demonstrates a pattern of infrastructure vulnerability in Canada to extreme weather events (Warren and Lemmen, 2014).

Extreme weather events are not the only climate risk to transportation. Other risks to the Canadian transportation system, associated with a changing climate, include the following:

- Temperature changes and fluctuations contribute to infrastructure deterioration and operational challenges, especially in permafrost regions of northern Canada, but also across southern Canada due to changing freeze-thaw cycles during the winter and heat waves during the summer.
- Changing ice conditions affect marine operations and vessel navigation, especially in northern Canada, with broad implications (both positive and negative) for economic development, trade, and security.
- Sea level rise and storm events can increase risks of coastal erosion, flooding, and associated damage, with implications for transportation infrastructure and operations in coastal areas of Canada.
- Low inland water levels (particularly in the Great Lakes) can reduce vessel capacity, and create navigation difficulties.

ADAPTATION OPTIONS

Adaptation options for transportation may include engineering and technological solutions, as well as policy, planning, management, and maintenance approaches. Some examples, from the chapters in this report, include:

- Changing pavement mixes for roads, for example using more heat-tolerant pavements;
- Expanding drainage capacity for infrastructure, including culvert size;
- Increasing maintenance, including clearing debris from culverts to reduce flooding risks, and clearing snow to preserve permafrost stability under vulnerable roads;

- Implementing heaters and cooling fans to improve tolerance of traffic signal controllers to extreme temperatures, and thermosyphons to maintain permafrost stability at airports;
- Changing infrastructure design requirements to include climate change considerations or to introduce new flood event thresholds;
- Elevating or relocating new infrastructure where feasible;
- Changing engineering procedures, such as increasing temperature thresholds for rail track to reduce risk of buckling during large temperature differentials;
- Increasing monitoring of weather events and infrastructure conditions;
- Implementing or enhancing travel advisories and alerts to communicate travel conditions and service delays during weather events.

There are two categories of response to climate change – mitigation and adaptation.

Mitigation refers to human interventions to reduce greenhouse gas emissions.

Adaptation refers to any activity that reduces the negative impacts of climate change and/or takes advantage of new opportunities. This includes actions taken before impacts are observed (anticipatory), and after impacts have been felt (reactive). Adaptation can be planned (i.e., the result of deliberate policy decisions), or spontaneous, in the case of reactive adaptation (Warren and Lemmen, 2014).

REFERENCES

Atkinson, D.E., Forbes, D.L., and James, T.S. (2016). Dynamic coasts in a changing climate. In D.S. Lemmen, F.J. Warren, T.S. James and C.S.L. Mercer Clarke (Eds.), *Canada's marine coasts in a changing climate* (pp. 27-68). Ottawa, ON: Government of Canada.

Brown, C., Moody, P., Lefever, D., and Morales, J. (2012). *Decision-making under climate change uncertainty in the International Upper Great Lakes Study: Synthesis report*. International Upper Great Lakes Study, International Joint Commission. Retrieved from http://www.iugls.org/project/Risk%20Assessment%20and%20Decision%20Making%20under%20Climate%20Change%20Uncertainty

Bush, E.J., Loder, J.W., James, T.S., Mortsch, L.D., and Cohen, S.J. (2014). An overview of Canada's changing climate. In F.J. Warren and D.S. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (pp. 23-64). Ottawa, ON: Government of Canada.

Dorling, R., and Hanniman, K. (2016). *Restoring water levels on Lake Michigan-Huron. A cost-benefit analysis*. Mowat Centre. Retrieved from https://mowatcentre.ca/restoring-water-levels-on-lake-michigan-huron/

Environment Canada. (2014). *Canada's top ten weather stories for 2013*. Retrieved from https://ec.gc.ca/meteo-weather/default.asp?lang=En&n=5BA5EAFC-1

Great Lakes Environmental Research Laboratory. (2015). *Water levels of the Great Lakes*. Retrieved from http://www.glerl.noaa.gov/pubs/brochures/lakelevels/

Institute for Catastrophic Loss Reduction. (2012). *Telling the weather story*. Prepared for the Insurance Bureau of Canada. Retrieved from http://assets.ibc.ca/Documents/Studies/McBean_Report.pdf

Shlozberg, R., Dorling, R., and Spiro, P. (2014). *Low water blues: An economic impact assessment of future low water levels in the Great Lakes and St. Lawrence River*. Mowat Centre and Council of the Great Lakes Region. Retrieved from http://mowatcentre.ca/low-water-blues/

Transport Canada. (2015). *Transportation in Canada 2014: Overview report and statistical addendum*. Retrieved from www.tc.gc.ca/eng/policy/anre-menu.htm.

Warren, F.J. and Lemmen, D.S. (2014). Synthesis. In F.J. Warren and D.S. Lemmen (Eds.), *Canada in a changing climate: Sector perspectives on impacts and adaptation* (pp. 1-18). Ottawa, ON: Government of Canada.