# 7 · Quebec

# CHAPTER 7: QUEBEC

**LEAD AUTHORS:**

MARIE-PIER BRETON[1],
GENEVIÈVE CLOUTIER[2]
E.O.D. WAYGOOD[3]

**EDITED BY:**

CAROLINE LARRIVÉE, OURANOS

**ACKNOWLEDGEMENTS:**

The authors would like to thank the Ministère des Transports, de la Mobilité durable et de l'Électrification des transports du Québec for its contributions to, and comments on, previous versions of the chapter.

**RECOMMENDED CITATION:**

Breton, M.-P., Cloutier, G., and Waygood, E.O.D. (2017). Quebec. In K. Palko and D.S. Lemmen (Eds.), *Climate risks and adaptation practices for the Canadian transportation sector 2016* (pp. 181-216). Ottawa, ON: Government of Canada.

---

1 École supérieure d'aménagement du territoire et de développement régional, Université Laval, Québec, QC
2 École supérieure d'aménagement du territoire et de développement régional, Université Laval, Québec, QC
3 École supérieure d'aménagement du territoire et de développement régional, Université Laval, Québec, QC

## TABLE OF CONTENTS

## KEY FINDINGS

- **Climate change will affect the natural environment of all regions of Quebec and may damage or cause service interruptions to transportation systems**. Nunavik has, and will continue to, experience significant climate change and will have to deal with the thawing of the permafrost on which transportation infrastructure is built. In eastern Quebec, the increase in relative sea level, loss of ice cover, freeze-thaw cycles and changes to storm systems will contribute to further erosion of riverbanks and shorelines. For all regions of Quebec, Surface runoff management is a challenge.
- **The vulnerability of transportation systems to climate change varies according to regional characteristics, the type of infrastructure and its use.** The condition and maintenance of infrastructure, the current use of transportation systems and the availability of alternatives during service interruptions, are all factors that influence the scope of climate change impacts on transportation systems.
- **Extreme weather events represent one of the greatest risks for the transportation sector, in all the regions of Quebec.** Episodes of heavy rain, floods, coastal erosion and landslides will affect both the transportation infrastructure and the mobility of people and goods. The isolation of communities that depend more on one particular mode of transportation could be accentuated by extreme weather events.
- **Although thawing permafrost is the most significant climate change impact affecting Quebec's northern communities, similar to the northern territories, rising temperatures are also reducing winter mobility due to shorter freezing periods.** The shorter winter season and loss of ice cover make access to the region and its resources more difficult for individuals who depend on them for their way of life.
- **Climate change adaptation issues represent significant social, institutional, environmental and economic challenges.** Success stories in this area are the result of multisectoral initiatives, involving players from the public and private sectors and civil society, and their inclusion in existing planning efforts.
- **Acquiring data to monitor the condition of infrastructure and efforts to search for effective solutions for transportation systems are key means of adapting to the inevitable changes.** Adaptation options will affect both the design and management practices for the operation and maintenance of infrastructure. Analysing the potential performance of these options depends on a solid knowledge of the transportation systems and the environment in which they operate.

# 1.0 INTRODUCTION

In Quebec, transportation plays a major role in supporting the vitality of regions, the distribution of goods and services, and the exploitation of natural resources. Most transportation infrastructure (road, rail, marine and air) was designed with a stable climate in mind, but climate change is affecting both the lifespan and condition of the infrastructure. The size of the province, the remote nature of certain Quebec communities, and the limited redundancy of the transportation system,[4] in the regions most affected by climate change, are also factors that increase its vulnerability.

For nearly 20 years, the Quebec government, carrier associations, expert panels, and companies have been making greater efforts to adapt transportation systems to climate change and thus strengthen its resilience. These efforts have enhanced knowledge about the impacts and potential solutions to improve the management of transportation infrastructure.

This chapter describes the organization of transportation in Quebec by mode and by region, and identifies its main vulnerabilities to climate change, based on existing literature and studies. The chapter also identifies adaptation practices that could be used to address these challenges.

## 1.1 REGIONAL PROFILE

### DEMOGRAPHICS AND SOCIO-ECONOMIC CONTEXT

Quebec covers more than 1.6M km$^2$ (Institut de la statistique du Québec, 2014) and has approximately 8,263,600 residents (Institut de la statistique du Québec, 2015; see Figure 1), making this province the second most populated in the country.  More than half (60%) of the Quebec population is concentrated in an area 10 km wide on either side of the St. Lawrence river (Institut de la statistique du Québec, 2014).

More specifically, the Quebec population is concentrated in a few large urban areas in the southern part of the province (Montréal, Québec City, Gatineau, Sherbrooke, Trois-Rivières). In other regions, the population is more dispersed. For example, Nunavik makes up a little less than one-third of the territory and has approximately 12,700 residents in 14 northern villages and the Cree community of Whapmagoostui.

Population growth is expected in 13 of the 17 administrative regions of Quebec by 2061 (Girard, B-Charbonneau and F-Payeur, 2014). The regions which are expected to see this population growth will be those supported by international migration (Montréal and Laval), inter-regional migration (Outaouais), internal migration (Laval, Lanaudière), and a rising fertility rate (Nunavik).

As shown in Table 1, the urban areas of the National Capital,[5] Montréal, Montérégie, Laval and the Outaouais are characterized by their significant industrial diversity, and account for 67.4% of the Gross Domestic Product (GDP). The proximity of these areas to waterways and international transportation infrastructure is vital to their success. Other regions depend more on the extraction of raw materials or tourism. The area of the gulf and estuary of the St. Lawrence is home to close to 5% of Quebec's population and accounts for a similar share of the province's economy (Beaulieu, 2014).

[4] The redundancy of a transportation system refers to the alternatives the system provides, ensuring additional routes and services if the first option is disrupted. A system with little redundancy provides few options.

[5] Québec City region

**Table 1: Population distribution and economic activity by region.** (Source: Soucy, 2015)

| Administrative Region | Population (2014) | Demographic Weight | Land Area | Density | Economic Weight |
|---|---|---|---|---|---|
| | Residents | % | KM² | Res/KM² | % |
| **01 Bas-Saint-Laurent** | 200,292 | 2.4 | 22,154 | 9.0 | 2.0 |
| **02 Sagueneay-Lac-Saint-Jean** | 277,786 | 3.4 | 95,870 | 2.9 | 3.2 |
| **03 Capitale-Nationale** | 731,838 | 8.9 | 18,663 | 39.3 | 10.0 |
| **04 Mauricie** | 266,794 | 3.2 | 35,531 | 7.5 | 2.5 |
| **05 Estrie** | 320,008 | 3.9 | 10,193 | 31.4 | 3.2 |
| **06 Montréal** | 1,988,243 | 24.2 | 500 | 3,992.5 | 34.6 |
| **07 Outaouais** | 383,182 | 4.7 | 30,331 | 12.6 | 3.6 |
| **08 Abitibi-Témiscamingue** | 147,868 | 1.8 | 57,550 | 2.6 | 2.1 |
| **09 Côté-Nord** | 94,906 | 1.2 | 235,582 | 0.4 | 2.3 |
| **10 Nord-du-Québec** | 44,256 | 0.5 | 697,152 | 0.1 | 0.9 |
| **11 Gaspésie-Îles-de-la-Madeleine** | 92,472 | 1.1 | 20,327 | 4.6 | 0.8 |
| **12 Chaudlières-Appalaches** | 419,755 | 5.1 | 15,001 | 27.8 | 4.2 |
| **13 Laval** | 420,870 | 5.1 | 246 | 1,710.9 | 4.1 |
| **14 Lanaudière** | 492,234 | 6.0 | 12,299 | 40.0 | 3.6 |
| **15 Laurentides** | 586,051 | 7.1 | 20,490 | 28.5 | 5.4 |
| **16 Montérégie** | 1,508,127 | 18.4 | 11,141 | 135.7 | 15.1 |
| **17 Centre-du-Québec** | 239,990 | 2.9 | 6,899 | 34.7 | 2.6 |
| **All of Quebec** | 8,214,672 | 100 | 1,300,815 | 6.3 | 100 |

## 2.0 ORGANIZATION OF TRANSPORTATION IN QUEBEC

The transportation of goods and people in Quebec is multimodal and interconnected (CPCS, 2013). While trucking is the preferred mode for transporting goods; railways and waterways that connect the St. Lawrence to the Great Lakes, also play an important role. Air transport, meanwhile, carries a lesser volume of goods, but remains a strategic mode when delivery must be done quickly and the weight of the goods is not an issue (CPCS, 2013: 2-29).

In Canada, the St. Lawrence is a key continental gateway. This multimodal axis of transportation is strategic for the economy, demographics and geography of the country, making Quebec a hub for the transportation of goods to other provinces and to the United States. The Quebec-Windsor corridor concentrates approximately 80% of the activities of VIA Rail Canada (2014). The St. Lawrence drainage basin, which includes the Great Lakes, is the largest drainage system in the world, draining more than one quarter of the world's fresh water reserves (Institut de la statistique du Québec, 2014).

Other regions of Quebec are connected to the southern part of the province by strategic corridors that allow for the exploitation of resources, such as forests, hydroelectricity and minerals. These regions depend primarily on roads for the transportation of goods and people. There are also air connections for each of these regions. The size of the area and the dispersed population result in major challenges in planning and managing transportation networks (Ministère des Transports du Québec, 2013a).

Finally, the 14 Inuit communities and the Cree community of Whapmagoostui in Nunavik are only accessible from the southern part of the province by air or sea, as are the Magdalen Islands and certain communities located in the far eastern portion of the lower North Shore.

In Quebec, the planning, design, and management of transportation infrastructure; as well as construction, repair and maintenance work, are the responsibility of several institutional and private partners. Various Quebec government departments, public transportation agencies, public transit agencies, federal government departments and agencies, carrier associations, inter-municipal councils and municipal transportation agencies, local municipalities, regional county municipalities, metropolitan communities and First Nations communities are all involved to varying degrees.

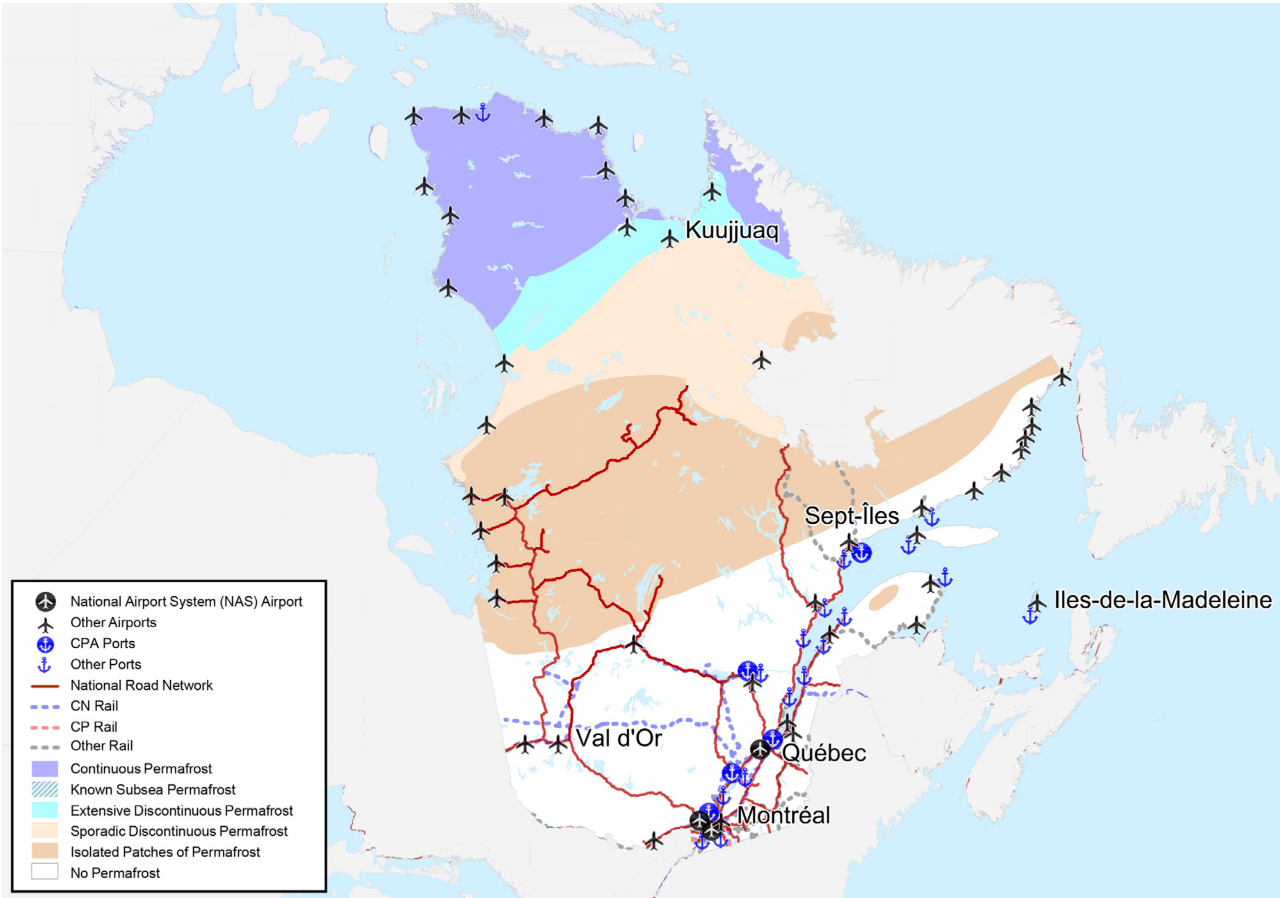
Quebec's Ministère des Transports, de la Mobilité durable et de l'Électrification des transports (MTMDET) plays a central role in the management and sharing of responsibilities for transportation infrastructure. Highways; national, regional and collector roads; and some access roads to remote resources and communities fall under Quebec's jurisdiction (Ministère des Transports du Québec, 2015b). The MTMDET shares the management of these networks with carriers and private operators, as well as some local and regional authorities.[6] The main railway networks are primarily under federal jurisdiction, but are also under provincial jurisdiction (short lines), as well as under the responsibility of a dozen private organizations, or large railway companies such as Canadian National (CN) or Canadian Pacific (CP). Quebec ports and airports are owned and managed by a wide range of public and private stakeholders.

Furthermore, the MTMDET produces manuals and guides to direct the design, management and maintenance of transportation structures and systems. These manuals are used as the main reference guide by Quebec municipalities for roads under their responsibility.

Figure 1 presents Quebec transportation infrastructure and shows the diversity of the main infrastructure in Quebec and the many organizations that share in its management.

[6] The Société de développement de la Baie-James (SDBJ) for the James Bay road network owned by Hydro-Québec, and the Kativik Regional Government for the Nunavik airports.

**Figure 1: Map of principle transportation infrastructure in Quebec.**




The Quebec-Ontario Continental Gateway and Trade Corridor initiative was undertaken jointly by the Quebec, Ontario and Canadian governments in 2007. It aimed to create an integrated multimodal transportation system that was reliable, sustainable and competitive to support international trade. In this respect, the St. Lawrence valley can be considered the main corridor in Quebec's transportation infrastructure network, and provides for much of the exchange between Quebec and its main economic partners. It includes the major urban hubs of Montréal and Québec City. Figure 2 illustrates this intermodality across Quebec.

**Figure 2: Intermodal hubs in Quebec.** (Source: Gouvernement du Québec, ministère des Transports, 2013 (data from 2010))


## 2.1 ROAD TRANSPORTATION

Road transportation is one of the most flexible and accessible modes and is proving to be the preferred mode for short-distance, inter-regional and inter-provincial transportation of goods and people (Ministère des transports du Québec, 2013b). In addition to ensuring access to much of Quebec, road infrastructure facilitates intermodal connections with rail terminals, ports and airports (CPCS, 2013).

There are approximately 319,000 km of roads in Quebec, including highways, national roads, collector roads, streets, bridges and overpasses, access roads and local roads (Ministère des Transports du Québec, 2015b; see Figure 3). There are also more than 300,000 kilometers of multi-use roads in forest settings.

Aging of infrastructure increases its vulnerability and maintenance costs. The average age of infrastructure provides a means of evaluating the condition of the network and the need for investments to ensure its maintenance. Reinvestment in this area since the early 2000's has reduced the average age of roads in Quebec from 18 years in 2000, to 13 years in 2009 (Gagné and Haarman, 2011).

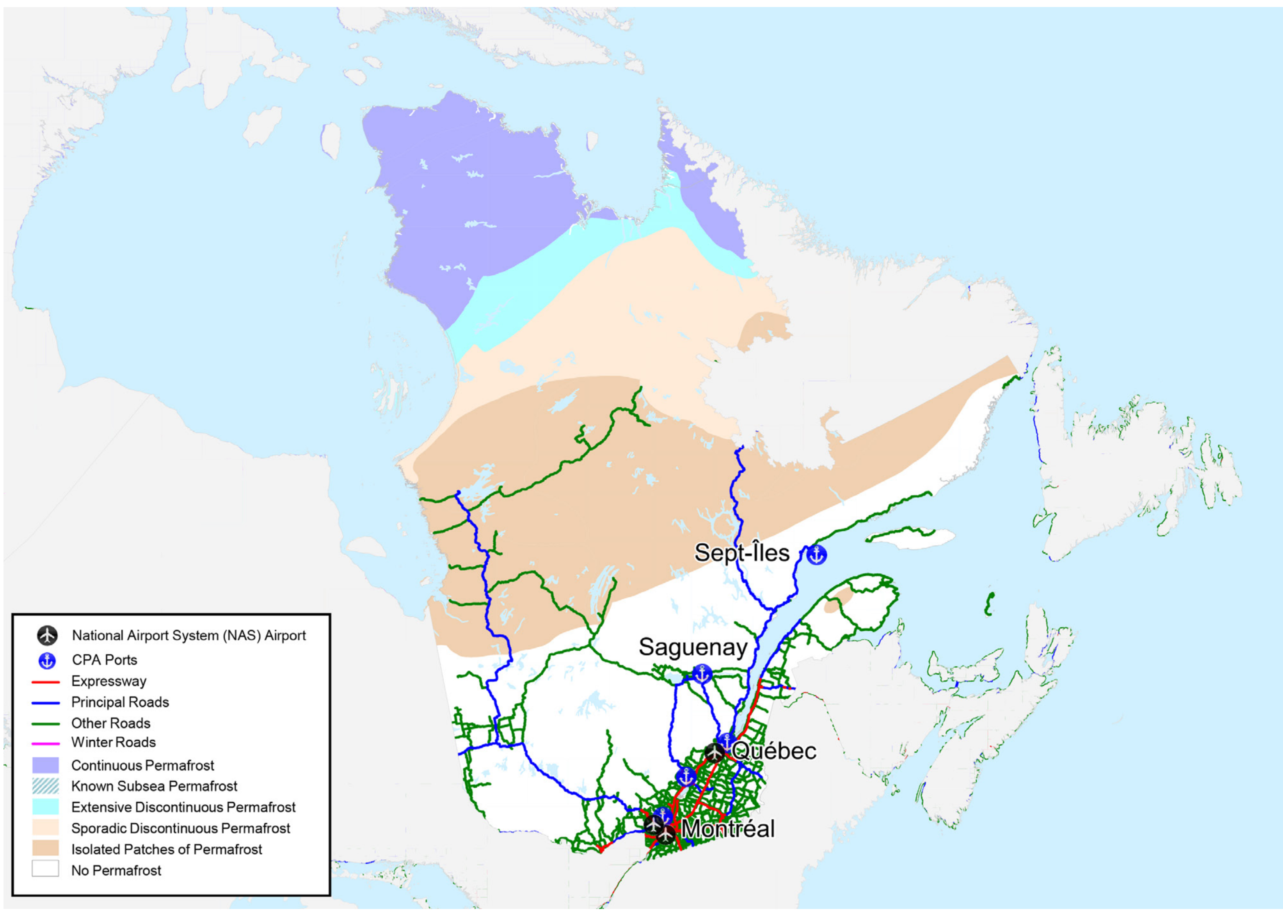
Certain regions are heavily dependent on a single road link for their regular supply and mobility needs. Accessibility to these regions could be significantly compromised after a major weather event (e.g., flood, landslide, erosion etc.,) causes damages to the road link.

Although user behaviour is often the cause of accidents, the contribution of weather conditions must also be considered in road safety management (Andrey, 2010). Moreover, the number of collisions increases during times of precipitation (Andrey and Mills, 2002). However, the number of road accidents has been on the decline since 2007, in Quebec and elsewhere in Canada.

Some tourist regions such as the Gaspé, the Magdalen Islands, the North Shore and the lower St. Lawrence have developed facilities and activities to promote the region and attract visitors. Theme routes,[7] such as the Route des baleines or the Route des Navigateurs, and national parks that draw on their relationship with the river (such as the Saguenay-St. Lawrence Marine Park and the Parc National du Bic) are pillars of tourist development in these regions. Loss of access to these parks due to erosion of roads bordering the river would affect economic and social development. The same is true for the Routes bleues, another theme route, and its related infrastructure, which are also affected by changes observed along the St. Lawrence (coastal erosion, decreasing water levels, etc.).

Finally, some portions of the Quebec road network are highly congested with traffic, especially in the two metropolitan areas of Québec City and Montréal (MTQ, 2013a). Reduced speed due to congestion increases transit time as well as the cost of road transportation. It also reduces the dependability or perceived dependability of the mode of transportation. Traffic congestion combined with the projected rise in summer temperatures and increased frequency, duration and intensity of heat waves, could also have important implications for road freight management systems in the future, particularly concerning new refrigeration requirements, choices of materials for pavement, and other factors. (Goodwin, 2004; James and James, 2010).

**Figure 3: Map of road transportation in Quebec.**




7 For more detailed information, visit http://www.sentiermaritime.ca/index.asp?id=522.

## 2.2 MARINE TRANSPORTATION

Marine transportation is closely tied to a number of key sectors of the Quebec economy, and plays a major role in the movement of goods along the St. Lawrence corridor. Marine transportation activity, including shipping, port and cruise tourism services, has been increasing in Quebec since 2000. In 2011, these activities represented sales of more than $2.3 billion.

Ports along the St. Lawrence primarily move mineral ore, forestry products, agricultural and food products, manufactured goods, fuel and chemical products, and machinery (St. Lawrence Economic Development Council, 2015), in addition to supplying industries and communities (see Figure 2).

Nunavik, the coastal communities in the Eeyou-Istchee James Bay region and several municipalities along the North Shore are also equipped with marine infrastructure consisting of breakwaters, access ramps, beacons, or floating pontoons that serve the local population. In most cases, this infrastructure is the main supply link for remote communities. Some larger marine infrastructure serves industrial activity in these same regions. For example, a private deep-water wharf at Baie Déception in Nunavik serves a mining operation, and other private industrial dock projects could be developed in the region with increased mining activity.

The main commercial ports in Quebec include the ports under the jurisdiction of Canadian port authorities in Montréal, Trois-Rivières, Québec City, Saguenay and Sept-Îles. Other ports and marine infrastructure play an important role in supporting recreational tourism activities and other local needs.

The port network in Quebec handled 130.4 million tonnes of goods in 2011, three quarters which were international goods (Statistics Canada, 2011). The Port of Montréal is the largest container port in eastern Canada (Port of Montreal, 2015), receiving more than one million 20-foot equivalent unit containers annually. Playing a pivotal role in the transportation of goods, it is directly connected to rail and road networks. Each week 80 trains pass through the port, with 5,000 trucks arriving and leaving each day (Port of Montreal, 2015). The ports of Sept-Îles-Pointe-Noire, Port-Cartier, Baie-Comeau and HavreSaintPierre on the North Shore are among the ten largest ports in Quebec in terms of tonnage of goods handled (Ministère de l'Énergie et des Ressources Naturelles, 2011). The deep water port in Québec City that specializes in transshipment serves as a true intermodal hub for trade in the Great Lakes – St. Lawrence River corridor. The port in Sept-Îles is the third largest port in Canada in terms of bulk tonnage handled.

Ferries managed by the Société des traversiers du Québec are linked to the land transportation system to enhance people's mobility. In some urban areas, connections to public transportation networks also facilitate intra-regional and inter-regional travel. Ferry activity, however, is subject to economic fluctuations (ROCHE-Deluc, 2010). Ferries are also exposed to weather conditions and the impact of climate change. On the St. Lawrence, 18 ferries operate year-round and serve more than five million passengers and more than two million vehicles (Société des traversiers du Québec, 2014).

## 2.3 RAIL TRANSPORTATION

The Quebec rail network mainly follows the St. Lawrence valley and extends to the north of the province toward regions of Abitibi-Témiscamingue, Saguenay-Lac-Saint-Jean and Chibougamau, the North Shore, and Labrador (see Figure 2). Among other services, it transports intermodal containers for forestry products, mining products and aluminum. A large number of rail cars run through the Montréal and Québec City regions on their way to other Canadian provinces and the United States (Ministère des Transports du Québec, 2008).

Several rail freight service companies serve Quebec. The largest are Canadian National (CN), Canadian Pacific (CP) and CSX Transportation, which together make up close to 58% of the current network in Quebec. A few manufacturing or resource extraction companies, such as Arcelor Mittal or Rio Tinto Alcan, also operate some of the province's railway lines. With a few exceptions, railways with tracks extending outside of Quebec are under federal jurisdiction, whereas all other tracks are under provincial jurisdiction. Transportation of people is primarily provided by Via Rail Canada Inc., but also by the Québec North Shore and Labrador Railway, by Amtrak for sections in the southernmost part of the province that lead to the United States, and by commuter trains and tourist trains.

Demand for rail services has increased somewhat since 2001, both for the transportation of goods and travelers (Réseau des chemins de fer du Québec, 2011). The rail network under provincial jurisdiction has grown in the last 20 years, from 564 kilometers of rail in 1993, to more than 1,700 km in 2015 (Ministère des Transports du Québec, 2015a).

### 2.4 AIR TRANSPORTATION

The airline sector provides transportation for passengers, freight and other activities, such as aeromedical evacuations, ice patrols, aerial application of products and more. Regarding freight services, close to 146,000 tonnes, equivalent to $3.7 billion, were transported by the 380 air transportation companies in Quebec in 2010 (MTQ 2013a).

There are two international airports (Montréal and Québec City) and various regional airports, 26 of which are owned by the Ministère des Transports (see Figure 2). There are also close to 150 aerodromes, approximately 50 seaplane bases and approximately 50 heliports.

Passenger air traffic in Quebec increased by 4% between 2013 and 2014, reaching 16.5 million passengers. (Statistics Canada, 2014). Passenger air traffic should continue to increase, according to 2012-2022 forecasts.

## 3.0 A CHANGING CLIMATE[8]

Climate risks for the transportation sector (infrastructure and services) vary by location and season. These considerations are important to better understand the potential impacts of expected changes, as they could accentuate the sector's vulnerabilities.

Québec's large territory and varied topography (altitude of up to 1,652 m) help to create different climates (Ouranos, 2015). These range from a cold and humid continental climate in the southern and eastern parts of the province to a sub-polar continental climate in the central regions, a polar tundra climate up north and more of a maritime climate in the coastal areas towards the Gulf of the Saint-Lawrence. All of Québec is affected by climate change and certain trends are already being observed.

### 3.1 RISING TEMPERATURES

Since 1950, temperature trends for both average and extreme temperatures have shown an increase in practically all regions in Québec, with extreme cold temperatures showing the most significant change. Over the period 1951-2010, decreases were recorded in the number of cold days and cold nights as well as in the length of cold spells (Donat et al., 2013). A significant increase was also observed during this same period in the number of hot days, hot nights and length of heat spells.

Projections suggest that these trends will continue, with northern latitudes being even more affected. Moreover, warming trends will be more prominent for extreme minimum and maximum temperatures

8 This chapter presents the current and future climate conditions for Québec for the indicators most relevant to the transportation sector. Unless otherwise indicated, all information is from the reference document "Towards Adaptation" (Ouranos, 2015), a state of knowledge document published by Ouranos in 2015. More information can be found in Chapter 1 of this document.

than for average temperatures. Figure 4 shows average observed and projected summer and winter temperatures for all of Québec.

**Figure 4a: Average observed and projected summer temperatures for all of Quebec.** (Source: Ouranos)

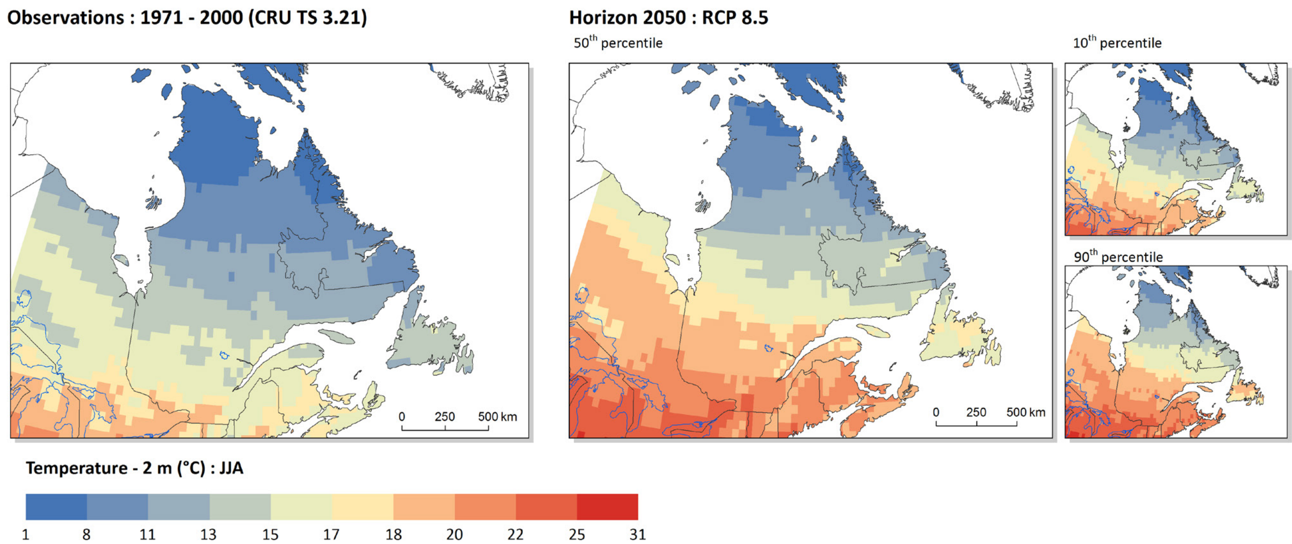



**Figure 4b: Average observed and projected winter temperatures for all of Quebec.** (Source: Ouranos)

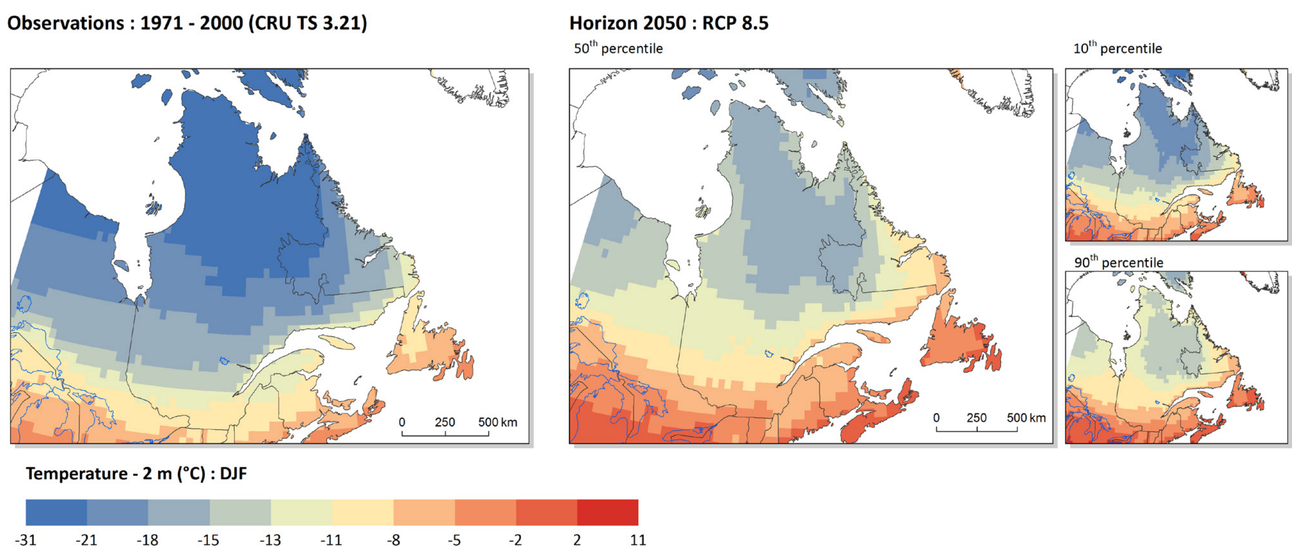
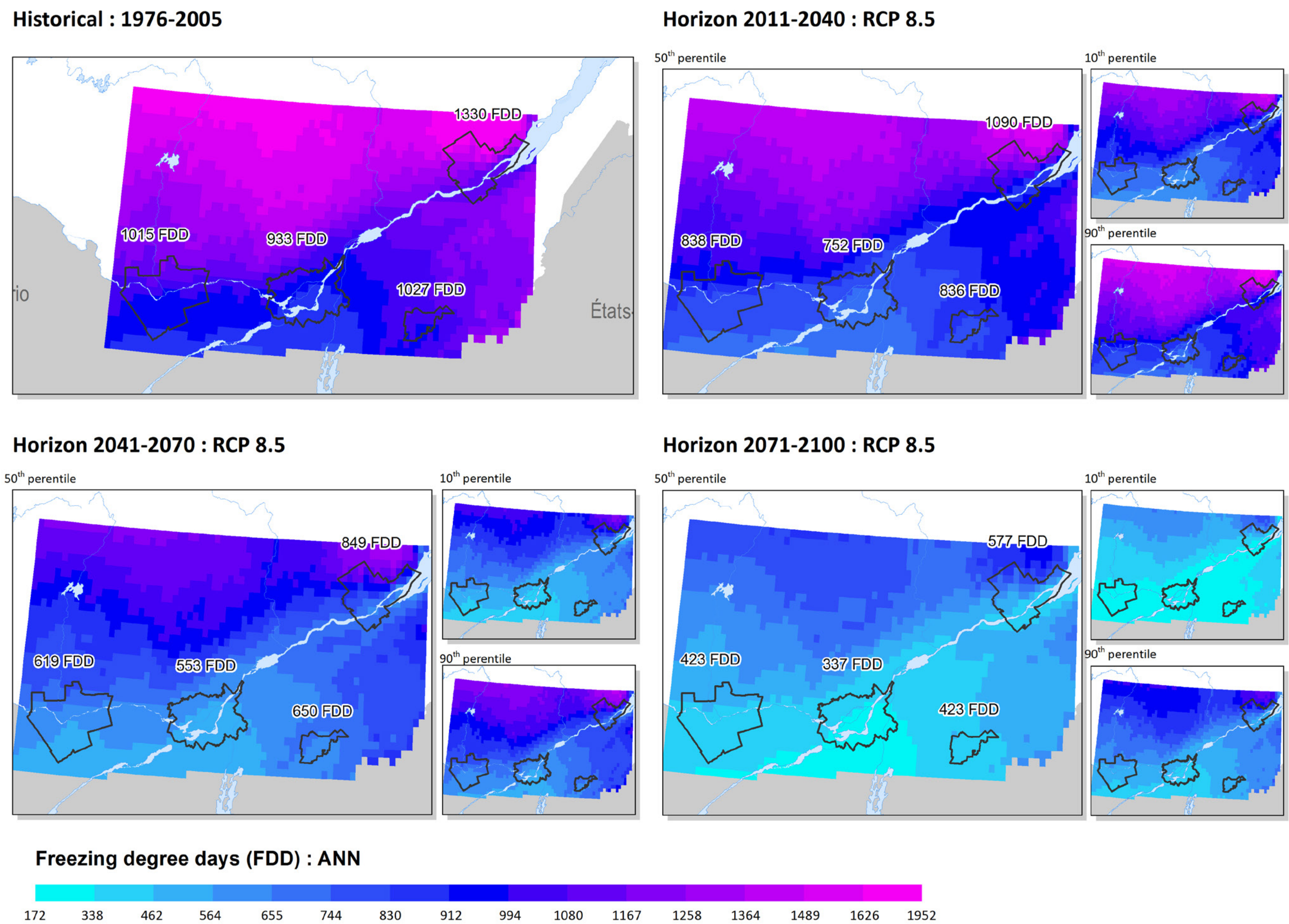



**Figure 4: Observed average summer (JJA: June, July and August) (Figure 4a) and winter (DJF: December, January and February) (Figure 4b) temperatures for the 1971-2000 period (left panel) and projected (right panels) for the 2050 horizon (2041-2070).** The observed average is calculated from CRU TS 3.21 dataset (CRU TS = Climatic Research Unit Timeseries, 3.21 dataset is the name of the release). Future maps present the ensemble median (i.e., the median of all the available projections) as well as the 10th and 90th percentiles (i.e., lower and higher bounds) of 29 future climate scenarios. Future climate scenarios were produced using the "delta" method calculated from the CMIP5 (Coupled Model Intercomparison Project Phase 5) simulations (RCP 8.5) and applied the observed data (see Charron, 2014). (Source: Ouranos)

Warming temperatures will also bring changes to other indicators that affect the transportation sector. For example, the cold season will begin later and end earlier, resulting in a season close to one month shorter in the south of the province by 2050 (Logan et al., 2016, in press). Projections of degree-days of freezing are shown in Figure 5.

**Figure 5: Simulated historical and future conditions of annual freezing degree days calculated from an ensemble of climate scenarios (n=11) following RCP 8.5 greenhouse gas forcing trajectory.** The historical panel represents the median of the 11 climate scenarios[9] while future horizons panels represent the median (i.e., the median of all available projections) (left), as well as the 10th and 90th percentiles (i.e., lower and higher bounds) (top and bottom right) of the climate scenario ensemble. The 30 year regional mean of four large urban centres (Gatineau/Ottawa, Greater Montréal, Sherbrooke and the Québec city region) is indicated above the black regional contours. (Source: Ouranos)




Recent observations show a rise in the number of daily freeze-thaw cycles during warmer years (Chaumont and Brown, 2010). However, projections for mid-century suggest a decrease in the number of freeze-thaw cycles. Indeed, from 2050, it is likely that the cold season will shorten to the extent that it will be difficult to reach the same number of freeze-thaw cycles currently observed in a given season.

9 Note that in this case the historical climate normal values are not calculated from observed data, but instead from simulated climate model output which has been corrected to consider observed values using a post-processing method.

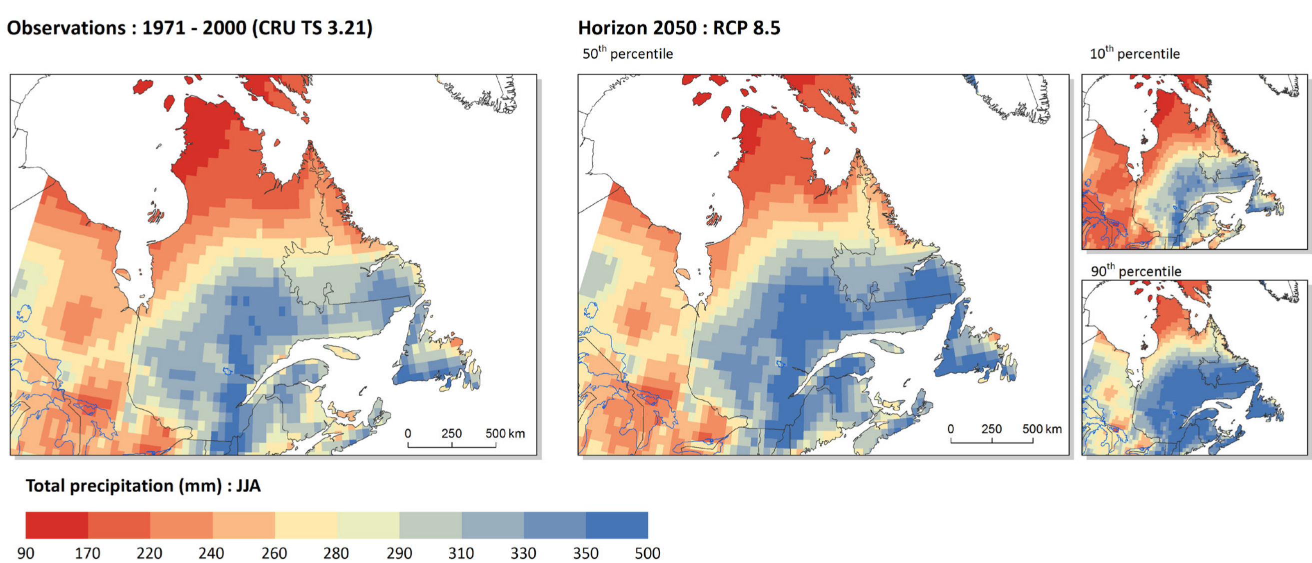
## 3.2 MORE INTENSE PRECIPITATION EVENTS

Total annual precipitation from observed data shows significant upward trends for many of the weather stations located in the south of the province. For some of these stations, the trends are associated with increases in spring and fall precipitation.

Increases in precipitation are expected in winter and spring throughout Québec. In the northern and more central regions, this would also be the case in the summer and fall seasons. As in the case of temperatures, these increases will be more significant for extreme precipitation events than for averages. In fact, all climate models agree on future upward trends for extreme precipitation events, everywhere in Québec, although these changes are more substantial moving northward. This applies for maximum annual amounts in addition to all durations and frequencies. For example, a maximum annual rainfall event with a 20-year return period over the 1986-2005 timeframe could occur more frequently by 2046-2065 with a return period of around 7 to 10 years. Preliminary studies suggest that future climate conditions could be more conducive to thunderstorms, which are usually accompanied by larger quantities of precipitation, although the robustness of these projections is uncertain.
For winter precipitation, the proportion of snow and rainfall relative to total accumulation depends on temperature. Given that the climate has been warming in the recent past, downward snow precipitation trends are already being observed in the south of Québec. An analysis of several different data sources reveals that snow cover duration has decreased by approximately 2 days per decade in the south of Québec between 1948 and 2005.

Even if snowfall events decrease due to a shorter cold season, rainfall events during this season should increase with warming temperatures in winter (see Figure 6). Changes in snow cover with respect to these trends will vary according to the region, altitude, climatic regime, type of surface and vegetation. Compared to the 1970-1999 average, snow cover duration by 2041-2070 could decrease by up to 25 days in the North of Québec, from 25 to 45 days in the central region, from 45 to 75 days for the Gulf of the St. Lawrence and between 45 and 65 days for the south of Québec.

**Figure 6: Observed total summer (JJA: June, July and August) and winter (DJF: December, January and February) precipitation for the period 1971-2000 (left panel) and projected (right panels) for the 2050 horizon (2041-2070).** The observed average is calculated using the CRU TS 3.21 dataset (CRU TS = Climatic Research Unit Timeseries, 3.21 dataset is the name of the release). Future maps present the ensemble median (i.e. the median of all available projections) as well as the 10th and 90th percentiles (i.e., lower and higher bounds) of 19 future climate scenarios. Future climate scenarios were produced using the "delta" method calculated from the using CMIP5 (Coupled Model Intercomparison Project Phase 5) simulations (RCP 8.5) applied to the observed data (see Charron, 2014). (Source: Ouranos)



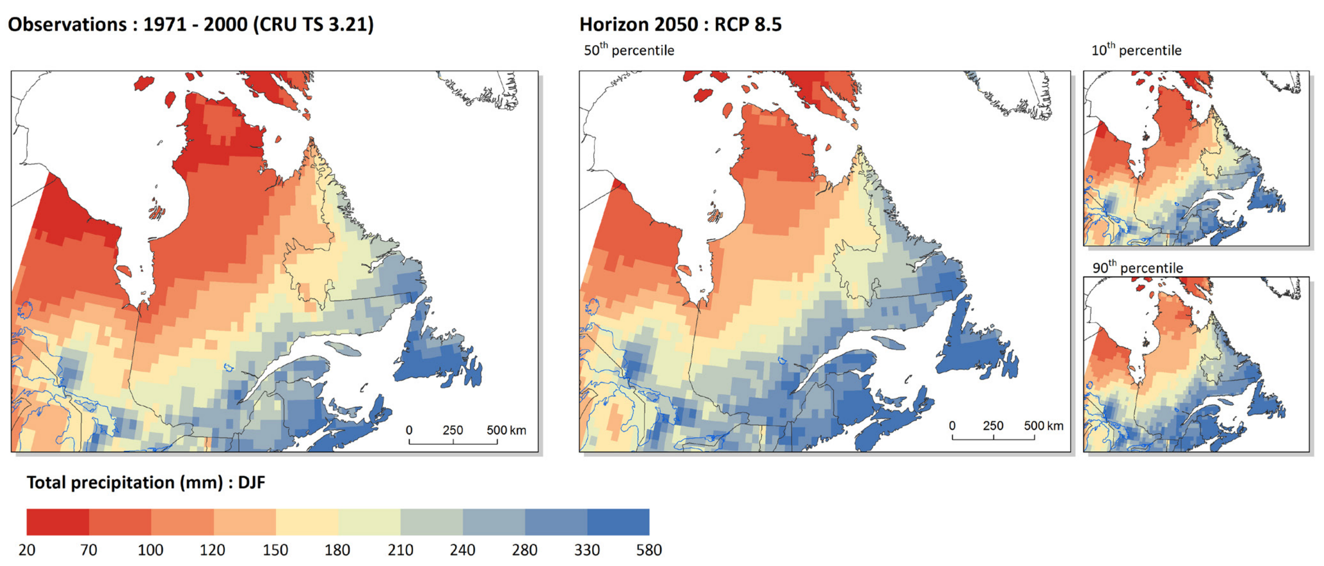
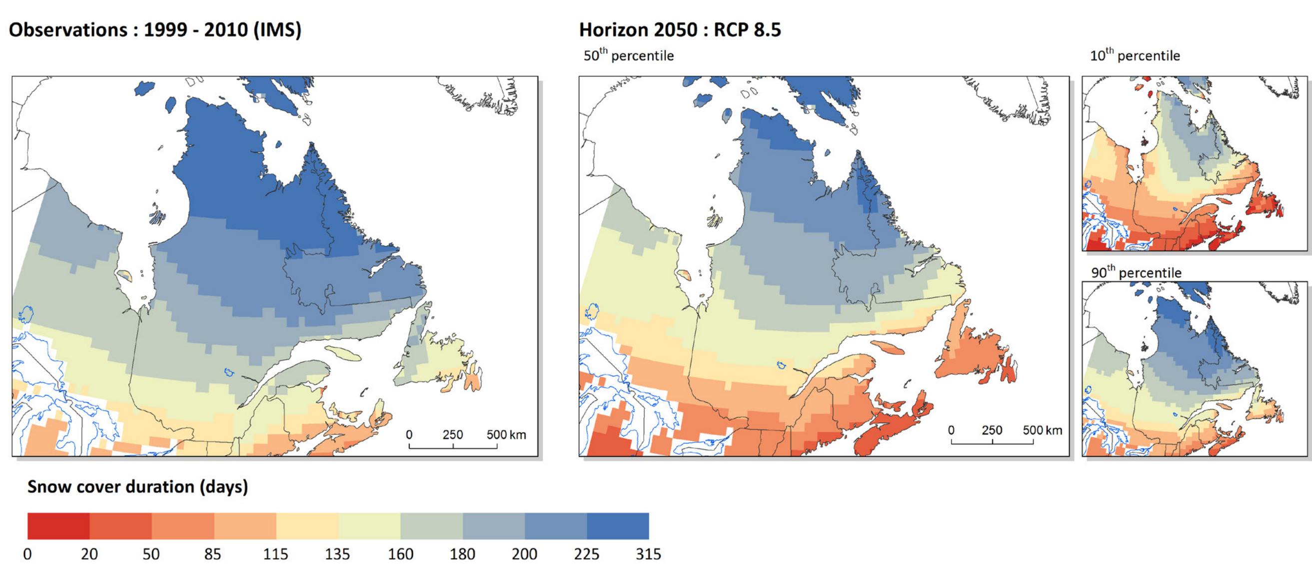



**Figure 7: Observed snow cover duration for the period 1999-2010 (left panel) and projected (right panels) for horizon 2050 (2041-2070).** The observed average is calculated using the IMS 24 dataset (IMS Ice mapping System 24 km resolution) (National Ice Center, 2008). Future maps present the ensemble median (i.e., the median of all available projections) as well as the 10th and 90th percentiles (i.e., lower and higher bounds) of 19 future climate scenarios. Future climate scenarios were produced using the "delta" method calculated from the CMIP5 (Coupled Model Intercomparison Project Phase) (RCP 8.5) and applied to the observed data (see Charron, 2014). (Source: Ouranos)




With respect to freezing rain, this is a phenomenon that predominantly affects the Saint-Lawrence valley due to its morphology and position (Ressler et al., 2012). While great progress has been made to improve knowledge in terms of the conditions likely to generate this type of event, it remains uncertain whether the number, duration and intensity of these events will change in Québec over the coming decades.

### 3.3 UNCERTAINTY CONCERNING WINDS

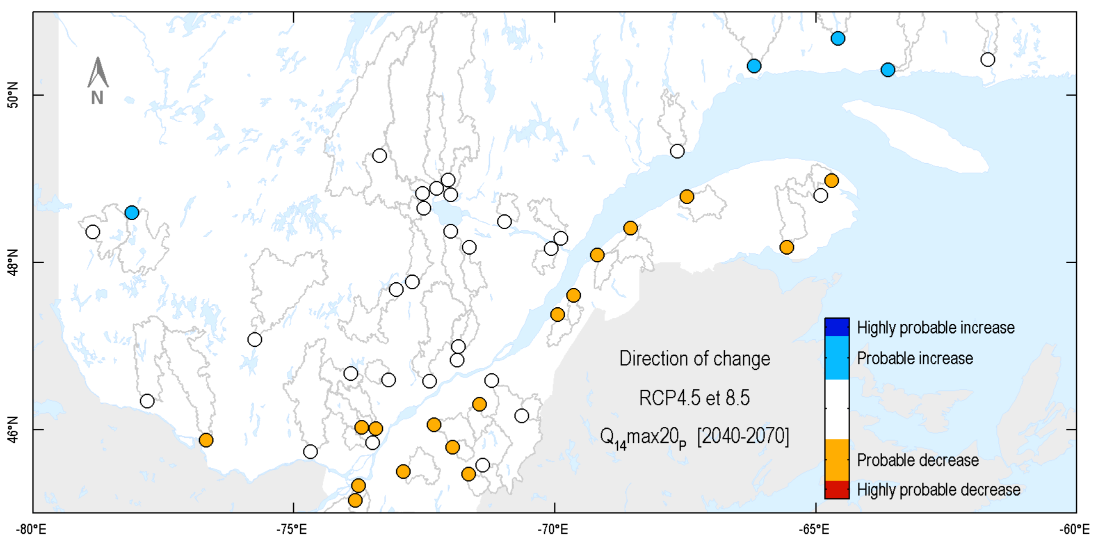
Average observed wind speeds for the great majority of weather stations varies only slightly from one season to another. With the exception of a few stations that show minor increases, most stations in Québec show downward trends in average wind speed throughout the year over the 1953 to 2006 period.

Projections of future winds remain uncertain since very few studies exist on this subject. Additional analyses based on a greater number of climate simulations at finer resolutions would be required.

### 3.4 FLUCTUATING AVERAGE RIVER FLOWS

Average river flows are expected to increase in winter throughout Québec by 2041-2070. Conversely, for the same time period in the south of Québec, decreases in average flows are likely to occur in the summer, spring and fall seasons although consensus between model outputs is not as high. Figure 8 shows expected changes in spring freshet, the spring thaw resulting from snow and ice melt in rivers. More information on future changes to watersheds in southern Québec can be found in the "*Atlas hydroclimatique du Québec méridional*" (Centre d'expertise hydrique du Québec, 2015).

**Figure 8: The hydrological indicator $Q_{14}max20_p$ provides an indication of the volume of spring freshet for the 20-year return period.** (Source: Centre d'expertise hydrique du Québec)




### 3.5 RELATIVE SEA LEVEL

Changes to relative sea level vary at regional scales because of several factors including marine currents, atmospheric circulation, seawater density (itself affected by surface temperatures, freshwater supply through waterways or glacier melt), the proximity to ice sheets and glaciers (gravitational effects) and other geophysical phenomena (rotational effects). Some of these phenomena occur in combination and cancel each other out or fluctuate in time over inter-annual or decadal scales, making it difficult to detect significant trends. As a result, rising relative sea levels will affect the marine estuary and Gulf of the St. Lawrence. In the Hudson Bay, a drop in relative sea level is expected due to postglacial isostatic adjustment in this area diminishing the effect of sea level rise. More information on this can be found in Chapters 3 and 8.

## 3.6 A PROGRESSIVE LOSS OF SEA ICE COVER

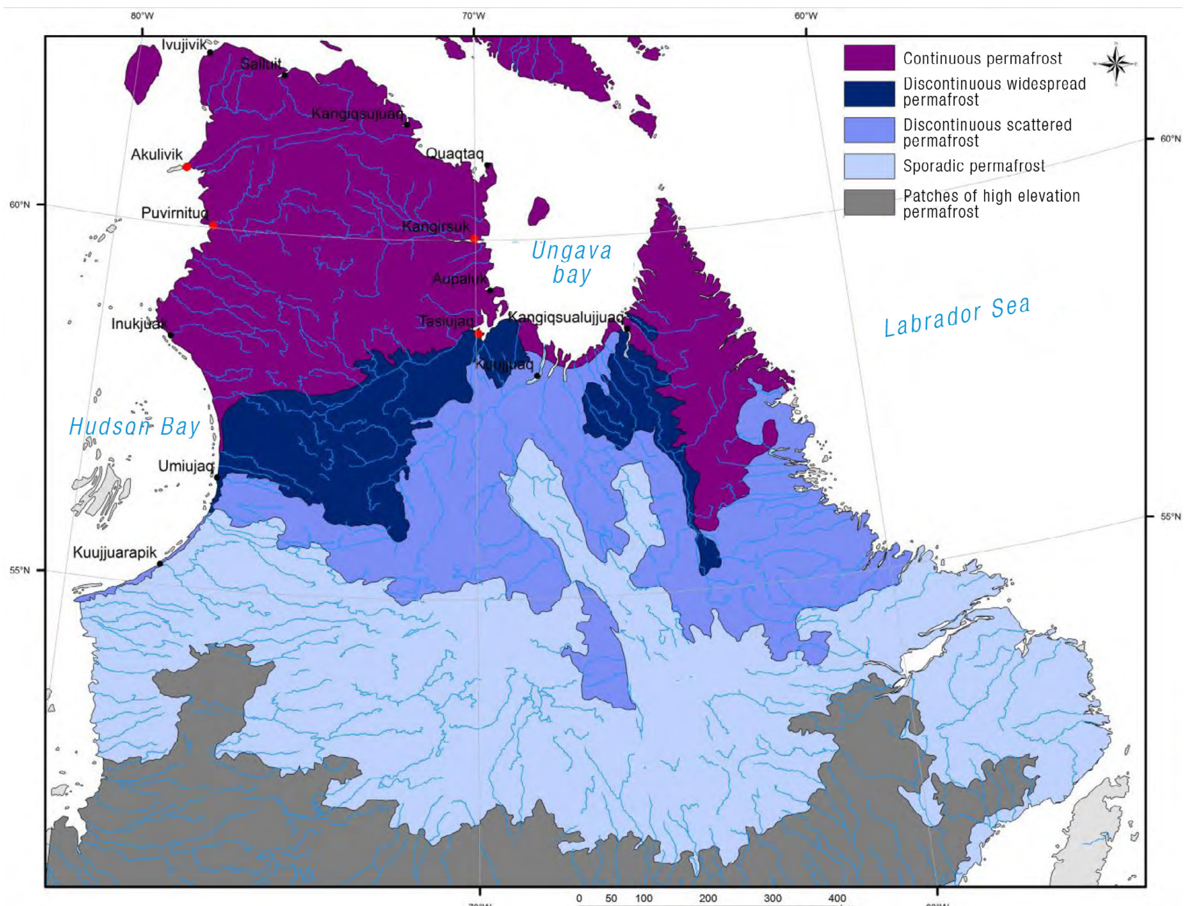
Warming temperatures will also affect sea ice cover (see Chapter 3). More specifically for Québec, a study of the marine estuary and Gulf of the St. Lawrence shows ice cover reductions between 1998 and 2012. The freeze-up season is shorter than in the past despite the fact that interannual variability is quite high (Senneville et al., 2014). This same study showed that the proportion of maximum ice cover in the region diminished from approximately 47 % (1968-1998) to 36 % (1998-2013).

These trends are likely to continue and projections indicate that freeze-up could arrive about 10-20 days later while thawing could begin 20 to 30 days earlier by 2041-2070, compared to 1982-2011 in the Gulf of the St. Lawrence. In the Hudson Bay area, the ice-free season could extend up to two months longer towards mid-century. Other regions in Québec could also be affected however, existing studies on the subject do not make it possible to determine the magnitude of expected changes.

## 3.7 THAWING PERMAFROST

Québec's northern region is located in an area of permafrost as illustrated in Figure 9. Permafrost is very sensitive to warming temperatures and changing precipitation patterns (see Chapter 3).

**Figure 9: Permafrost distribution in northern Québec.** (Source: Allard and Lemay, 2012)




These conditions will affect the transportation sector at different levels. The following section will describe in more detail the main vulnerabilities for the different modes of transportation throughout Québec.

# 4.0 TRANSPORTATION VULNERABILITIES TO CLIMATE CHANGE

Although the projected climate outlook shows that all regions of Quebec can expect rising temperatures and heavier precipitation events, the consequences will affect each economic activity differently, including transportation infrastructure and mobility. Extreme weather events are likely one of the greatest risks for all regions of Quebec. In addition, the built environment in Quebec is aging, and certain transportation infrastructure is reaching the end of its useful life or needs considerable refurbishment (Canadian Infrastructure Report Card, 2012). It may therefore be more vulnerable to the impacts of climate change.

The following sections present the main climate vulnerabilities identified for road, marine, rail and air transportation in Quebec. One section also deals with the telecommunication networks on which these modes of transportation depend. The vulnerabilities described are those of infrastructure, but also, more generally, those of transportation services operations and management. More information is available on road transportation, which underscores the importance of this mode in terms of modal share, as well as current research and development efforts.

## 4.1 GROUND TRANSPORTATION

### 4.1.1 VULNERABILITIES OF ROAD TRANSPORTATION IN SOUTHERN QUEBEC AND ALONG THE ST. LAWRENCE

In the area that extends to the east of Québec City to the lower North Shore (covering the Lower St. Lawrence, the Gaspé Peninsula and the Magdalen Islands), roads and villages are located along the coast. One third of the population in this region and close to 60% of national roads are located less than 500 metres from the shoreline (Drejza et al., 2014; Boyer-Villemaire et al., 2014). Some portions of Route 132 that follow the entire south shore of the St. Lawrence, from the United States border west of Montréal to Gaspé, are located anywhere from a few meters to a few dozen meters from the shore (McHugh et al., 2006).

In the 20th century, this proximity to the river was seen as favourable for transportation, due to the supply of natural resources and marine exploitation. However, the establishment of roads and facilities along the St. Lawrence now appears to be a factor that exacerbates their vulnerability (Drejza et al., 2015). The rise in annual average temperatures and especially rising winter temperatures recorded since the 1980's (Bernatchez et al., 2008, Bernatchez, 2015; Savard et al., 2008) have various consequences such as a reduction in ice cover, a relative rise in sea level and an acceleration of cryogenic processes, which contribute to erosion (Bernatchez et al., 2011; Bernatchez et al., 2015; Boyer-Villemaire et al., 2014). More than half of the St. Lawrence estuary and gulf coastlines are prone to erosion (Drejza et al., 2015). Along the estuary and gulf coastal zone, 294 kilometers of roads are considered to be at risk by 2065 (Bernatchez et al., 2015). The growth in the built environment along the St. Lawrence estuary increases the magnitude of the impact (Bernatchez and Fraser, 2011; Bernatchez et al., 2015; Ouranos, 2015). The impacts of climate change are already being felt on road infrastructure (Drejza et al., 2014). Several studies have found that erosion problems have required considerable investment to move roads or build remedial works (Ouranos, 2015; Bernatchez et al., 2015).

Freeze-thaw cycles are also causing the erosion of several rock cliffs in the St. Lawrence estuary and gulf, in southern Quebec (Bernatchez et al., 2014) (*see box on coastal erosion in the Magdalen Islands*), especially in the middle of the cold season by contributing to the continuous expansion of water in the ground, in cliffs or in road surfaces, which can cause cracks, splitting and detachment of cliffs or mud slides (Boucher-Brossard and Bernatchez, 2013; Drejza et al., 2015). Although surfaces are usually designed to resist frost for approximately four months and to withstand large quantities of snow and melt, rapid snow and ice melt renders these surfaces more vulnerable. Mild temperature periods, which are projected to rise in frequency (Ouranos, 2015) also increase and intensify roadway damage (Chaumont and Brown, 2010; Doré et al., 2014). Roadways currently have a reduced useful lifespan specifically because of the cracking phenomenon that lets rain water penetrate and consequently increase the saturation level of the soil and of roadway materials (Masseck, 2014).

The relative rise in sea level of approximately 40 centimeters since the beginning of the 20th century exposes several portions[10] of the Quebec road system, in particular along Highway 20 and Route 132 (Bernatchez and Fraser, 2011). The rise of relative sea level, among other things, reduces soil stability under buildings, infrastructure and roads in Quebec (Bernatchez et al., 2012). It decreases the stability of the transport system as a whole and, consequently, that of the supply and mobility system. The acceleration of this phenomenon is likely to increase the risk of road flooding from storm surges in the St. Lawrence corridor (Savard et al, 2016. Lemmen et al., 2008; Intergovernmental Panel on Climate Change, 2013). The problem of waves and tides on the Quebec coast along the Gulf and up the middle estuary is further compounded by the fact that the coast will be less protected by decreasing ice cover. In addition, submersion events could become increasingly frequent and intense and reach areas that, until now, were not highly affected. Without adaptation measures that respect the coast's geomorphology, erosion will continue to affect the natural system, the integrity of the built environment and the quality of life for most communities living in coastal areas (Bernatchez, 2015; Ouranos, 2015).

Riprap[11], seawalls, jetties, etc., are forms of protection that reinforce the public's sense of safety (Cooper and Pile, 2014; Friesinger and Bernatchez, 2010; Linham and Nicholls, 2010). That said, these methods are costly and may be a factor in the breakdown of some natural slopes and beaches (lowering, shrinking, etc.), especially if they are used to protect slopes in loose zones (Bernatchez et coll., 2008; Bernatchez, 2015). Where sediment is loose, riprap reduces beaches' natural ability to absorb the energy from storm surges. It is therefore likely to contribute to erosion (Drejza et al., 2014; Bernatchez et al., 2011; Bernatchez and Fraser, 2011) and scour at the edges of riprap and other artificial linear structures. Furthermore, turbulence that occurs when water hits the edges of a structure erodes the sand of any unprotected neighboring areas (Bernatchez and Fraser, 2011).

In the SeptÎles and Percé regions, the width of beaches has shrunk by 85% and 44% respectively, where the shoreline was artificially enhanced by a rigid protective structure (Bernatchez and Fraser, 2011). Other effects of climate change on terrestrial infrastructure are associated with the increased intensity of rain precipitation in the winter that could create negative impacts, in particular for the management of surface water runoff (Groleau et al., 2007). For example, existing drainage systems on coastal roads can sometimes contribute to the formation of ravines where water collects (Ministère de la Sécurité publique du Québec, 2012), and this may trigger landslides and speed up erosion. On the other hand, in the south of the province, around the St. Lawrence Valley, rising average temperatures and changes in precipitation patterns could have a positive impact due to less snow and ice on roads, which could translate into lower costs for ice and snow removal of roads (Webster *et al*., 2008).

Other effects of climate change on land infrastructure are summarized in Table 2.

10 A portion of road corresponds to a route itinerary. It can be regional or local.

11 Riprap is an adaptation option built by dumping of stones of various size with a soft slope in order to absorb and dissipate wave energy before it reaches the shore (Circé et al., 2016)

**Table 2: Summary of certain climate change effects on roadways. Adapted from Thiam (2014)**

| Causes | Possible effects on roadways |
|---|---|
| **Rise in temperature in cold areas and increase in the number of mild periods in the winter** | Decrease in the freezing index in winter, decrease in frost depth resulting in less roadway deterioration due to frost heaves and reduction in thermal cracking |
| | Possible increase in damages due to partial thaw of subbase (rutting and cracking and weakening of roadways) |
| **Increase in extremely hot temperatures** | Increase in flow ruts (creep effect) |
| **Increase in the availability of water during the summer** | Rise in the level of the water table, causing a weakening of the structural layers and a decrease in lifespan<br><br>Increased rutting<br><br>(Korkiala-Tantuu and Dawson, 2007). |
| **Increase in the frequency and intensity of extreme rainfalls** | Increase in water content of roadway soil immediately after rain |
| | Increase in water content of roadways and decrease in their rigidity |

### 4.1.2 LAND TRANSPORTATION VULNERABILITIES IN NUNAVIK

Transportation infrastructure in northern villages is built on continuous, discontinuous or sporadic permafrost (see Figure 10 in Chapter 3). Permafrost thaw, especially due to rising temperatures, and also by snow and drainage management, decreases the structural integrity of roads (Doré et al., 2014; Ouranos, 2015). The differential settlement associated with permafrost thaw, and its structural consequences on embankments specifically, affect drainage networks and alter their integrity (Beaulac, 2006; Dumais and Doré, 2013) by causing cracks or settling that require more frequent maintenance, as is the case for access roads to the Umiujaq (Figure 10) and Salluit airports.

**Figure 10: Significant settling on the Umiujaq access road.** (Source : Allard, M., Fortier, R., Sarrazin, D. et al., 2007)

A changing climate also affects the mobility of local populations in Nunavik. In winter, frozen lakes and streams offer various possibilities for travel by all-terrain vehicle, snowmobile and dog sled. As the frost period shortens, these possibilities are reduced (Tremblay et al., 2006; Nickels et al., 2005; Bernier et al., 2014). Changes in ice conditions and the shortening of the period when ice is present complicate access to natural resources and to subsistence activities (Clerc et al., 2011; Tremblay et al., 2006). Access to hunting, gathering, and fishing territory is essential to northern communities, and their local economy. Alternative trails can be used, but this change in traditional land reduces possibilities to exploit quality nutritional resources (Barrett, 2013). Moreover, local know-how and experience no longer allow snow and ice conditions to be predicted as reliably to plan and organize travel (Nickels *et al*., 2005; Samson *et al*., 2013). These consequences are likely to affect the cultural identity and health of northern populations, in addition to their economic development.

### 4.1.3 EXTREME WEATHER EVENTS AND ROAD TRANSPORT

Extreme weather events will affect road transportation in all regions. Events such as heavy precipitation, storms and temperature variations (e.g., freeze-thaw cycles) cause accelerated wear of road infrastructure (Auld and MacIver, 2005; Case, 2008; Larrivée, 2010). Moreover, when infrastructure nears the end of its useful life it becomes more vulnerable to extreme weather events (Ouranos, 2015). This could increase road maintenance requirements. The integrity and performance of culverts and bridges may also be affected.

In Nunavik, an increase in the occurrence of extreme weather events will have an impact on transportation. Some events (e.g., blizzards, wind, heavy snow) reduce visibility, affecting driving conditions and the safety of travel on land, causing delays and isolating communities from essential services.

Extreme weather events can also isolate communities, particularly those that depend on a single mode of transportation. The absence of alternative transportation services contributes to the vulnerability of populations in these regions. For example, the strong waves and storm surges produced by strong winds that hit the shores of the Lower Saint-Lawrence, Gaspé, Magdalen Islands and the North Shore on December 5th and 6th, 2010 generated tides 5.54 meters above chart datum in Rimouski, an exceptional height (Quintin et al., 2013). The storm flooded several roads, including Routes 132, 199, 299, 198, rendering them impassable to traffic. The assault of the waves and strong rains damaged roadways, certain retaining walls, and the area surrounding walls and culverts (see Figure 11). On the basis of replacement costs per kilometer and taking into account the existing geographical situation and means of coastal protection (Bernatchez et al., 2015), damage was estimated at several million dollars and several hundred people had to be evacuated (St-Amour, 2011). This winter storm demonstrates the effects that a combination of factors, such as a reduction in ice cover, a relative rise in sea level, and wind direction and storms, can have on natural and built environments.

**Figure 11: Major deterioration of the Route 132 roadway in the Gaspé Peninsula, in December, 2010.**
(Source: Ministère des Transports, de la Mobilité durable et de l'Électrification des transports du Québec)

Storm surges are related to the height of the sea above the astronomical tide during heavy storms. More frequent storm surges could increase marine submersion events as well as erosion of natural environments such as beaches and dune ridges. Storms can also cause the collapse of breakwaters, dams and other hydraulic structures (Bernatchez et al., 2012).

If sandy beaches are exposed to strong winds for long periods of time in the spring and fall, the winds can carry sand and contribute to moving dunes. This affects road maintenance in the Magdalen Islands.

The main meteorological factors that can affect forest fires include temperature, wind speed and direction, relative humidity, precipitation and atmospheric stability (Ordre des ingénieurs forestiers du Québec, 2009). These factors vary in time and space, and will likely have a greater adverse effect in the northwest region of the province (Boulanger et al., 2013). The section of the road system located within the limits of commercial forestry operations primarily serves this industry. Fires caused by lightning can have a major impact on road access to resources and at the same time, on the vitality of these industries' operations and the communities that depend on them.

In 2013, the Société de protection des forêts contre le feu (SOPFEU) fought 84 fires (SOPFEU, 2014). During the summer of that same year, major fires at the northern limit of the commercial forestry operations required protection of the Eastmain and Baie-Johan-Beetz communities. In the James Bay region, the only road connecting Matagami to Radisson was closed for over 300 kilometers, requiring the evacuation of several hundred workers, leaving communities isolated by the flames (Gouvernement du Québec, 2013; see Figure 12).

Other types of disturbances to road transportation are also associated with extreme weather events. The uprooting of trees can disrupt road access due to the presence of debris. Also, transport planning and road maintenance could be disrupted due to the increased frequency and intensity of heat waves, as extreme heat can expose workers to occupational illnesses and injuries (e.g., heat stroke, heat exhaustion and heat cramps) (National Institute for Occupational Safety and Health, 2016). Recommended controls for reducing workplace heat stress include engineering controls (e.g., use of reflective or heat-absorbing shielding or barriers) and work practices (training, hydration, acclimatization and rest breaks) (National Institute for Occupational Safety and Health, 2016; Commission des normes, de l'équité, de la santé et de la sécurité du travail, 2016).

**Figure 12: Forest fire in Chibougamau in 2005.** (Source: Société de protection des forêts contre le feu)

## 4.2 MARINE TRANSPORTATION

Some marine infrastructure dates back several decades, with the exception of northern infrastructure which was created at the turn of the 21st century by the provincial and federal governments and local authorities (Clerc et al., 2011; Ministère des Transports du Québec, 2011). Aging infrastructure, along with rising temperatures, reduced ice cover and increased frequency and intensity of extreme weather events, could increase marine transportation vulnerability.

### 4.2.1 MARINE TRANSPORTATION IN THE ST. LAWRENCE CORRIDOR

Scientific studies differ on the precise effect of climate change on fluctuations in water levels and flow between Lake Ontario and the St. Lawrence. Due to human interventions (e.g., buildings, water level control, etc.), it is difficult to establish the expected magnitude of associated levels and flow (Bouchard and Cantin, 2015). That said, simulations of the effect of higher temperatures on evaporation in the Great Lakes tend toward a possible reduction of levels and flow in the river portion of the St. Lawrence (Bouchard and Cantin, 2015). Conversely, in the lower St. Lawrence, in the estuary and the gulf, a changing climate would likely result in a rise in water level.

In the Montréal area, where an average of approximately 2,200 vessels pass each year and where more than one million twenty foot equivalent unit (TEU) containers are transported annually (Port of Montréal, 2015), this reduction could be in the order of 0.5 to 1.0 meter (Croley, 2003; Fagherazzi et al., 2004; Lefaivre, 2005; Roy and Boyer, 2011). Such a decrease could potentially cause a decline in the number of container ships stopping at the Port of Montréal (Slack and Comtois, 2016).

Anticipated changes to flow and water levels will affect marine traffic, as well as the entire intermodal freight transportation system organized around the Port of Montréal. At the same time, rising temperatures could provide a business opportunity to the Port of Montréal, due to a longer commercial navigation season upstream. The navigation season currently extends from the end of March to the end of December.

Tidal and ice movements associated with a rise in temperatures also affect sediment transport and silting. This could require adjustments in the management and maintenance of waterways and marine infrastructure. Sediment transport will likely affect navigation throughout the St. Lawrence corridor. In some strategic areas, the accumulation of sediment can reduce water levels and become an obstacle to navigation, which could increase the need to dredge channels and other areas surrounding marine infrastructure (Slack and Comtois, 2016).

Climate projections indicate that in 2040-2070 (compared to the 1982-2011 baseline period), freezing will occur 10 to 20 days later in the estuary and the Gulf, and thaw will be 20 to 30 days earlier (Senneville *et al*., 2014). As a result, the period of time when ice traditionally covers the St. Lawrence (the months of January, February and March) could be considerably shortened. Ice protects the coasts against wave and storm erosion. Although a reduction in the freeze-up period benefits navigation, an absence or decrease in ice cover will cause waves and storms to erode the coastline, even in the winter (Bernatchez *et al*., 2015; Bernatchez *et al*., 2010; Savard *et al*., 2010). Also, ice pile-up near marine infrastructure, caused by strong winds and sea currents, could contribute to the deterioration of these facilities.

The movement of ferries is also restricted by ice formation. When ice forms rapidly, icebreaking services may be needed from the Canadian Coast Guard, or services to some communities must be provided by air transport (Société des traversiers du Québec, 2014). See Chapter 6, case study 4: "Water levels, ice removal and adaptive management at the St. Lawrence Seaway Management Corporation".

### 4.2.2 MARINE TRANSPORTATION IN NUNAVIK

Climate change will affect storm systems and ice cover in Hudson Bay and, consequently, wave systems, extreme water levels and the moisture balance of coastal drainage basins (Clerc et al; 2012; Savard et al., 2016). The main cause of damage to marine infrastructure is the occurrence of strong waves associated with the passing of storms. Damage often occurs during extreme conditions, which are rare but very intense, and result in the combination of several phenomena (e.g. strong waves and extreme water levels) caused by the overlapping of spring tides and storm surges (Ouranos, 2015). Studies are underway to precisely quantify the vulnerability of Nunavik marine infrastructure to climate change.

## 4.3 RAIL TRANSPORTATION

In general, climate change vulnerabilities for rail transportation in Quebec are poorly documented. The rail management system, which involves private stakeholders and representatives from different levels of government (local, provincial and federal) interacting within an international institutional framework (Canada and the United States), contributes to the complexity of identifying vulnerabilities specific to Quebec infrastructure. Nevertheless, it is clear that any impact on the rail system has significant repercussions on the entire supply chain in Canada (QGI Consulting, 2009). See Chapter 5 for more information on these challenges.

Managing water runoff along train tracks is a major concern (AREMA, 2003). Extreme weather events and episodes of heavy rain can cause drainage and erosion problems, and increase the risk of a system breach due to disruptions in communications. For example, an episode of heavy rain in 2010 eroded the soil under the tracks of a section of the Arcelor Mittal railway. In addition to preventing the trains from moving, the erosion caused a rupture in the fiber optic cables that ensure communication throughout the system. Extreme weather events can also increase the risk of tracks being blocked by debris. As the climate continues to warm, extreme weather events and episodes of heavy rain will become more frequent and/or more pronounced (Ouranos, 2015) increasing the vulnerability of rail transportation in Quebec.

Brakes are also frequently tested during bad weather. In some sectors, particularly in the center of the province, personnel must remain on site and in personnel camps, during heavy storms. Maintenance work is then suspended and delays associated with performing inspections and additional maintenance costs are to be expected based on the increasing frequency of such events (Gouvernement du Québec, 2015).

Climate factors that contribute to triggering landslides (e.g., abundant rain, rapid snow melt and such other events likely to increase as the climate warms) have a tendency to increase rail system vulnerability.  This would be especially significant in areas prone to landslides, such as the clay rich regions of the St. Lawrence valley, where soil characteristics interact with land use and exacerbate the vulnerability of rail transportation systems.

Similar to road transportation, rail transportation is vulnerable to impacts from forest fires caused by lightning. The economic impact of fires is particularly significant for the network in the center of the province, where there is little redundancy. In 2013, Arcelor Mittal Mines Canada, which uses rail tracks in Quebec and has three camps for its staff, saw its operations restricted for several days near Manic-Cinq due to fires and smoke. Access to industrial sites, including those for general maintenance activities, was restricted by near zero visibility conditions. Decreased visibility created by bad weather (fires, heavy rains, etc.) also makes operating a locomotive more complex and dangerous.

Changes in freeze-thaw cycles also affect track integrity and can reduce the lifespan of infrastructure. They can also trigger landslides, which is particularly problematic on tracks where required clearances around the infrastructure are minimal.

Tracks undergo a certain expansion during times of extreme heat and a certain contraction during deep freezes, but generally react well to temperature variations. However, in the context of significant thermal variation, this expansion phenomenon can damage tracks.

### 4.3.1 RAIL TRANSPORTATION IN THE ST. LAWRENCE CORRIDOR

Bank erosion, flooding and submersion problems, phenomena heightened by climate change, affect coastal train tracks such as the Charlevoix Railway Inc. and the Gaspé Railway Company, as well as railways located along streams, like the Compagnie de chemin de fer de l'Outaouais and the Chemin de fer Québec Central.  Erosion can compromise network structural integrity, and even cause a complete interruption of activities in the affected region. A landslide in Gascons on the Gaspé Peninsula suggests such rail network vulnerabilities in this region (Locat et al., 2013). Furthermore, in the Charlevoix and North Shore areas (around Sept-Îles particularly), some track segments are affected by challenges related to slope stability, geotechnical issues, or rockfall (Leroueil et al., 2001).

## 4.4 AIR TRANSPORTATION

Meteorological conditions, including localized events such as strong winds, thunderstorms and heavy precipitation, influence flying conditions throughout Quebec. Combinations of multiple events, such as freezing rain followed by strong winds, complicate take-offs and landings.

In southern Quebec, air transportation involves multiple national and international connections for passengers and goods. As a reduction in the duration and frequency of freeze-thaw events is expected in southern Quebec, runway and aircraft maintenance needs and associated costs could be reduced (Mills, 2004), which would be positive for air transportation in the region.

Nevertheless, an increased frequency and intensity of extreme weather events could increase the frequency of flight delays and cancellations, limiting the mobility of passengers and goods.

Villages in Nunavik, those on the Magdalen Islands, and those in the far east of the North Shore are particularly vulnerable to disruptions in air transportation, as they rely heavily on this mode for inter-regional travel.

Airport infrastructure in Nunavik was designed between 1984 and 1991 for a stable climate with no special measures to protect against permafrost thaw (Guimond et al., 2010). However, rising temperatures, and in some cases increased precipitation and runoff, are contributing to permafrost thaw, resulting in differential soil settlements, and premature damage to infrastructure. Snow accumulation along runways and embankments serves as an insulator and warms the ground, also contributing to thaw (Savard, 2006; Guimond and Boucher, 2013). Some infrastructure is showing signs of deterioration attributable to permafrost thaw (Guimond et al., 2010). Access roads and landing strips in this region could see their lifespan diminish and thus compromise emergency management and services, and require additional maintenance work. Freeze-thaw events in this region further complicate de-icing and increase maintenance costs for landing strips.

Extreme weather events also contribute to the vulnerability of air transportation in Nunavik. Although few studies have been done on wind, the Quaqtamiut note [translation] "[...] a worsening of strong winds and storms in past years" (Clerc et al., 2011). In addition, flight time and, consequently, fuel consumption, fluctuate based on winds (Morris, 2011).

Finally, the Société de protection de la forêt regularly flies over central Québec as well as other commercial airlines that have connecting flights between the south and north of the province. Air transportation is sensitive to extreme weather events. A projected increase in the occurrence of such events would increase runway maintenance needs and, as a result, costs associated with labour, rental, machinery and products needed to address them. In addition, forest fires and smoke considerably reduce visibility for planes, which must adapt their flying methods to ensure safety (Transport Canada, 2015, p. 211).

## 4.5 DISTRIBUTION AND TELECOMMUNICATION NETWORKS

Transport and mobility depend greatly on information technology and communications systems. Information and telecommunication networks can be affected by strong winds, thunderstorms, lightning, and ice. Although it is difficult to know how climate change will modify the frequency or intensity of specific conditions, breaches and breakages caused by these events are likely to affect the entire transportation system. The ice storm in southern Quebec in 1998 illustrates the cascading effects a disruption due to extreme weather can have on various networks (telecommunications, services, electricity, etc.) and thus on the entire transportation system ( Dupigny-Giroux, 2000).

# 5.0 ADAPTATION MEASURES

Climate change affects all regions of Quebec without concern for administrative limits or shared jurisdictions, and depends on the collaboration of various levels of government and Quebec's civil society (Ouranos, 2015).

Climate change will have both positive and negative effects on construction costs and the lifespan of land-based infrastructure (Doré et al., 2014). Several actions can contribute to making infrastructure more resilient. Above all, it is important to consider a set of complementary measures. Changing design can improve (or maintain) structural performance. However, increased maintenance activities and methods to detect early failure can help significantly reduce vulnerability. It is also important to pursue work that evaluates the technical, economic and environmental performance of potential adaptation measures (Doré et al., 2014; Ouranos, 2015).

This section reviews plans and projects implemented over the last several years by the Quebec government, regional and local organizations and authorities, and transportation companies. There is relatively little documentation on actions planned or implemented by the private sector to adapt Quebec's transportation infrastructure, management and planning systems to climate change.

## 5.1 ADAPTATION MEASURES PLANNED AND IMPLEMENTED BY THE QUEBEC GOVERNMENT

In 1996, the Quebec government developed its first Climate Change Action Plan (CCAP), which equipped government authorities to better understand climate risks in Quebec. The CCAP developed for 2006-2012 ($99 million) aimed to provide government stakeholders, the scientific community and non-governmental organizations the means to implement actions to reduce greenhouse gas emissions and to adapt to climate change (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2015). Among the 26 measures of this action plan, Measure 23 was specifically related to transportation, and gave the MTMDET the mandate of evaluating and conducting research that helped better understand phenomena that could affect the Quebec transportation system. Studies conducted during this period improved understanding of the coastal environment and how it might change due to the effects of climate change, and considered the challenges of erosion and flooding within the long-term management of exposed infrastructure. Other studies helped better define issues concerning permafrost thaw and integrate appropriate strategies for the design, repair and management of infrastructure.

In 2012, the Quebec government adopted a Government Strategy for Climate Change Adaptation 20132020 (Gouvernement du Québec, 2012a). The Strategy aims to raise public awareness of climate change and mobilize several departments and partners, including the MTMDET, regarding the sustainability and adaptation of transportation infrastructure. To improve services offered to the public and to adapt transportation, the 2013-2015 MTMDET strategic plan for MTMDET supports diversifying modes of transportation. Consideration of climate change is a major part of the plan (MTQ, 2012).

The importance of transportation is also recognized in the current action plan on climate change entitled « Le Québec en action vert 2020 » "Quebec Green Action 2020" (Gouvernement du Québec, 2012a). This plan, based on the Government Strategy for Climate Change Adaptation (Gouvernement du Québec, 2012a), supports crosscutting actions specific to health, the economy, infrastructure and the natural environment. Land-use planning is a key element of the plan, aimed at strengthening community resilience. Urban densification is identified as a tool for reducing future infrastructure needs, including roads (Gouvernement du Québec, 2012a; 2012b). Communication among residents and public and private stakeholders is also identified as a cross-cutting action to support climate change adaptation. Moreover, the plan provides for "specific training, awareness-building, knowledge transfer and decision support tools, and technical assistance [...] to targeted audiences" (Gouvernement du Québec, 2012a). Efforts on this element have already been launched, specifically for government employees.

## 5.2 ADAPTATION MEASURES ON A REGIONAL AND LOCAL SCALE

Local knowledge and community involvement are also important. Knowledge and stories about changes to modes of travel and traditional routes help identify changes to the climate that are otherwise difficult to document (Grimwood et al., 2012; Samson et al., 2013).

Significant progress (action, research, awareness-raising) has been made in the last ten years to promote anticipatory adaptation (Cuerrier et al., 2015; Bernatchez et al., 2012; Plante et al, 2015). In northern Quebec for example, adaptation measures were implemented when the first signs of deterioration to transportation infrastructure were observed, before significant climate impacts were felt (Guimond et Boucher, 2013).

Since 2003, the MTMDET has had a thermal monitoring program for airport infrastructure in Nunavik (under its jurisdiction), built on land sensitive to thaw (Guimond et Boucher, 2013). In the last decade, mapping of permafrost areas in northern communities has been undertaken to support land-use planning (L'Hérault et al., 2013). By using data from geotechnical research, such mapping determines which areas to avoid, which require more information, and which require special construction techniques to address problem areas identified. A better understanding of constraints helps prioritize procedures for the area, based on existing knowledge (L'Hérault et al., 2013; also see Case Study 2).

In 2007, 12 communities were the subject of a soil classification project led by the Center for Northern Studies, and other more detailed studies are underway (Allard, Calmels, et al., 2007; L'Hérault et al., 2013). More specifically, the impact of a changing climate on landing strip stability in Nunavik has been the subject of several studies since the early 2000's (Allard, Fortier, et al., 2007; Doré et al., 2014; Allard et al., 2013.) Researchers have identified methods of intervention to maintain air operations, including more frequent maintenance and improvements to drainage techniques (L'Hérault et al., 2013).

The MTMDET and the Center for Northern Studies recently collaborated in the development of an adaptation strategy for airport structures vulnerable to permafrost thaw (Guimond et al., 2010). Temperature monitoring devices were embedded at 13 airports in Nunavik to monitor the condition of runways in real-time. Adaptation techniques were tested on two problem sites (see Case Study 1). The Kuujjuaq landing strip was the subject of a study by Transport Canada, while more generally, regular monitoring is undertaken to verify the condition of transportation facilities (airports, access roads and marine infrastructure).

In addition, each municipality is developing a land-use master plan that identifies the areas suitable for building in order to ensure the sustainability of transportation infrastructure and operations (L'Hérault et al., 2013). Awareness tools and best practice guides have also been developed by municipal authorities in order to inform employees and suggest concrete actions to reduce the impact of climate change on infrastructure (for example, drainage and snow management on land infrastructure).

CASE STUDY 1

## CASE STUDY 1: MONITORING THE THERMAL BEHAVIOUR OF THE SALLUIT AIRPORT ACCESS ROAD AND TESTING A METHOD TO DETECT PERMAFROST DEGRADATION ALONG LINEAR STRUCTURES IN THE CONTEXT OF CLIMATE CHANGE

A section of the Salluit Airport access road in Nunavik is built on permafrost made up of ice-rich marine deposits. Since the early 2000's, researchers have observed significant degradation linked to permafrost thaw in this section. In 2012, the MTMDET proceeded with the reconstruction of this section of road in order to maintain safe land access year-round, in the context of a changing climate. The embankment design was adapted by integrating it with new design criteria that aimed to promote a rise in the permafrost table. Within the framework of this project, two technological innovations were tested: the use of fiber optic cable to detect sectors at risk of deterioration along the road, and the implementation of an embankment with a large scale heat sink as an adaptation solution. This project was undertaken by the MTMDET, in collaboration with the Center for Northern Studies and the Laval University surface engineering research group. http://www.mddelcc.gouv.qc.ca/changementsclimatiques/bilan-2012-2013/adaptation.htm

Monitoring the state of the environment and infrastructure is important and several management measures (e.g., snow removal along roads; more frequent cleaning of culverts; identification of alternative routes) and design measures (e.g., lessening the slope of the dyke; replacing culverts) can be implemented to reduce the impact of climate risks (Transportation Association of Canada, 2010). See the chapter on the Northern Territories for additional information on maintenance, monitoring and construction practices aimed at maintaining the integrity of infrastructure built on permafrost.

CASE STUDY 2

## CASE STUDY 2: DAM BREAK AND FLOODING OF THE SAGUENAY

In 1996, heavy rains hit the Saguenay region of Quebec. A series of floods forced the evacuation of 16,000 people and destroyed several roads and bridges, isolating some populations.

Following these events, the Centre de géomatique du Québec (Quebec Geomatics Center) and the Ministère de la Sécurité publique (Department of Public Safety) implemented an interactive on-line mapping tool (GéoRISC portal) to guide dam managers and limit the consequences of dam breaks and flooding in the region. This management system (SCORE) has been online since 2008, providing continuous access to descriptive data for dams in Saguenay-Lac-Saint-Jean. Among other uses, modelling with this data makes it possible to consider the consequences of a dam collapse, recognize the impact that precipitation has on the road system, and plan alternative routes.

A research chair in coastal and fluvial engineering was created in 2013 (Gouvernement du Québec, 2012b). This chair, created within the Institut national de la recherche scientifique (INRS), with the collaboration of the MTMDET and MSP, has conducted various research projects on the adaptation of design criteria for coastal remedial works (Ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques, 2014). In addition, studies on the vulnerability of road infrastructure in eastern Quebec were conducted by the chair in coastal geoscience at the Université du Québec in Rimouski (Drejza et al, 2014; Drejza et al, 2015.).

Ongoing efforts to model the hydrology of the St. Lawrence drainage basin are helping to plan for the impact of climate change on hydrological systems influencing marine transportation (Bouchard et Cantin, 2015). However, port authorities and marine industry representatives appear less equipped to anticipate extreme weather events such as storms, hurricanes, etc., that will have a greater effect on their operations in the coming years (Slack and Comtois, 2016).

Following a study by INRS (Mailhot et al., 2014), as of 2015 the MTMDET has applied a new loading factor of 18 or 20% for watershed flows of 25 km$^2$, depending on the region of Quebec, to account for climate change (MTMDET 2015). This adjustment factor was 10% until recently. The use of the GéoRISC portal also contributed to dam management (see Case Study 2).

On a more local level, several studies (see summary in Savard et al., 2008) led jointly by the Ministère de la Sécurité publique, the Université du Québec à Rimouski, Ouranos and the City of SeptÎles, contributed to a better understanding of the causes and factors associated with coastal erosion. The municipality of Sept-Îles then zoned its territory to better control usage along the shoreline and performed a cost-benefit analysis of various solutions for structures already threatened by the loss of coastal terrain. The City of Sept-Îles, where roads are seriously affected by bank erosion, has implemented a sand refill strategy for those beaches that are most threatened by erosion. It has also prohibited riprap in several areas.

Although it is included on a list of remedial works to prevent road erosion, riprap may be less advantageous from an economic and structural perspective than alternative protection options depending on the nature of the coast (Bernatchez and Fraser, 2012). Similarly, because sand refill, riprap and oversizing alone cannot ensure the resilience of coastal areas to heightened erosion and an increased frequency, duration and intensity of extreme weather events, the City of Sept-Îles is working with the SeptRivières RMC and the Quebec government to come up with a plan for coastal procedures (Natural Resources Canada, 2015). This plan will help determine the sectors most at risk and consider various scenarios for transferring equipment and infrastructure.

The procedural plan for emergency management in the Magdalen Islands identifies buildings and roads at risk of erosion. It presents scenarios for interventions as well as transferring infrastructure and equipment, and identifies potential partners, including the MTMDET. The plan also highlights municipal willingness to integrate an "appropriate city regulation" into the city plan (Municipality of the Magdalen Islands, 2010).

With respect to fires and their impact on roads, a study on lightning was conducted in Quebec by the Canadian Forest Service (Morrissette, 2009). It made it possible to localize events and determined that lightning density is higher in the southern and western regions of the province. In 2005, a drought resulted in numerous forest fires, forcing the emergency evacuation of nearly 1,000 residents in the City of Chibougamau (Gouvernement du Québec, 2005). The MTMDET collaborated with the Société de protection des forêts contre le feu and municipalities in central Quebec to improve knowledge regarding climate hazards, including forest fires, and associated transportation vulnerabilities; to develop decision-making tools; and, to prepare land-use plans aimed at ensuring the sustainability of transportation infrastructure and services.

## 6.0 CONCLUSIONS AND FUTURE RESEARCH NEEDS

Transportation networks play a critical role in supporting economic competitiveness and quality of life. However, the high level of interdependence among systems renders the challenges associated with climate change more complex (Ouranos, 2015).

Climate change will modify the natural environment in all areas of Quebec. Most of Quebec's coastal areas will experience an increase in erosion, in addition to flooding in areas that were minimally affected until now.

In Nunavik, thawing permafrost contributes to the collapse and cracking of roads and airport infrastructure, which are essential to serving the communities (Transport Canada, 2015). Maintenance techniques and rehabilitation, as well as the frequency of interventions, must be modified resulting in significant additional costs and challenges for planning. In this region of Quebec, changes in ice cover and changes in storm regimes also significantly affect winter mobility. Management of runoff and drainage are also affected by climate change. Maps characterizing permafrost areas can help to better plan development, and are an important tool to protect infrastructure in this region. Many challenges remain in the area of northern infrastructure adaptation, particularly in relation to knowledge transfer, acquisition of long-term data, the use of new technologies to optimize data acquisition, and interventions (Transport Canada, 2015).

In urban areas, frequent and more intense rains cause local flooding and will likely increase with climate change. A combination of measures would help better manage stormwater issues.

Extreme weather events appear to pose the greatest risk for infrastructure and transportation systems in all seasons. Infrastructure design, along with all aspects of operation, maintenance, management and refurbishment is, and will continue to be, affected by climate change.

Adaptation is a social and institutional challenge that should be treated in an integrated fashion. The impact of climate change on infrastructure cannot be studied in isolation from other factors (social, political, cultural, environmental and economic) that influence infrastructure usage and management. Local and global vulnerabilities of the Quebec transportation system must be recognized in order to develop relevant adaptation tools and measures that help maintain the condition of infrastructure and transportation operations.

The Quebec government has dedicated considerable efforts over the last two decades to better understanding the impact of climate change on the natural environment as well as on transportation infrastructure and mobility. The challenges related to storm water management such as bank erosion and permafrost thaw are particularly well documented. Strategies to develop solutions to these problems are becoming better understood. On the basis of this work, the government has started to implement concrete actions to increase overall resilience. Nevertheless, transportation adaptation continues to be a subject requiring further research.

There is also a need to better document climate risks to organizations, companies and operating systems. Understanding the interaction between natural environmental changes caused by climate change and the design, organization and management of transportation systems could benefit from more studies.

With respect to road transportation, more research is need for the coordination between different stakeholders and assessments of the impact of climate change on road signalling and peripheral equipment, as well as on the use and development of informal roads and corridors in the North.

As for rail transport, few studies were identified. Therefore, it remains difficult to determine specific rail transportation challenges in Quebec.

In the area of marine transportation, there is a need to improve and further document knowledge of the vulnerability of infrastructure and marine transportation to climate change, especially in southern Quebec. Several themes are worth looking into, such as: assessing premature damage to infrastructure associated with climate change; and studying the combined impact of increased navigation and climate change on invasive marine species.

With respect to electrical transmission and distribution, the thresholds and tolerance levels of equipment and infrastructure to hostile conditions (strong winds, lightning, freezing rain, etc.) need to be determined. This can help prevent disruption to communications systems in transportation infrastructure such as the fibre optic cables used in the Arcelor Mittal railway damaged due to heavy rain.

Finally, monitoring the condition of infrastructure relative to a well-documented baseline condition would help improve the understanding of potential vulnerabilities, evaluate the performance of measures implemented, and intervene in a more intelligent and strategic manner in problem areas. Thus, long-term data collection is important both to continue to document the impact of climate change, and to define design criteria and best practices for maintenance and management. Enhanced knowledge also allows for the exchange of best practices regarding infrastructure design, construction and maintenance.

## REFERENCES


Allard, M., Calmels, F., Fortier, D., Laurent, C., L'Hérault, E., and Vinet, F. (2007). *Cartographie des conditions de pergélisol dans les communautés du Nunavik en vue de l'adaptation au réchauffement climatique* [Final scientific report for Ouranos]. Montreal, QC. p. 49.

Allard, M., Fortier, R., Calmels, F., Savard, C., Guimont, A., and Tuarussov, A. (2007). *L'évaluation de l'impact du réchauffement climatiques sur la stabilité des pistes , au Nunavik: première étape vers une stratégie d'entretien.* Presented at the 2007 Annual meeting of the Transportation Association of Canada, Saskatoon, SK.

Allard, M., Lemay, M., Barrette, C., L'Hérault, E., Sarrazin, D. et al. (2012). Permafrost and climate change in Nunavik and Nunatsiavut: Importance for municipal and transportation infrastructures. In: Allard, M. and M. Lemay (Eds), Nunavik and Nunatsiavut: From science to policy. An Integrated Regional Impact Study (IRIS) of climate change and modernization. ArcticNet Inc., Quebec City, Canada, p. 171-197

Andrey, J. (2010). Long-term trends in weather-related crash risks. *Journal of Transport Geography, 18*, 247-258.

Andrey, J., and Mills, B. (2002). Climate change and transportation: potential interactions and impacts. In *The potential impact of climate change on transportation: Summary and discussion papers* (pp. 77-88). DOT Center for Climate Change and Environmental Forecasting, Federal Research Partnership Workshop, October 1-2, 2002. Retrieved from http://climate.dot.gov/documents/workshop1002/mills.pdf

AREMA (Ed.). (2003). *Practical guide to railway engineering* (2nd Edition). Lanham, MD: The American Railway Engineering and Maintenance-of-Way Association (AREMA). p . 569.

Auld, H., and MacIver, D. (2005). Cities and communities: The changing climate and increasing vulnerabililty of intrastructure. In D. MacIver and L. Erda (Eds). *Climate change: Building the adaptive capacity* (pp. 254 - 288). Retrieved from http://projects.upei.ca/climate/files/2012/10/Book-5_Paper-19.pdf

Barrett, M. (2013). *Les changements climatiques au Nunavik* [Video]. Retrieved from http://monclimatetmoi.ca/videos/les-changements-climatiques-au-nunavik/

Beaulac, I. (2006). *Impacts de la fonte du pergélisol et adaptations des infrastructures de transport routier et aérien au Nunavik* (Masters thesis). Université Laval, QC. p. 276.

Beaulieu, P. (2014). *Portrait économique des régions du Québec* (2015 edition). Québec, QC: Ministère de l'Économie, de l'Innovation et des Expotations. Retrieved from http://www.economie.gouv.qc.ca/fileadmin/contenu/documents_soutien/regions/portraits_regionaux/portrait_socio_econo.pdf.

Bernatchez, P. (2015, February). *Bilan des connaissances sur l'érosion et la submersion côtière au Québec : enjeux, causes et perspectives.* Presentation at the 15th Symposium on Civil Security and Fire, Quebec. Retrieved from http://www.securitepublique.gouv.qc.ca/fileadmin/Documents/securite_civile/colloques/2015/presentations/bernatchez2015.pdf

Bernatchez, P., Boucher-Brossard, G., Corriveau, M., and Jolivet, Y. (2014). *Impacts des changements climatiques sur l'érosion des falaises de l'estuaire maritime et du golfe du Saint-Laurent* [Final scientific report for the Quebec Ministry of Public Safety and Ouranos]. Rimouski, QC: Chaire de recherche en géoscience côtière, Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 166.

Bernatchez, P., Boucher-Brossard, G., and Sigouin-Cantin, M. (2012). *Contribution des archives à l'étude des événements météorologiques et géomorphologiques causant des dommages aux côtes du Québec maritime et analyse des tendances, des fréquences et des temps de retour des conditions météo-marines extrêmes* [Report presented to the Quebec Ministry of Public Safety]. Rimouski, QC: Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 140.

Bernatchez, P., Dugas, S., Fraser, C., and Da Silva, L. (2015). Évaluation économique des impacts potentiels de l'érosion des côtes du Québec maritime dans un contexte de changements climatiques [Scientific report for Ouranos]. Québec, QC: Université du Québec à Rimouski. p. 45 and annexes. Retrieved from https://ouranos.ca/wp-content/uploads/2016/03/RapportBernatchez2015_FR.pdf

Bernatchez, P., and Fraser, C. (2011). Evolution of coastal defence structures and consequences for beach width trends, Quebec, Canada. *Journal of coastal research, 28*(6), 1550-1566.

Bernatchez, P., Fraser, C., Friesinger, S., Jolivet, Y., Dugas, S., Drejza, S., and Morissette, A. (2008). *Sensibilité des côtes et vulnérabilité des communautés du golfe du Saint-Laurent aux impacts des changements climatiques* [Scientific report for Ouranos and FACC]. Rimouski, QC: Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 256. Retrieved from https://www.ouranos.ca/wp-content/uploads/2016/03/RapportBernatchez2008_FR.pdf

Bernatchez, P., Fraser, C., Lefaivre, D., and Dugas, S. (2011). Integrating anthropogenic factors, geomorphological indicators and local knowledge in the analysis of coastal flooding and erosion hazards. *Ocean and Coastal Management, 54* (8), 621–632.

Bernatchez, P., Toubal, T., Van-Wierts, S., Drejza, S., and Friesinger, S. (2010). *Caractérisation géomorphologique et sédimentologique des unités hydrosédimentaires de la baie de Plaisance et de Pointe-aux-Loups, route 199, Îles-de-la-Madeleine.* [Final report submitted to Quebec Ministry of Transport]. Rimouski, QC: Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 177.

Bernier, M., Gignac, C., Gauthier, Y., and Poulin, J. (2014). *Projet ICEPAC - Atlas interactif sur la probabilité de l'aléa glace à l'échelle des infrastructures maritimes et côtières dans un contexte de changements climatiques* [2013-2014 Progress report to Ouranos and Natural Resources Canada]. Montreal, QC: Institut national de la recherche scientifique, Centre Eau-Terre-Environnement. p. 50. Retrieved from http://espace.inrs.ca/2694/1/R001577.pdf

Bouchard, A., and Cantin, J.-F. (2015). Évolution des niveaux et débits du fleuve Saint-Laurent, *Suivi de l'état du Saint-Laurent, Plan d'action Saint-Laurent*. Retrieved from http://planstlaurent.qc.ca/fileadmin/publications/fiches_indicateurs/Fiche-debits_niveaux_eau_F_final.pdf

Boucher-Brossard, G., and Bernatchez, P. (2013). *Analyse historique et récente de l'érosion du talus côtier, secteur des Cayes, municipalité de Rivière-Saint-Jean, Côte-Nord* [Research report submitted to the Quebec Ministry of Transport, Direction de la Côte-Nord]. Rimouski, QC: Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 37.

Boulanger, Y., Gauthier, S., Gray, D.R., Le Goff, H., Lefort, P., and Morissette, J. (2013). Fire regime zonation under current and future climate over eastern Canada, *Ecological Applications*, 23(4), pp. 904-923.

Boyer-Villemaire, U., Marie, G., and Bernatchez, P. (2014). *Vulnérabilité des infrastructures routières de l'Est du Québec à l'érosion et à la submersion côtière dans un contexte de changements climatiques : Analyse des stratégies internationales et recommandations en matière de réduction de la vulnérabilité des infrastructures de transport face aux risques naturels côtiers* [Research report submitted to the Quebec Ministry of Transport]. Rimouski, QC: Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 165 and annexes.

Canadian Infrastructure Report Card (CIRC). (2012). *Municipal roads and water systems.* Canadian Infrastructure Report Card, Volume 1: 2012. p. 75. Retrieved from http://www.canadainfrastructure.ca/downloads/Canadian_Infrastructure_Report_Card_FR.pdf

Case, T. (2008). Climate change and infrastructure issues. *Drinking Water Research* (Special Edition)*, 18* (2), 15-17.

Centre d'expertise hydrique du Québec (CEHQ). (2015). Atlas hydroclimatique du Québec méridional: Impacts des changements climatiques sur les régimes de crue, détiage et d'hydraulicité à l'horizon 2050. Québec, QC: Centre d'expertise hydrique du Quéec (CEH). p. 81.

Charron, I. (2014). Guide sur les scenarios climatiques: Utilisation de l'information climatique pour guider la recherche et la prise de decision en matiere d'adaptation. Montreal, QC: Ouranos. Retrieved from https://www.ouranos.ca/wp-content/uploads/2016/03/GuideCharron2014_FR.pdf

Chaumont, D., and Brown, R. (2010). Analyse de simulations régionales du climat et d'indices climatiques associés au transport routier dans le sud du Québec. *Routes/Roads*, (345), 78-79.

Circé, M., Da Silva, L., Mercier, X., Boyer-Villemaire, U., Desjarlais, C. and Morneau, F. (2016) Cost-benefit analysis of coastal adaptation options in Percé. Ouranos, Montreal. 150 pages and appendices Retrieved from https://www.ouranos.ca/publication-scientifique/Report-CBA-Perce.pdf

Clerc, C., Gagnon, M., Breton-Honeyman, K., Tremblay, M., Bleau, S., Gauthier, Y., Aloupa, S., Kasudluak, A., Furgal, C., Bernier, M., and Barrett, M. (2011). *Changements climatiques et infrastructures marines au Nunavik - Connaissances locales et point de vue des communautés des Quaqtaq, Uniujaq et Kuujjuaq* [Research report No R-1273f presented to Aboriginal Affairs and Northern Development Canada]. Québec, QC: Institut national de la recherche scientifique, Centre Eau-Terre-Environnement. p. 123 and annexes

Clerc, C., Poulin, J., Gauthier, Y., Bernier, M., Bleau, S., Gignac, C., Bédard, J.-S., and Duhamel-Beaudry, É. (2012). *Descripteurs et indicateurs de la couverture glacielle au Nunavik: Quaqtaq, Umiujaq et Kuujjuaq: changements climatiques et infrastructures marines au Nunavik: Impacts et adaptations* [Research report no. R1389 submitted to the Quebec Ministry of Transport, Ouranos Quebec Consortium and Aboriginal Affairs and Northern Development Canada]. Québec, QC: Institut national de la recherche scientifique, Centre Eau-Terre-Environnement. p. 188.

Commission des normes, de l'équité, de la santé et de la sécurité du travail. (2016). *Coup de chaleur: Comment prévenir les coups de chaleur*. Québec, QC. Retrieved from http://www.csst.qc.ca/prevention/theme/coup_chaleur/Pages/comment-prevenir.aspx

Cooper, J.A.G., and Pile, J. (2014). The adaptation-resistance spectrum: A classification of contemporary adaptation approaches to climate-related coastal change. *Ocean & Coastal Management*, 94, 90-98.

CPCS. (2013) Étude multimodale de transport *des marchandises au Québec en appui aux plans territoriaux de mobilité durable, Bloc 3: Caractérisation du transport des marchandises à l'échelle du Québec, des grands corridors de transport et des territoires de PTMD, vol. 1: Introduction, méthodologies et portrait provincia*l [Report prepared for the Québec Ministry of Transport]. Montréal, QC: CPCS. p. 396.

Croley, T.E. (2003). *Great Lakes climate change hydrologic impact assessment: IJC Lake Ontario-St. Lawrence River regulation study* [NOAA Technical Memorandum GLERL-126]. Ann Arbor, MI: US Department of Commerce, National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory. p. 77. Retrieved from https://www.glerl.noaa.gov/pubs/tech_reports/glerl-126/tm-126.pdf

Cuerrier, A., Brunet, N.D., Gérin-Lajoie, J., Downing, A., and Lévesque, E. (2015). The study of Inuit knowledge of climate change in Nunavik, Quebec: A mixed methods approach. *Human Ecology, 43*(3), 379-394.

Donat, M. G., Alexander, L. V., Yang, H., Durre, I., Vose, R., Dunn, R. J. H., Willett, K.M., Aguilar, E., Brunet, M., Caesar, J., Hewitson, B., Jack, C., Klein Tank, A.M.G., Krueger, A.C., Marengo, J., Peterson, T.C., Renom, M., Oria Rojas, C., Rusticucci, M., Salinger, J., Elrayah, A.S., Sekele, S.S., Srivastava, A.K., Trewin, B., Villarroel, C., Vincent, L.A., Zhai, P., Zhang, X., and Kitching, S. (2013). Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. *Journal of Geophysical Research: Atmospheres*, 118(5), 2098–2118.

Doré, G., Bilodeau, J.-P., Masseck Thiam, P., and Perron Drolet, F. (2014). *Impact des changements climatiques sur les chaussées des réseaux routiers québécois* [Final scientific report for Ouranos]. Québec, QC: Université Laval. p. 63.

Drejza, S., Friesinger, S., and Bernatchez, P. (2014). Vulnérabilité des infrastructures routières de l'Est du Québec à l'érosion et à la submersion côtière dans un contexte de changements climatiques : Caractérisation des côtes, dynamique hydrosédimentaire et exposition des infrastructures routières à l'érosion et à la submersion, Est du Québec, Volume I [Projet X008.1]. [Report for the Quebec Ministry of Transport]. Rimouski, QC: Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 226 and annexes.

Drejza, S., Friesinger, S., and Bernatchez, P. (2015). Vulnérabilité des infrastructures routières de l'Est du Québec à l'érosion et à la submersion côtière dans un contexte de changements climatiques. Volume 3 : Développement d'une approche et d'un indice pour quantifier la vulnérabilité des infrastructures routières à l'érosion et à la submersion côtière dans un contexte de changements climatiques sur 9 sites témoins [Project X008.1] [Report for the Quebec Ministry of Transport]. Rimouski, QC : Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski. p. 308 and annexes. Retrieved from http://www.bv.transports.gouv.qc.ca/mono/1166760/03_Volume_3.pdf

Dumais, S., and Doré, G. (2013). Utilisation de surfaces à albédo élevé afin de contrer la dégradation du pergélisol sous les infrastructures de transport *Via Bitume, 8*(3), 26-27. Retrieved from http://www.viabitume.com/include/pdf/via-octobre-2013.pdf

Dupigny-Giroux, L.-A. (2000). Impacts and consequences of the ice storm of 1998 for the North American north-east. *Weather, 55*(1), 7-15.

Fagherazzi, L., Guay, R., and Sassi, T. (2004). *Analysis of climate change impacts on the Ottawa river system* [Preliminary report to the International Joint Commission - Lake Ontario-St. Lawrence River Study on discharge regulation]. p. 72.

Friesinger, S., and Bernatchez, P. (2010). Perceptions of Gulf of St. Lawrence coastal communities confronting environmental change: Hazards and adaptation, Québec, Canada. *Ocean and Coastal Management, 53*( 11), 669–678.

Gagné, R., and Haarman, A. (2011). *Les infrastructures publiques au Québec: évolution des investissements et impact sur la croissance de la productivité*. Montréal, QC: Centre sur la productivité et la prospérité de HEC Montréal. p. 34. Retrieved from http://cpp.hec.ca/cms/assets/documents/recherches_publiees/PP-2010-03_Infrastructures.pdf

Girard, C., Binette Charbonneau, A., and Payeur, F. (2014). *Le bilan démographique du Québec. Édition 2014.* Québec, QC: Institut de la statistiques du Québec. p. 162. Retrieved from http://www.stat.gouv.qc.ca/statistiques/population-demographie/bilan2014.pdf

Goodwin, P. (2004). *The economic costs of road traffic congestion*. University College London, The Rail Freight Group.

Gouvernement du Québec. (2005, June 7). *Les feux de forêts de Chibougamau* [Press release]. Retrieved from http://www.premier-ministre.gouv.qc.ca/actualites/communiques/2005/juin/2005-06-07_en.asp

Gouvernement du Québec. (2012a). *Le Québec en action vert 2020. Plan d'action 2013-2020 sur les changements climatiques, phase 1*. Retrieved from http://www.mddelcc.gouv.qc.ca/changements/plan_action/pacc2020.pdf

Gouvernement du Québec. (2012b). *Stratégie gouvernementale sur l'adaptation aux changements climatiques*. Retrieved from http://www.mddelcc.gouv.qc.ca/changements/plan_action/stategie-adaptation2013-2020.pdf

Gouvernement du Québec. (2013, July 8). *Incendies de forêt dans le nord du Québec. La première ministre fait le point sur l'évolution de la situation* [Press release]. Retrieved from https://www.premier-ministre.gouv.qc.ca/actualites/communiques/details.asp?idCommunique=2171

Gouvernement du Québec, ministère des Transports. (2013). Portrait québécois du transport des marchandises de la Porte continentale et du Corridor de commerce Ontario-Québec.

Gouvernement du Québec. (2015). *Loi sur la sécurité du transport terrestre guidé. Règlement sur la sécurité ferroviaire.*

Grimwood, B., Cuerrier, A., and Doubleday, N. (2012). Arctic community engagement during the 2007-2008 International Polar Year. *Polar Geography, 35 (3-4)*, 189-193.

Groleau, A.**,** Mailhot, A., and Talbot, G. (2007). Trend analysis of winter rainfall over Southern Québec and New Brunswick (Canada). *Atmosphere-Ocean, 45*(3), 153-162. doi:10.3137/ao.450303.

Guimond, A., and Boucher, M. (2013) L'adaptation aux changements climatiques des infrastructures de transport du Ministère des Transports au Nunavik: de la recherche à l'application. *Routes et Transports* [revue de l'AQTR], *42*(4), 26-29.

Guimond, A., Grondin, G., and Boucher, M. (2010). *Nouvelle approche de planification et de gestion des infrastructures aéroportuaires du ministère des Transports du Québec au Nunavik dans un contexte de changements climatiques: Vers une stratégie d'adaptation*. Presented at the 2010 annual meeting of the Transportation Association of Canada in Halifax, Nova Scotia, p. 16. Retrieved from http://conf.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2010/docs/r1/anick.pdf

Institut de la statistique du Québec (ISQ). (2014). *Territoire*. Retrieved from http://www.stat.gouv.qc.ca/statistiques/quebec_statistique/ter_ter/ter_ter_4.htm

Institut de la statistique du Québec (ISQ). (2015). *Population du Québec, 1971-2015*. Retrieved from http://www.stat.gouv.qc.ca/statistiques/population-demographie/structure/qc_1971-20xx.htm

Intergovernmental Panel on Climate Change (IPCC). (2013). *Climate change 2013: The physical science Basis*. IPCC AR5 Working Group 1. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SummaryVolume_FINAL.pdf

James, S. J., & James, C. (2010). The food cold-chain and climate change. *Food Research International*, *43*(7), 1944-1956.

Korkiala-Tanttu, L., and Dawson, A. (2007). Relating full-scale pavement rutting to laboratory permanent deformation testing. *International Journal of Pavement Engineering*, 8(1), 19-28.

Larrivée, C. (2010). Élaborer un plan d›adaptation aux changements climatiques. Guide destiné au milieu municipal Québécois. Montréal, QC: Ouranos, p. 48.

Lefaivre, D. (2005). *Effet des changements climatiques sur les niveaux d'eau du fleuve Saint-Laurent entre Montréal et Québec. Projections pour les années, 2050* [Report for the St. Lawrence Action Plan Navigation Coodination Committee - Phase 4, Maurice-Lamontagne Institute, Ocean Sciences Directorate]. p. 34.

Lemmen, D.S., Warren, F.J. Lacroix, J., and Bush, E. (Ed.) (2008). *From impacts to adaptation: Canada in a changing climate 2007*. Ottawa, ON: Government of Canada. p. 448.

Leroueil, S., Locat, J., Sève, G., Picarelli, L., and Faure, R.M. (2001). Slopes and movements. In K. Rowe (Ed.), *Geotechnical and Geoenvironmental Engineering Handbook* (pp. 397-428). New York, NY: Kluwer Academic Publishers.

L'Hérault, E., Allard, M., Fortier, D., Carbonneau, A.-S., Doyon-Robitaille, J., Lachance, M.-P., Ducharme, M.-A., Larrivée, K., Grandmont, K., and Lemieux, C. (2013). *Production de cartes des caractéristiques du pergélisol afin de guider le développement de l'environnement bâti pour quatre communautés du Nunavik* [Final scientific report to Ouranos, Natural Resources Canada and the Green Fund]. Québec, QC: Centre for Northern Studies, Université Laval. p. 84.

Linham, M. M., and Nicholls, R. J. (2010). Technologies for climate change adaptation. In X. Zhu (Ed.), *Coastal Erosion and Flooding.* New Delhi, India: Magnum Custom Publishing. Retrieved from http://www.unep.org/pdf/TNAhandbook_CoastalErosionFlooding.pdf

Locat, J., Cloutier, C., Turmel, D., and Charbonneau, F. (2013). *Développement d'outils de gestion du risque de mouvements de terrain dans le secteur Gascons de la société du Chemin de fer de la Gaspésie* [Final report, report LERN-GASCONS-13-01]. Québec, QC: Laboratoire d'études sur les risques naturels (LERN), Département de géologie et de génie géologique, Université Laval. p. 236. Retrieved from http://www.bv.transports.gouv.qc.ca/mono/1163242.pdf

Logan, T., Bilodeau, J.-P., and Henry, K. (2016, in press). *Frost action and climate change*.

Mailhot, A., Panthou, G., and Talbot, G. (2014). *Recommandations sur les majorations à considérer pour les courbes Intensité-Durée-Fréquence (IDF) aux horizons 2040-2070 et 2070-2100 pour l'ensemble du Québec PHASE II. Rapport de recherche (R1515).*Québec, QC: INRS, Centre Eau-Terre-Environnement.

McHugh, R., Bilodeau, F., Rivest, S., Bédard, Y., and Michaud, M. (2006, October). Analyse du potentiel d'une application SOLAP pour une gestion efficace de l'érosion des berges en Gaspésie Iles-de-la-Madeleine. Presentation to the Conference "Géomatique 2006", Montréal, QC.

Mills, B. (2004). Transportation. In D. Lemmen and F. Warren (Eds.), *Climate change impacts and adaptation: A Canadian perspective* (Chapter 8). Ottawa, ON: Government of Canada. Retrieved from http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/perspective/pdf/report_f.pdf

Ministère du Développement Durable de l›Environnement et de la Lutte contre les Changements Climatiques (MDDELCC). (2014). *Plans d'action sur les changements climatiques. Bilan 2012-2013*. Retrieved from http://www.mddelcc.gouv.qc.ca/changementsclimatiques/bilan-2012-2013/bilan-PACC-2012-2013.pdf

Ministère du Développement Durable de l'Environnement et de la Lutte contre les Changements Climatiques (MDDELCC). (2015). *Bilan des plans d'action sur les changements climatiques*.

Ministère de l'Énergie et des Ressources Naturelles (MERN). (2011). *Plan nord - Infrastructures d'accès au territoire*. Retrieved from ftp://ftp.mern.gouv.qc.ca/Public/Biblointer/Mono/2011/12/1084145.pdf.

Ministère de la Sécurité publique du Québec (MSP). (2012). *L'érosion des berges.* Retrieved from http://www.securitepublique.gouv.qc.ca/securite-civile/surveillance-territoriale/erosion-berges.html

Ministère des Transports du Québec (MTQ). (2008). *Transport des marchandises - ferroviaire*. Retrieved from http://transports.atlas.gouv.qc.ca/Marchandises/MarchandisesFerroviaire.asp

Ministère des Transports du Québec (MTQ). (2011). *Projet de recherche visant à évaluer l'impact des changements climatiques sur les infrastructures maritimes du Nunavik et à déterminer les solutions d'adaptation* [Programme de travail]. Québec, QC: Ministère des transports du Québec. p. 24.

Ministère des Transports du Québec (MTQ). (2013a). *Plan stratégique 2013-2015*. Québec, QC: Gouvernement du Québec. p. 58. Retrieved from https://www.transports.gouv.qc.ca/fr/ministere/acces-information-renseignements-personnels/documents-reglement-diffusion/Documents/plan-strategique/Plan-Strategique_2013-2015.pdf

Ministère des Transports du Québec (MTQ). (2013b). *Portrait québécois du transport des marchandises de la Porte continentale et du Corridor de commerce Ontario-Québec*. Québec, QC: Direction des communications du ministère des Transports du Québec. p. 133. Retrieved from http://www.bv.transports.gouv.qc.ca/mono/1129600.pdf

Ministère des Transports du Québec (MTQ). (2015a). *Sécurité ferroviaire*. Retrieved from http://www.mtq.gouv.qc.ca/partenairesprives/transportferroviairemaritimeaerien/Pages/securite-ferroviaire.aspx

Ministère des Transports du Québec (MTQ). (2015b). *Rapport annuel de gestion 2014-2015*. Québec, QC: Gouvernement du Québec. Retrieved from https://www.ceic.gouv.qc.ca/fileadmin/Fichiers_client/centre_documentaire/CEIC-R-3554_02.pdf

Ministère des Transports, de la Mobilité durable et de l'Électrification des Transports (MTMDET). (2015, January). *Normes sur les ouvrages routiers, Tome III - Ouvrages d'art*. Chapter 2, p. 3-4.

Morris, D. (2011). Aux commandes - la rotation de la Terre a-t-ell un effet sur la durée d'un vol? *Air Canada - En Route*. Retrieved from http://gofar.aircanada.com/fr/go-far-answers/question/does-the-earth%E2%80%99s-rotation-affect-the-duration-of-flight/

Morrissette, J. (2009). Étude de la foudre au Québec. *Les Brèves du Service canadien des forêts.* Centre de foresterie des Laurentides (18).

Municipalité des Îles-de-la-Madeleine (2010). *Plan directeur d'Intervention des Îles-de-la-Madeleine*. p. 104.

National Ice Center. (2008). IMS daily Northern Hemisphere snow and ice analysis at 4 km and 24 km resolution [1999-2010]. Updated daily. Boulder, CO: National Snow and Ice Data Center. Retrieved from http://dx.doi.org/10.7265/N52R3PMC

National Institute for Occupational Safety and Health. (2016). *Heat stress recommendations*. National Institute for Occupational Safety and Health Education and Information Division. Retrieved from https://www.cdc.gov/niosh/topics/heatstress/recommendations.html

Natural Resources Canada (2015). *Coping with shoreline erosion in Sept-Îles*. Retrieved from http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/case-studies/16307

Nickels, S., Furgal, C., Buell, M., and Moquin, H. (2005). *Unikkaaqatigiit—putting the human face on climate change: Perspectives from Inuit in Canada*. Ottawa, ON: Joint publication of the Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments of Laval University and the Ajunnginiq Centre of the National Aboriginal Health Organization. p. 123. Retrieved from https://www.itk.ca/canadian-inuit-perspectives-climate-change-unikkaaqatigiit/

Ordre des ingénieurs forestiers du Québec. (2009). *Manuel de foresterie*. Québec, QC: Multimondes edition.

Ouranos. (2015). *Summary of the synthesis on climate change knowledge in Quebec. 2015 edition*. Montréal, QC: Ouranos, p. 13. Retrieved from https://www.ouranos.ca/publication-scientifique/Synthesis_Summary.pdf

Plante, S., Vasseur, L., and Da Cunha, C. (2015). Adaptation to climate change and participatory action research (PAR): Lessons from municipalities in Quebec, Canada. In J. Baztan, O. Chouinard, B. Jorgensen, P. Tett, J.-P. Vanderlinden and L. Vasseur (Eds.), *Coastal zones: 21st century challenges* (p. 319-334). Amsterdam, Netherlands: Elsevier.

Port of Montreal. (2015). *Container market [Brochure*]. Retrieved from http://www.port-montreal.com/files/PDF/publications/2015-05_brochure-conteneur-EN.pdf

QGI Consulting (2009). Description of Canada's rail based freight logistics system [Report prepared for the Rail Freight Service Review]. Edmonton, AB: QGI Consulting. p. 135. Retrieved from http://www.qgiconsulting.ca/railway_freight_reports_e.htm

Quintin, C., Bernatchez, P., and Jolivet, Y. (2013). *Impacts de la tempête du 6 décembre 2010 sur les côtes du Bas-Saint-Laurent et de la baie des Chaleurs* (Report submitted to «la Sécurité publique du Québec»). Rimouski, Québec : Laboratoire de dynamique et de gestion intégrée des zones côtières et Chaire de recherche en géoscience côtière, Université du Québec in Rimouski. Volume I: p. 48 and Volume II: p. 170.

Réseau des chemins de fer du Québec. (2011). *Mémoire présenté par le Réseau des chemins de fer du Québec à la Commission de l'aménagement du territoire sur l'avant-projet de loi sur l'aménagement durable du territoire et l'urbanisme*. Québec, QC: Réseau des chemins de fer du Québec. p. 27. Retrieved from http://www.assnat.qc.ca/Media/Process.aspx?MediaId=ANQ.Vigie.Bll.DocumentGenerique_46339&process=Default&token=ZyMoxNwUn8ikQ+TRKYwPCjWrKwg+vIv9rjij7p3xLGTZDmLVSmJLoqe/vG7/YWzz

Ressler, G. M., Milrad, S. M., Atallah, E. H., and Gyakum, J. R. (2012). Synoptic-scale analysis of freezing rain events in Montreal, Quebec, Canada. *Weather and Forecasting*, 27(2), 362–378. doi:10.1175/WAF-D-11-00071.1

Roche-Deluc. (2010). *Prévisions d'achalandage 2010-2025* [Final report for the «Société des Traversiers du Québec»]. Québec, QC: Roche ltée / Roche-Deluc. p. 104. Retrieved from https://www.traversiers.com/fileadmin/fichiers_client/Documentation/previsions_achalandage_2010_2025.pdf

Roy, A., and Boyer, C. (March 2011). *Impacts des changements environnementaux sur les tributaires du Saint-Laurent*. Presentation to «Colloque en agroclimatologie du Centre de référence en agriculture et agroalimentaire du Québec», Montréal, QC.

Samson, G., Gérin-Lajoie, J., Lévesque, E., Gagnon, F., Gauthier, Y., and Cuerrier, A. (2013). Les savoirs traditionnels au service des savoirs scientifiques: Limites et défis - Le rôle des Inuits aînes du nord québécois. *Esprit Critique, 17*, 94-109.

Savard, C. (2006). *Imagerie Électrique de la sous-fondation pergélisolée des pistes d'atterrissage au Nunavik*. [Masters thesis]. Université Laval, QC. Retrieved from http://theses.ulaval.ca/archimede/fichiers/23595/23595.html

Savard, J.-P., Bernatchez, P., Morneau, F., Saucier, F., Gachon, P., Senneville, S., Fraser, C., and Jolivet, Y. (2008). Étude de la sensibilité des communautés du golfe du Saint-Laurent aux impacts des changements climatique. Summary of results. Montréal, QC: Ouranos. p. 48. Retrieved from https://www.ouranos.ca/wp-content/uploads/2016/03/RapportSavard2008_FR.pdf

Savard, J-P., van Proodij, D., and O'Carroll, S. (2016). Perspectives on Canada's East Coast region. 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. 99-152). Ottawa, ON: Government of Canada.

Senneville, S., St-Onge-Drouin, S., Dumont, D., Bihan-Poudec, A.-C., Belemaalem, Z., Corriveau, M., Bernatchez, P., Bélanger, S., Tolszczuk-Leclerc, S., and Villeneuve, R. (2014). *Modélisation des glaces dans l'estuaire et le golfe du Saint-Laurent dans la perspective des changements climatiques* [Final report presented to Quebec Ministry of Transport]. Rimouski, QC: ISMER-UQAR. p. 384. Retrieved from http://www.bv.transports.gouv.qc.ca/mono/1147874.pdf

Slack, B., and Comtois, C. (2016). Climate change and adaptation strategies of Canadian ports and shipping: The case of the St-Lawrence-Great Lakes system. In A.K.Y. Ng., A. Becker, S. Cahoon, S-L. Chen, P. Earl, and Z. Yang (Eds.), *Climate change and adaptation planning for ports* (pp. 45-48). New York, NY: Routledge.

St. Lawrence Economic Development Council. (2015). *The marine industry: A vital asset for Quebec's development*. http://www.st-laurent.org/wp content/uploads/2015/05/9147_Brochure_IndusMaritime_en_LR.pdf

Société de protection des forêts contre le feu (SOPFEU). (2014). *Rapport annuel 2013.* Québec, QC: SOPFEU. p. 13. Retrieved from http://www.sopfeu.qc.ca/fr/sopfeu/publications/rapports-annuels

Société des traversiers du Québec. (2014). *Rapport annuel de gestion 2013-2014*. Québec, QC: Gouvernement du Québec. Retrieved from https://www.traversiers.com/fileadmin/fichiers_client/Diffusion_info/RAG_STQ_2014.pdf

Soucy, A. (2015). *Le Québec chiffres en mains. Édition 2015*. Québec, QC: Institut de la statistique du Québec. Retrieved from http://www.stat.gouv.qc.ca/quebec-chiffre-main/pdf/qcm2015_fr.pdf

St-Amour, J. (2011). Bas-Saint-Laurent et Gaspésie-Iles-de-la-Madeline. Le réseau routier du MTQ endommagé. *Inter-Action,* 2(1). Retrieved from http://www.securitepublique.gouv.qc.ca/securite-civile/publications-et-statistiques/inter-actionexpress/archives/hiver-printemps-2011/decembre-2010-dans-l-est-du-quebec/reseau-routier-endommage.html?MP=18526-18550

Statistics Canada. (2011). *Shipping in Canada 2011*. (Catalogue no 54-205-X). Retrieved from http://www.statcan.gc.ca/pub/54-205-x/54-205-x2011000-eng.htm

Statistics Canada. (2014). *Air Carrier Traffic at Canadian Airports* (Catalogue no 51-203-X). Retrieved from http://www.statcan.gc.ca/pub/51-203-x/51-203-x2014000-eng.pdf

Thiam, P-M. (2014). *Effets des futurs changements climatiques sur la performance à long terme des chaussées souples au Québec* [Masters thesis]. Université Laval, QC. Repéré à http://i3c.gci.ulaval.ca/fileadmin/i3c/documents/Ajouts_Octobre_2013/Memoire_Papa_Masseck_Thiam_taille_reduite.pdf

Transport Canada. (2015). *Compendium d'articles sélectionnés - le réseau d'expertise sur la recherche de l'infrastructure du transport du Nord*.

Transportation Association of Canada. (2010). *Dossier d'information sur le développement et la gestion des infrastructures de transport dans les régions du pergélisol*. Transportation Association of Canada (TAC), p. 9.

Tremblay, M., Furgal, C., Lafortune, V., Larrivée, C., Savard, J.-P., Barrett, M., Annanack, T., Enish, N., Tookalook, P., and Etidloie, B. (2006). Communities and ice: Linking traditional and scientific knowledge. In R. Riewe and J. Oakes (Eds.), *Climate change: Linking traditional and scientific knowledge* (pp. 123-138). Winnipeg, MB: University of Manitoba, Aboriginal Issues Press.

VIA Rail Canada (2014) *Annual report 2014.* Retrieved from http://www.viarail.ca/en/about-via-rail/governance-and-reports/annual-report

Webster, A., Gagnon-Lebrun, F., Desjarlais, C., Nolet, J., Sauvé, C., and Uhde, S. (2008). *L'évaluation des avantages et des coûts de l'adaptation aux changements climatiques* [General information report written under the direction of Ouranos with support from Eco-Ressources consultants]. Retrieved from http://www.mamrot.gouv.qc.ca/pub/observatoire_municipal/etudes_donnees_statistiques/evaluation_avantages_couts_adaptation.pdf