# 8 · Atlantic Canada

# CHAPTER 8: ATLANTIC CANADA

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**RECOMMENDED CITATION:**

Rapaport, E., Starkman, S., and Towns, W. (2017). Atlantic Canada. In K. Palko and D.S. Lemmen (Eds.), *Climate risks and adaptation practices for the Canadian transportation sector 2016* (pp. 218-262). Ottawa, ON: Government of Canada.

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## KEY FINDINGS

- **The climate risks of greatest concern to transportation operators, provincial governments, and municipalities in Atlantic Canada are extreme weather events and storm surges.** Hurricanes, high winds, heavy precipitation, and extreme snowfall have resulted in costly damage and shipping disruptions for marine ports, delayed flights and ferry services and washed-out roads and railways. As storm frequency and intensity increases, these impacts will likely continue to be severe.

- **While most actions to enhance the climate resilience of transportation systems have been taken in response to past impacts from extreme weather, future climate risks (such as sea level rise) are increasingly spurring planning and investments**. Coordinated partnerships and initiatives suggest Atlantic provinces are actively engaged in adaptation planning. Risk assessments and regional cost-benefit analyses, which include transportation systems within their scope, will help inform future decision-making.

- **Transportation practitioners are accounting for projected climate changes in the planning and operation of some roads, bridges, railways, and marine ports in Atlantic Canada, but actions related to airports are less well-documented.** While this is reflective of the dominance of road and marine transportation in the region, significant research gaps exist regarding adaptation strategies for all modes.

- **A number of strategies are being specifically used to enhance the resilience of transportation infrastructure to flood risks**. These include constructing physical barriers (seawalls, breakwaters, and dykes), improving stormwater management (updating design flows, enlarging culverts) and relocating and/or elevating infrastructure.

- **Regionally-focused weather- and climate-monitoring technologies are helping transportation operators identify and adapt to climate risks in Atlantic Canada.** Examples include SmartAtlantic monitoring buoys to inform extreme-weather preparedness and better understand changes in ocean climate, and the Coastal Impact Visualization Environment (CLIVE) tool, which allows users to visualize changing coastlines in Prince Edward Island. These technologies assist with risk assessment and help practitioners communicate the magnitude of short- and long-term impacts to decision-makers.

# 1.0 INTRODUCTION

Atlantic Canada includes the provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador. While each province has unique geographic and cultural characteristics, their shared proximity to the Atlantic Ocean and combined coastlines (exceeding 40,000 km) (Environment Canada, 2012) result in many common climate vulnerabilities for transportation systems. These include risks associated with both extreme weather events (e.g., flooding, seasonal storms) and gradual, long-term changes (e.g., sea-level rise, changing patterns of temperature and precipitation). Governments and the private sector have recognized the need for adaptive action to reduce losses, avoid future costs, and benefit from potential opportunities.

This chapter examines the risks and opportunities for Atlantic Canada's transportation sector, as well as practices to increase its resilience to a changing climate. It addresses all four major transportation modes (roads, rail, marine, and air).

Literature examining the impacts of climate on transportation systems in Atlantic Canada is quite limited. Therefore, this chapter draws heavily upon other sources of information, including interviews with transportation professionals. This research complements other assessments of climate impacts and adaptation for Atlantic Canada as a whole (Vasseur and Catto, 2008) and the Atlantic coast more specifically (Savard et al., 2016).

## 1.1 ENVIRONMENTAL CHARACTERISTICS

Atlantic Canada has a diversity of landscapes, including five distinct terrestrial ecozones (Environment Canada and Agriculture and Agri-Food Canada, 1999). Prominent landforms include rugged mountains (e.g., the Torngat Mountains in Labrador), fertile valleys (e.g., the Saint John River Valley in New Brunswick and the Annapolis Valley in Nova Scotia), and extensive coastlines. The interior regions of New Brunswick, Nova Scotia, and Newfoundland and Labrador are dominated by rolling to rugged uplands, and are much more sparsely populated than the coasts.

Climate regions range from cool humid-continental to Arctic tundra, with the influence of the warm Gulf Stream in the south giving way to the cold Labrador Current in the north. Seasonal conditions reflect competing tropical and polar, and continental and maritime, influences. The Atlantic coasts experience the full range of tropical and extra-tropical storm systems frequently associated with high winds, precipitation, and storm surge.

## 1.2 DEMOGRAPHIC CHARACTERISTICS

Atlantic Canada is home to approximately 2.4 million people. The region experienced modest population growth from 2006 to 2011 (a provincial average of 2.2 percent), although at lower rates than the national average (5.9 percent) (Statistics Canada, 2011). Population shifts within the region demonstrate significant migration from rural areas to urban centres, with much greater population growth in major cities (see Table 1).

**Table 1: Population and population changes in Atlantic provinces and census metropolitan areas (CMAs).** (Source: Statistics Canada, 2011)

| Location | Area ($km^2$) | 2011 Population | 2006 Population | Population growth 2006-2011 |
|---|---|---|---|---|
| **New Brunswick** | 73,440 | 751,171 | 729,997 | 2.9 % |
| **Newfoundland & Labrador** | 405,720 | 514,536 | 505,469 | 1.8 % |
| **Nova Scotia** | 55,490 | 921,727 | 913,462 | 0.9 % |
| **PEI** | 5,590 | 140,204 | 135,851 | 3.2 % |
| **Halifax CMA** | 5,490.28 | 390,328 | 372,858 | 4.7 % |
| **St. John's CMA** | 804.65 | 196,966 | 181,113 | 8.8 % |
| **Moncton CMA** | 2,406.31 | 138,644 | 126,424 | 9.7 % |
| **Fredericton CMA** | 4,886.40 | 94,268 | 86,226 | 9.3% |
| **Saint John CMA** | 3,362.95 | 127,761 | 122,389 | 4.4% |
| **Charlottetown CA** | 798.54 | 64,487 | 59,325 | 8.7 % |

## 1.3 ECONOMIC CHARACTERISTICS

The majority of trade in Atlantic Canada is conducted with partners outside of the region – primarily with the United States and other provinces, although international markets are becoming more important.

Almost half of all freight traffic originating from New Brunswick and Nova Scotia is destined for other provinces, while less than 25 percent is intra-provincial (Gauthier, 2014). Prince Edward Island shares a similar freight pattern, with the majority of exports distributed across Canada. Newfoundland and Labrador is more closely connected to global supply chains than other Atlantic provinces, with approximately one-third of freight traffic destined for the United States, and one-third destined for the rest of the world (Lambert-Racine, 2013).

The Atlantic region is North America's closest access point to Europe, and major ports in New Brunswick, Nova Scotia, and Newfoundland and Labrador play an important role (Canada's Atlantic Gateway, 2010). The regional economy is positioned for further growth in global trade, including increasing connections with emerging Asian markets through the Suez Canal. These trends are already underway – for example, the values of exports from Newfoundland and Labrador to China, the United Kingdom, Netherlands and France increased by more than 400 percent from 2010 to 2013 (Newfoundland and Labrador Statistics Agency, 2015). As trade activity along many regional and external routes expands, transportation operators are working to provide the capacity to meet this demand.

Key exports from the Atlantic region include crude oil and refined energy products, fish, shellfish, minerals, lumber and pulp products, potatoes, and other vegetables. Key imports include many of these same commodities, as well as machinery/mechanical parts (Atlantic Canada Opportunities Agency, 2012).

# 2.0 REGIONAL CLIMATE PROFILE

## 2.1 OBSERVED CLIMATE TRENDS

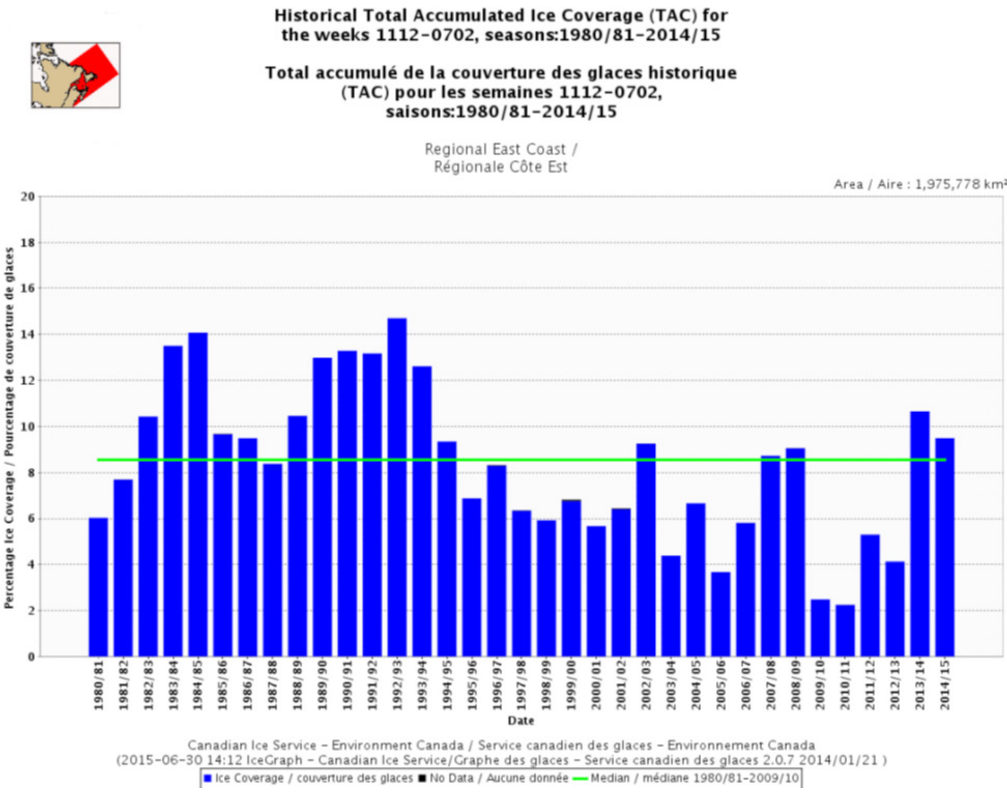
Atlantic Canada's historic climate record is characterized by high year-to-year variability, as well as variability in long-term trends (over several decades) in several key climate parameters. For the period 1948-2014, mean annual temperature in the Atlantic Canada Climate Region[4] increased 0.7°C, similar to the global average for the same period and representing the least amount of warming of any Canadian region (Environment Canada, 2015a). Increases have also been observed in sea-surface temperatures and ocean acidity (Loder et al., 2013). No clear trend is evident for mean annual precipitation in the region, although both summer and fall have experienced precipitation increases (Mekis and Vincent, 2011).

Of greater interest to Atlantic Canada's transportation system are changing patterns of extreme weather, such as heavy precipitation and seasonal storms. These events increase flood risks (both inland and coastal), and exacerbate issues in areas prone to erosion. Due to the rarity of extreme weather events, it is difficult to identify trends in the historic record, particularly at the regional scale. For example, from 1950-2010 the occurrence of heavy precipitation shows a statistically significant increase at some locations in Atlantic Canada, but a decrease at others (Bush et al., 2014). While changes in average wind speeds and direction are absent from the historic record, analysis of the density of intense storm centres for the period 1961-2000 indicates that Atlantic Canada includes some of the stormiest areas in North America (Savard et al., 2016). While the frequency of North Atlantic hurricanes shows no long-term significant change (United States Environmental Protection Agency, 2015), the Intergovernmental Panel on Climate Change's Fifth Assessment Report (2013) and the United States Global Change Research Program (2014) note that hurricane intensity has increased in the Atlantic region since the 1980s.

Changes in sea ice cover and sea levels have implications for marine and coastal transportation infrastructure. Sea ice coverage has decreased significantly in recent decades, although inter-annual variability remains high (Figure 1). Reduced sea-ice cover makes coasts more vulnerable to erosion by waves during winter storms. Trends in relative sea level for most of Atlantic Canada, excluding Labrador, show slow and steady sea-level rise. This increase is primarily due to glacial isostatic adjustment in the Atlantic provinces, referring to the slow vertical land motion or "rebounding" of land depressed by hundreds of metres under ice sheets during the most recent ice age (James et al., 2014). Sea-level rise results in impacts from waves and storm surge at higher coastal sites not previously at risk (Atkinson et al., 2016).

[4] Including New Brunswick, Nova Scotia, Prince Edward Island, and the island of Newfoundland, but excluding Labrador.

**Figure 1: Historical total accumulated ice coverage for the weeks of December 11-February 7 from 1980 to 2015 in Atlantic Canada and the St. Lawrence estuary (see inset map).** (Source: Environment and Climate Change Canada)




## 2.2 FUTURE CLIMATE PROJECTIONS

Projected changes in climate in Atlantic Canada for the 21st century include continued warming of air and water temperatures, as well as increased precipitation. Recent analysis as part of a global climate model comparison project[5] suggest increases in mean annual temperature of 1°C in the near term (2016-2035) to about 3°C by the end of the century. The greatest warming is projected to occur in winter. Mean annual precipitation is projected to increase by about 3 percent in the near term and almost 10 percent by the end of the century throughout the region, with the greatest increases occurring in winter and spring. Snowfall is likely to comprise a reduced proportion of total precipitation; the seasonal duration of snow cover will likely decrease (Swansburg et al., 2004); and freezing rain events are likely to increase during winter (Cheng et al., 2011). Tables A1-A4 (located in the annex of this chapter) present provincially-specific temperature and precipitation projections for the Atlantic region to 2100 over three time horizons. Seasonal periods include winter (December-February), spring (March-May), summer (June-August), and autumn (September-November). Data was derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) global climate model under an ensemble of RCP2.6, RCP4.5, and RCP8.5 scenarios (Canadian Climate Data and Scenarios, 2015). These data reflect uncertainty associated with these projections by presenting a range of values from the 25th-75th percentiles of CMIP5 outputs. The median value (50th percentile) appears in brackets following the range.

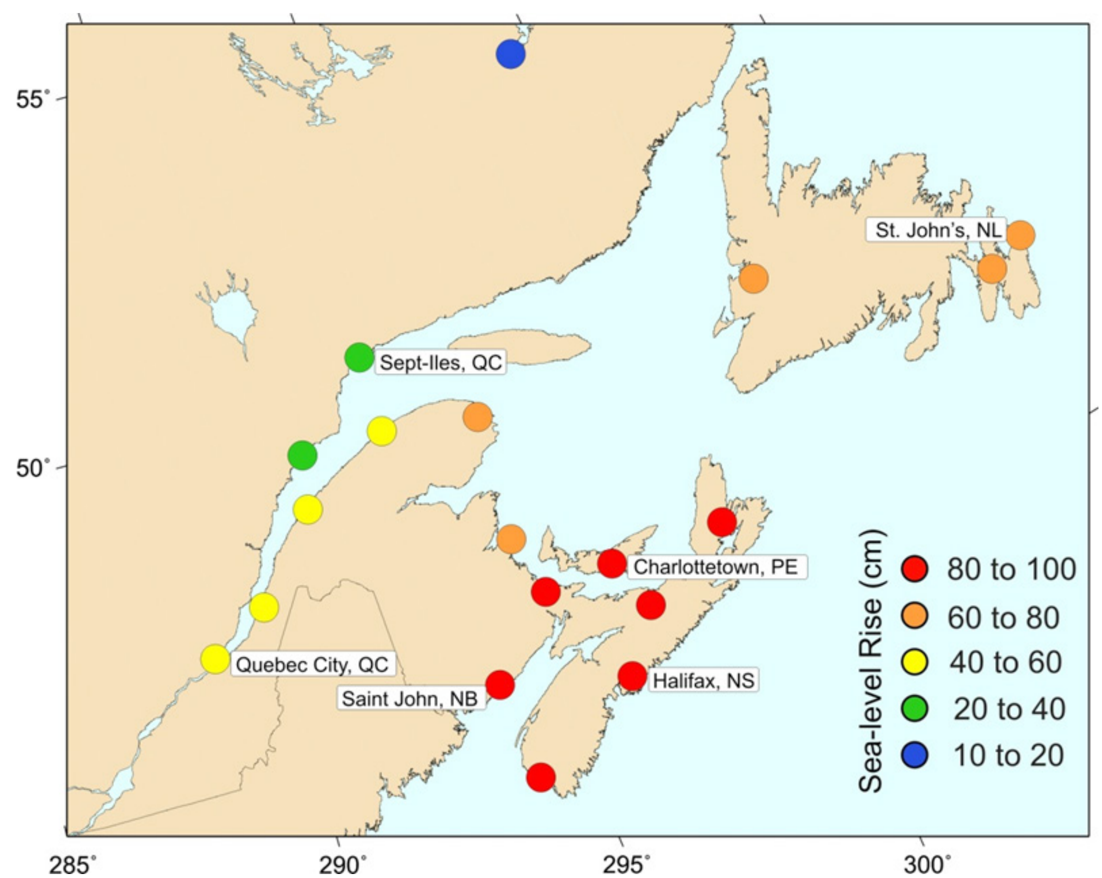
[5] CMIP5 - Coupled Model Intercomparison Project, Phase 5 (Taylor et al., 2012).

Global projections forecast an increasing frequency of extreme heat and decreasing frequency of extreme cold in Atlantic Canada (Williams and Daigle, 2011). Extreme precipitation events are also likely to become more frequent (Swansburg et al., 2004). Significant changes in wind speeds are not anticipated, but there is likely to be a northward shift in storm tracks through the current century, increasing storm frequency in Atlantic Canada (Loder et al., 2013).

Sea ice will continue to decrease in extent, thickness, concentration, and duration, with models projecting that it will be almost completely absent in the Gulf of St. Lawrence by 2100 (Senneville et al., 2013).

In areas of Atlantic Canada currently experiencing sea-level rise, the rate of change will accelerate throughout the current century. In areas such as Nain, Labrador, where sea level is currently falling due to glacial isostatic rebound, sea level will either continue to fall at a slower rate, or it may start to rise, depending on the magnitude of change in global mean sea level (James et al., 2014). Projections for Atlantic Canada indicate that under a high-emissions scenario, up to 100 cm of sea level rise is possible at some locations by 2100 (Figure 2), and that larger increases cannot be precluded (Savard et al., 2016; Atkinson et al., 2016). Global mean sea level will continue to rise for centuries after 2100, with the magnitude of future changes influenced by the success of efforts to reduce global greenhouse gas emissions (Intergovernmental Panel on Climate Change, 2013).

**Figure 2: Projections of relative sea-level rise for the year 2100 for the median value of the high-emissions scenario (RCP8.5; after James et al., 2014).** See Atkinson et al. (2016) for additional information on sea-level projections, and Savard et al. (2016) for additional details on sites in Atlantic Canada. (Source: Natural Resources Canada)



An important consequence of sea-level rise is the extreme water levels associated with wave run-up (also referred to as "swash," the height above the still-water elevation of the sea) and storm surge (the difference between observed water level and the predicted astronomical tide, resulting from variations in atmospheric pressure and wind). Sea-level rise will result in both more extensive storm-surge flooding, and increased frequency of events that contribute to coastal flooding and erosion. For example, analysis for Halifax Harbour indicates that a 40 cm rise in sea level by 2050 will yield drastic changes in extreme water levels – by mid-century, storm surges which currently have a return period of once in 50 years are likely to occur (on average) more than once every five years (Forbes et al., 2009).

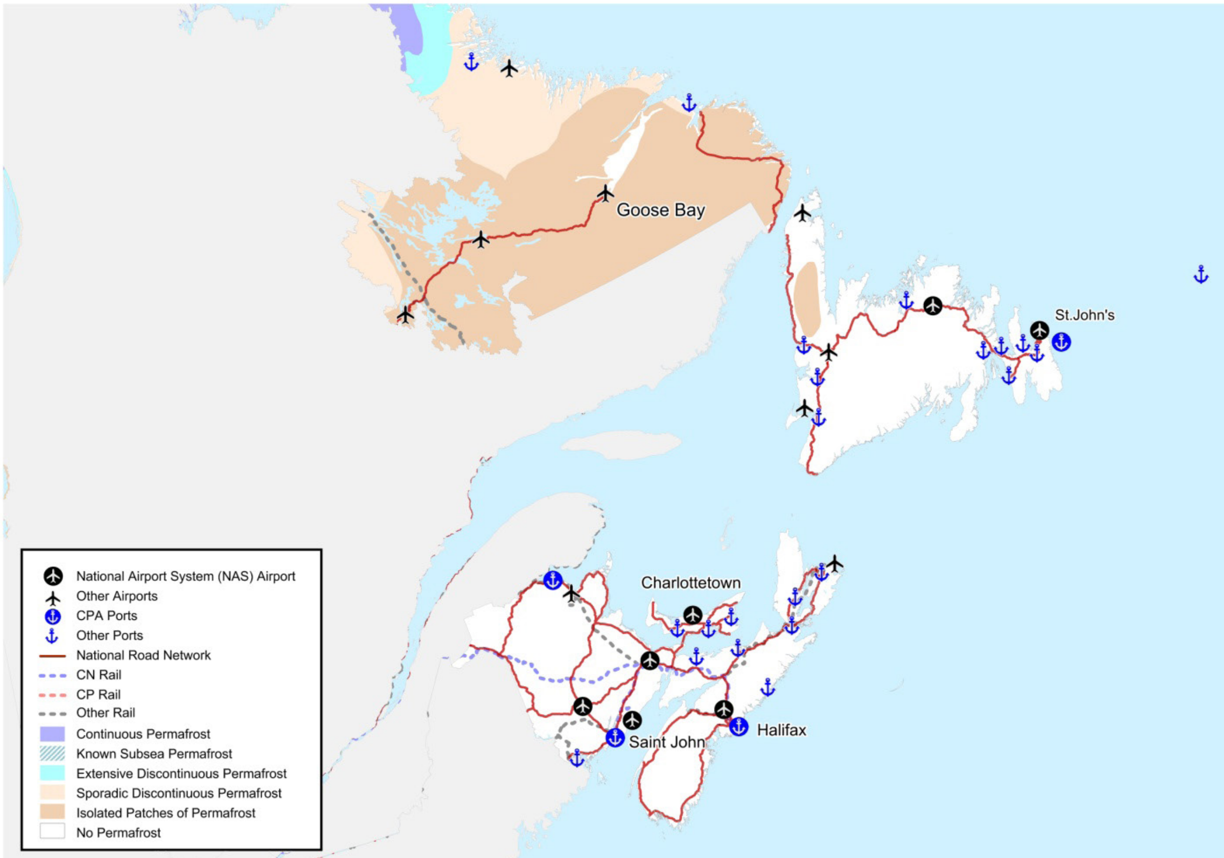
## 3.0 ATLANTIC CANADA'S TRANSPORTATION SYSTEM

The following sections discuss the physical assets and operations for each mode of transportation in Atlantic Canada, with an overview in Table 2, and an illustration of principle networks in Figure 3.

**Table 2: Transportation assets in each Atlantic province.** (Source: New Brunswick Department of Transportation and Infrastructure, 2014; Newfoundland and Labrador Department of Transportation and Works, 2014; Nova Scotia Department of Transportation and Infrastructure Renewal, 2015a; Prince Edward Island Department of Transportation and Infrastructure Renewal, 2012; Province of Nova Scotia, 2009a; Railway Association of Canada, 2015; Transport Canada, 2014)

| Transportation assets | New Brunswick | Newfoundland and Labrador | Nova Scotia | Prince Edward Island |
|---|---|---|---|---|
| **Highways and provincial roads (km)** | 18,785 | 9,759 | 23,000 | 3,849 paved<br>1,521 unpaved |
| **Bridges** | 3,212 | 1,327 | 4,100 | 257 |
| **Canadian Port Authorities** | Saint John and Belledune | St. John's | Halifax | n/a |
| **Ferries and Terminal Ports** | 10 crossings<br>18 terminal ports | 18 crossings<br>40 terminal ports | 7 provincial<br>2 municipal<br>5 private<br>39 terminal ports | 2 crossings<br>2 terminal ports |
| **Rail (km)** | 1159 | 261 | 674 | No rail services |
| **Airports** | 3 NAS Airports (Fredericton, Moncton, Saint John)<br>3 Regional/Local (Charlo, Chatham, St. Leonard) | 2 NAS Airports (Gander, St. John's)<br>6 Regional/Local (Churchill Falls, Deer Lake, Goose Bay, Stephenville, St. Anthony, Wabush) | 1 NAS Airport (Halifax)<br>2 Regional/Local (Sydney, Yarmouth) | 1 NAS Airport (Charlottetown) |

**Figure 3: Principle transportation networks in Atlantic Canada.**

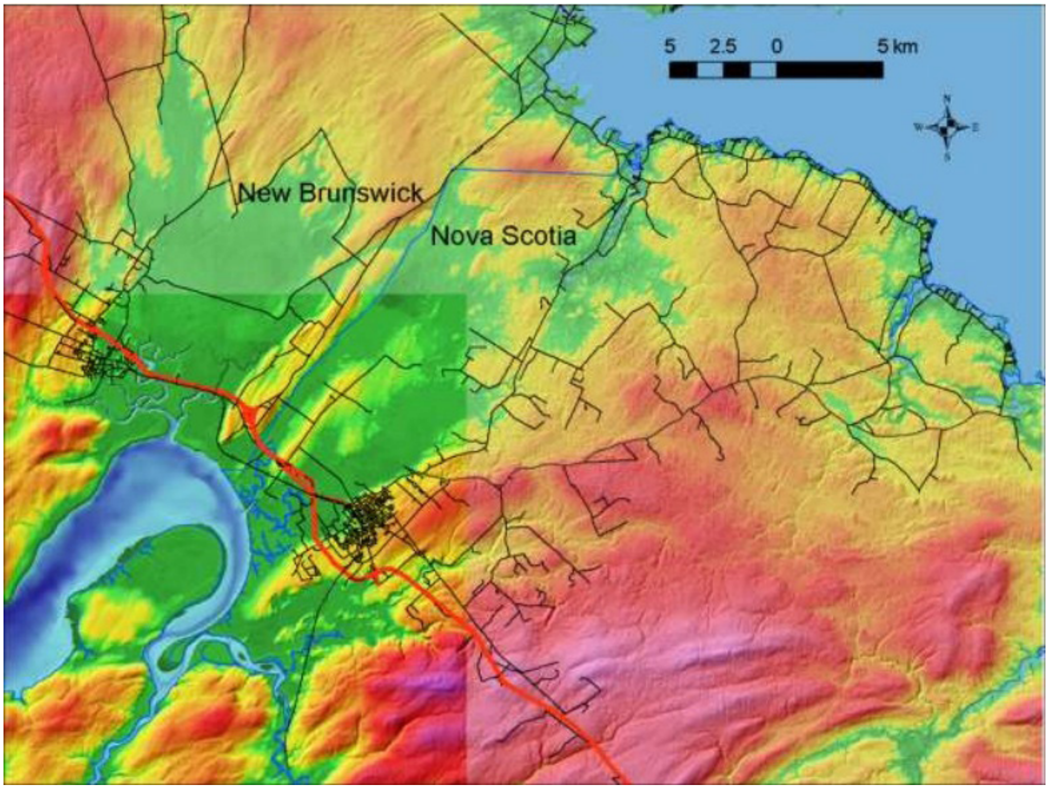



## 3.1 ROAD AND RAIL TRANSPORTATION

Atlantic Canada's extensive surface transportation infrastructure (road and rail) reflects its regional importance in moving people and goods. Each Atlantic province is reliant on roads, while rail plays a very significant economic role in Nova Scotia and New Brunswick in the form of the CN Rail system that crosses the Chignecto Isthmus. About $19.5 billion in trade flows annually by rail across the Isthmus, which represents about 45% of the total annual trade movements throughout Atlantic Canada (Webster et al., 2012; Marlin, 2013). The corridor is the only land connection between Nova Scotia and New Brunswick, and is highly vulnerable to storm surge and sea level rise (Figure 4; also see Case Study 5). A system of dykes, which includes rail embankments in some stretches, was originally built by the Acadians to create agricultural land and currently protects land and rail, road and other infrastructure in the Isthmus (Webster et al., 2012).

A second important rail link in Atlantic Canada is a short section of rail in Labrador that connects to the Quebec North Shore and Labrador Railway (QNS & L). The shipment of iron ore from Labrador via the QNS & L represents the largest component of total commercial rail tonnage moving out of Atlantic Canada (Stassinu-Stantec Limited Partnership, 2011). Prince Edward Island and the island of Newfoundland do not have operational rail lines, while a few independently-owned short-line systems operate in New Brunswick and Nova Scotia.

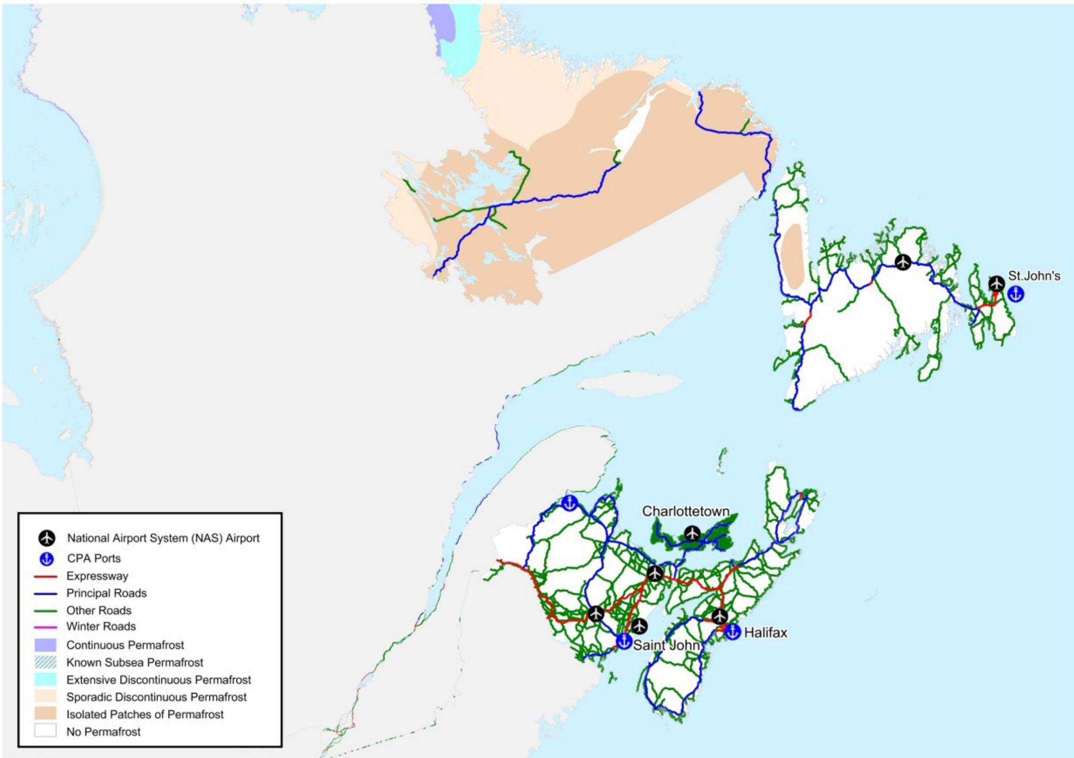
**Figure 4: Colour-shaded relief digital elevation model of the Chignecto Isthmus at the New Brunswick-Nova Scotia border. Green depicts especially low-lying areas.** The Isthmus separates the Bay of Fundy to the southwest from the Northumberland Strait (Gulf of St. Lawrence) to the northeast. (Source: Applied Geomatics Research Group, Nova Scotia Community College)




Large freight volumes are also moved by truck in Atlantic Canada. While the majority is destined for other Canadian provinces, a significant portion is also shipped to the United States (crossing primarily at Woodstock and St. Stephen, New Brunswick (Transport Canada, 2014). Major highways and connector roads also link cities, towns, and provinces in Atlantic Canada (see Figure 5).

St. John's, Newfoundland is the easternmost point of the Trans-Canada Highway and joins continental Canada via ferry, while a highway to northern Quebec joins Labrador to the rest of the country. Prince Edward Island is linked to New Brunswick via the Confederation Bridge. Completed in 1997, the 12.9 km stretch is the longest bridge in the world over seasonally ice-covered water (Strait Crossing Bridge Ltd., 2015) and facilitates the movement of people and goods between the mainland and the island year-round. The Trans-Canada Highway connects New Brunswick to Quebec and areas west through the most northwestern point of the province, and to Nova Scotia across the Chignecto Isthmus). Trucking accounts for about $500 million in trade flow annually across the Isthmus (Webster et al., 2012; Marlin, 2013).

**Figure 5: Atlantic Canada's road network.**




## 3.2 MARINE TRANSPORTATION

Each Atlantic province has specialized marine transportation infrastructure. The Port of Halifax is the most significant marine hub in Nova Scotia and the third-largest container port in Canada. Its deep, ice-free harbour provides services for both international and short-sea shipping, and contributed $1.6 billion to the Atlantic economy in 2013 (Port of Halifax, 2015; Cirtwill et al., 2001). The Port also features significant intermodal infrastructure, transferring goods to railcars and trucks bound for the U.S. Northeast and Midwest, Quebec, and Ontario (Canada's Atlantic Gateway, 2010). It recently completed a $35 million expansion to host wider, post-Panamax[6] containerships (Power, 2012).

The Ports of Saint John in New Brunswick and Placentia Bay in Newfoundland also move significant volumes of freight, and handle more crude oil and refined petroleum products than Halifax (Canada's Atlantic Gateway, 2010). These products make up the majority of Atlantic Canada's marine freight, much of which originates in Newfoundland. Ferries also play an important role in moving freight (as well as people). Marine Atlantic, a crown corporation providing ferry services, accounts for approximately 50 percent of all goods shipped to and from Canada's mainland to Newfoundland via Port aux Basques and/or Argentia to North Sydney crossings (Marine Atlantic, 2015).

Marine tourism is another important contributor to the region's economy, operating at peak capacity in summer. The cruise industry is growing in Atlantic Canada, accounting for 31 percent of Canada's total marine passenger traffic in 2012 (Cruise Lines International Association, 2013; Transport Canada, 2014). The Charlottetown Harbour Authority reports an increase in cruise ship passenger traffic of approximately 400% between the years 2007 and 2015 (Corryn Morrissey, Charlottetown Harbour

[6] Post-Panamax describes ships that do not fall within the current allowable dimensions for passing through the Panama Canal. Operators of the Panama Canal are currently constructing a new lock system, designed to handle these larger "post-Panamax" ships.

Authority, personal communication, 2016). Ferry routes support tourism and regional connectivity. In Newfoundland and Labrador, a number of ferry routes travel from Labrador to the island of Newfoundland, including St. Barbe-Blanc Sablon and Goose Bay-Cartwright-Lewisporte. Ferries from North Sydney, Nova Scotia travel to Newfoundland, while Nova Scotia connects to Prince Edward Island via the Caribou-Wood Island Ferry. Other key routes include the Nova Scotia-New Brunswick route via Digby to Saint John, and the route operating between Prince Edward Island and Îles de la Madeleine, Quebec (Souris to Cap-aux-Meules) (Ferry CTMA, 2015).

### 3.3 AIR TRANSPORTATION

Atlantic Canada's airports move over 7.8 million people annually, a figure more than three times the region's population size (Atlantic Canada Airports Association, 2012). The airport system includes seven National Airports System (NAS)[7] airports (below) in addition to many smaller community airports:

- Fredericton International Airport, Greater Moncton International Airport, and Saint John Airport (New Brunswick);
- Gander International Airport, and St. John's International Airport (Newfoundland and Labrador);
- Halifax Stanfield International Airport (Nova Scotia); and
- Charlottetown Airport (Prince Edward Island).

Less freight is moved by air than by other modes in the Atlantic region – usually only time-sensitive or specialty goods. However, freight volumes are still significant, with over 60,000 metric tonnes moved annually (Atlantic Canada Airports Association, 2012).

## 4.0 ROAD TRANSPORTATION: IMPACTS AND ADAPTATIONS

### 4.1 PAST IMPACTS AND FUTURE RISKS

A number of climate-related variables, including extreme weather events, storm surges, and freeze-thaw cycles, have impacts on both road infrastructure and operations in Atlantic Canada.

#### EXTREME EVENTS

The most severe regional-scale impacts are related to tropical or post-tropical storms, and associated with heavy precipitation, strong winds, and storm surges. Examples include Hurricane Juan (September 2003), which resulted in $100 million in direct damages to infrastructure in Halifax alone, including roads and highways (Bowyer, 2003a), and Hurricanes Earl and Igor, which struck within a week of each other in September, 2010 resulting in road closures throughout Atlantic Canada. In Newfoundland and Labrador, approximately 150 communities were isolated by road closures during Hurricane Igor, and parts of the Trans-Canada Highway were washed away (Canadian Climate Forum, 2014). The prospect of more frequent extreme weather events (i.e. shortened return periods) will increase the risk of roadway flooding which strands users, increases driving times, disrupts freight flows, and can disrupt emergency services (Chu, 2012; Vasseur and Catto, 2008).

Wind gusts from 80-160 km/h have been recorded regionally during tropical and post-tropical storm events (Environment Canada, 2013b). High winds have closed major Atlantic bridges such as Halifax's MacDonald Bridge and the Confederation Bridge (Catto et al., 2006). In summer 2014, Hurricane

[7] The NAS designation is given to airports in provincial capitals and other airports with annual traffic exceeding 200,000 passenger movements (Transport Canada, 2010).

Arthur uprooted hundreds of trees in Fredericton, New Brunswick, blocking streets until city crews could remove the fallen vegetation (Case Study 1).

High winds also occur independently of tropical storms. For instance, 170 km of highway (from Moncton, New Brunswick to Truro, Nova Scotia) through the Chignecto Isthmus has been closed due to strong winds and blowing snow (CBC News, 2015a). Also, the stretch of Trans-Canada Highway near Wreckhouse, Newfoundland and Labrador often experiences strong winds funnelled from the southern end of the Long Range Mountains. Trucking companies in this region use constant-monitoring technology to reduce accident risks. One Newfoundland company has reported trucks overturning due to high winds in Wreckhouse and the Northern Peninsula (Fleming, 2014).

CASE STUDY 1

## CASE STUDY 1: HURRICANE ARTHUR'S IMPACTS ON TRANSPORTATION IN FREDERICTON

Fredericton, New Brunswick (population 57,000) is located on a broad sweep of the Saint John River. Flooding, from spring freshets and heavy rain events has historically been difficult for Fredericton to manage.

On Saturday July 5, 2014, Hurricane Arthur transformed into a strong post-tropical storm and made landfall in western Nova Scotia. Fredericton experienced a prolonged period of heavy rain and high winds from the storm system, including 150 mm of rain (recorded at Base Gagetown near Fredericton) and 100 km/h wind gusts at Fredericton International Airport. The combination of wind and rain saturated the soil and caused widespread tree damage and power outages in the city.

The storm affected roads and sidewalks, the public walking trail network, and Fredericton International Airport. City crews struggled to remove trees that had fallen across roadways and trails, disrupting traffic. In many cases, electrical lines were intertwined with branches, requiring a joint response from New Brunswick Power and the City to clear routes for emergency vehicles. The airport also experienced a lengthy power outage and relied on generators to maintain operations.

Hurricane Arthur was not typical in that it was an early-season tropical storm, hitting Fredericton when trees were at their heaviest due to the weight of new leaf growth (and before branches and trunks had strengthened to support this growth). More intense and unusual weather events, such as Arthur, have the City rethinking standard business practices, including:

- Planting different tree species and varieties in public rights- of-way to ensure resilience and minimize tree failure, which will reduce impacts to the street, trail, and sidewalk system;
- Implementing an intensive pruning program to enable trees to withstand severe weather; and
- Reviewing and upgrading staff training and equipment in anticipation of future storms.

The City is also working jointly with the University of New Brunswick Forestry program to undertake a street-tree inventory. Prior to replanting trees, characteristics such as height, root system, canopy, and resilience of various species will be assessed to ensure that new trees can better withstand high winds and soil saturation.

This example illustrates the indirect impacts of extreme weather on transportation operations, particularly in urban environments. Collaboration across sectors such as electricity, forestry, and transportation is important to enhance the resilience of urban systems to climate change.

*Written by Ken Forest (Growth and Community Services, City of Fredericton, New Brunswick).*

Storm surges can cause coastal erosion and flooding, affecting roadways close to shore (Province of Nova Scotia, 2009b). The structural integrity of one major bridge in Corner Brook, Newfoundland, has nearly been compromised on multiple occasions by storm surges. City officials have been forced to close the bridge at times for safety (Rayna Luther, City of Corner Brook Infrastructure and Public Works, personal communication, 2015). The segment of Trans-Canada highway in the Chignecto Isthmus is also sensitive to storm-surge inundation (see Case Study 5).

In Prince Edward Island, where no point is more than 16 km from the sea, infrastructure is especially vulnerable to high-water damage. For example, a severe storm surge in December 2010 resulted in several bridge closures and significant washouts at various locations including Oyster Bed Bridge, Corran Ban Bridge and Rustico Bridge (Figure 6). Additionally, the predominantly sandstone composition of Prince Edward Island's coastline is inherently susceptible to erosion resulting from storm surge and high water events. In Prince Edward Island, at least two coastal public roads have been abandoned in recent years, due to erosion (Brian Thompson, Government of Prince Edward Island, personal communication, 2016). This results not only in disruptions to property owners, and the traveling public, but in unscheduled government expenditures to secure land and construct alternate routes where applicable (Brian Thompson, Government of Prince Edward Island, personal communication, 2016). Coastline erosion rates have been increasing in P.E.I. The average rate of erosion grew from 28 cm per year between 1968 and 2010, to 40 cm per year between 2000 and 2010 (Webster, 2012). Without taking into account rising sea levels and increasing storms associated with climate change, an assessment of coastal infrastructure in the province identified over 40 kilometres of roads at risk from coastal erosion by 2100 (Fenech, 2014).

The frequency and magnitude of storm-surge flooding will increase over the 21st century in areas that experience sea-level rise, including most of Atlantic Canada. This in turn increases risks to coastal roads and bridges.

**Figure 6: Flooding of Oyster Bed Bridge during a storm in December, 2010.** (Source: Don Jardine)

### TEMPERATURE AND PRECIPITATION CHANGES

Freeze-thaw cycles are taxing on road systems, particularly when temperature changes are rapid. When the frequency of freeze-thaw cycles increases, the potential for rapid road deterioration and higher maintenance costs rises as well. For example, by the end of approximately three weeks of fluctuating winter conditions in February 2015, Halifax had over 1,000 outstanding potholes – approximately 300 were more than two inches deep and therefore assigned a "priority" designation (Bradshaw, 2015). These cycles are expected to become more frequent throughout most of the Atlantic region over the short term. Freeze-thaw frequency is expected to decline over the long term as average winter temperatures rise (Boyle et al., 2013).

Rain-on-snow events also affect Atlantic Canada's roads. In 1962, approximately 180 mm of rain on heavy snow on Prince Edward Island's southern coast caused extensive washouts and damage to paved highways (Atlantic Climate Adaptation Solutions Association, 2011). A similar event in December 2014 caused $9 million in damages to bridges and roadways in Prince Edward Island (McCarthy, 2014; Wright, 2015). Rapid snow melt can also cause problems for municipal drainage systems. When temperatures ranged from -27°C to 7°C in the span of a month in Corner Brook, Newfoundland, mass snow-thaws resulted in the infiltration of large water volumes in short periods of time, overloading the capacity of stormwater management infrastructure (Rayna Luther, City of Corner Brook Infrastructure and Public Works, personal communication, 2015).

Warmer winters are associated with more frequent freezing rain and black-ice conditions, affecting traffic flow, accident rates, maintenance costs, and the use of anti-icing chemicals (Andrey et al., 2013). Warmer winter temperatures also affect the safety and usability of informal seasonal ice routes in northern Labrador and New Brunswick that provide access to and from communities across frozen bodies of water (CBC News, 2012; Nalcor Energy, 2014).

Extreme temperatures also have negative effects on road infrastructure. Interior regions of New Brunswick and Nova Scotia have already experienced an increase in the frequency of hot days, and this trend is expected to continue (Steeves, 2013), increasing the risk of road damage and adding stress to bridge joints. While extreme cold is not likely to increase in frequency, abnormally cold days will continue to occur (Gao et al., 2015), reducing the fuel-efficiency of vehicles and contributing to icy conditions.

## 4.2 ADAPTATION PRACTICES

In light of these impacts, governments and private operators are using a number of strategies to enhance the resilience of road infrastructure. Flood risks are a particular focus of these efforts.

### PHYSICAL PROTECTION MEASURES

Some Atlantic municipalities are constructing seawalls, breakwaters, and dykes to protect roads against sea-level rise and higher storm surges (Liverman et al., 1994; Batterson et al., 1999; Halifax Regional Municipality, 2012). These buffers protect low-lying infrastructure from overtopping (which occurs when water rises higher than a dyke or levee). The construction of higher dykes and breakwaters may mediate the impacts of unpredictable flows of water in parts of Atlantic Canada (Graham and Musselman, n.d.). Case Study 2 discusses an example of this type of adaptation in Halifax, Nova Scotia.

In areas of extreme concern, such as the Chignecto Isthmus corridor, "hardening" of the surrounding land by means of a dyke system has protected the roads to date, although further efforts (hard, soft and hybrid engineering approaches) to protect infrastructure and communities under projected climate scenarios have recently been investigated (see Case Study 5).

CASE STUDY 2

# CASE STUDY 2: DEFENSIVE ADAPTATION IN COW BAY (HALIFAX, NOVA SCOTIA)

The Cow Bay Causeway is a 350 m stretch of road built over a beach of cobble and boulder. For many years, despite protection by a breakwater, the road was susceptible to damage from wave overwash. Three specific problems were identified with the existing breakwater:

1. The breakwater was not high enough in some areas to prevent waves from overtopping.
2. Most of the existing armour stone was not of sufficient size to resist the force of waves during a major storm; the causeway was closed at least twice a year for safety reasons.
3. Voids between the existing armour stones allowed small stones and seaweed to wash through the breakwater and be deposited on the roadway.

As a result, the causeway often experienced extensive damage from storms, and required repairs every three to five years. The severity and impacts of recent storms (including Hurricane Juan in 2003, post-tropical storm Noel in 2007, and a January 2010 storm) and risks of future impacts prompted the Halifax Regional Municipality to commission a study and recommendations for the redesign of the causeway and its breakwater. The study employed a statistical risk assessment model known as the Coastal Infrastructure Adaptation Planning System (CIAPS) to analyze the interaction of future tidal and storm-surge conditions along the coast with the anticipated performance of the existing breakwater, as well as to determine the appropriate elevations for more resilient infrastructure (Davies et al., 2010). Four adaptation alternatives were identified:

1. Erosion-proofing the causeway by replacing gravel shoulders with articulated concrete mats;
2. Erosion-proofing, plus elevating the roadway to minimize overtopping risks;
3. Rebuilding the barrier in its entirety (including impermeable technologies); or
4. Rebuilding the barrier in prioritized phases (Davies et al., 2010).

**Figure 7: Cow Bay Causeway experiencing a storm.** (Photo of Cow Bay Causeway taken January 26th, 2010 by M. Davies, Coldwater Consulting Ltd)

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The risk assessment suggested that the cost-optimized solution was to rebuild the causeway's breakwater in two phases. The design included:

- An increase in the height of the breakwater;
- A 600 mm-by-2.5 m concrete core;
- 4-to-8-tonne armour stone on the outer face of the breakwater;
- A breakwater crest approximately 9 m wide; and
- A seaward slope (two blocks horizontal for one block vertical).

Each phase included completion of approximately half of the breakwater length, and the design allowed for the increase in wave height anticipated under future sea-level and storm-surge conditions. The project was tendered in 2012, and Phase 1 was awarded with a budgeted construction cost of $670,000 (Davies et al., 2010; Halifax Regional Municipality, 2012). Phase 2 was completed in 2013.

While the new breakwater has not yet dealt with a major hurricane event, local practitioners suggest that the infrastructure has been successful in mitigating the effects of heavy storms and wave action to date (David Hubley, Halifax Regional Municipality, personal communication, 2016).

*Written by Eric Rapaport with input from David Hubley (Halifax Regional Municipality).*

### STORMWATER MANAGEMENT PRACTICES

Throughout Atlantic Canada, cities are reducing risks to roadways from flood events by improving stormwater management practices. These include:

- using future climate projections to update design flows in stormwater management networks to account for increased precipitation. Examples include the City of Fredericton, New Brunswick (Arisz, n.d.), the City of Corner Brook, Newfoundland (City of Corner Brook, 2012), and the Town of Stratford, Prince Edward Island (CBCL Ltd., 2012).
- using the Public Infrastructure Engineering Vulnerability Committee's (PIEVC) risk assessment protocol to assess the climate change vulnerability of roads and stormwater management systems. Examples include Sandy Point, Nova Scotia; Miramichi, New Brunswick; and, Placentia, Newfoundland and Labrador (Municipality of the District of Shelburne, 2011; City of Miramichi, 2013; Engineers Canada, 2014). In response to PIEVC recommendations, Sandy Point is investing in new pumping stations to reduce infiltration and flows onto infrastructure, and both Miramichi and Placentia are considering larger culvert sizes along the road corridors that were assessed (City of Miramichi, 2013; Engineers Canada, 2014).

Additional stormwater management practices identified in the literature may also be relevant to Atlantic Canada. These include building rain gardens/retention ponds; using permeable pavement materials; planting trees (to increase infiltration and reduce water pooling on roads), and coordinating stormwater management at the watershed-scale (i.e. maintaining natural river channels and wetlands) (Marsalek and Schreier, 2010; Kessler, 2011).

### INFRASTRUCTURE RELOCATION

Relocating or flood-proofing road infrastructure may be required, where the shoreline is at risk of being inundated or unusable, due to sea-level rise, storm surges, and coastal erosion (Transportation Research Board, 2008; Davidson-Arnott and Ollerhead, 2011). Some municipalities in Atlantic Canada have chosen to locate new roads away from coastal areas (Graham and Musselman, n.d.); or elevate infrastructure when feasible (i.e. Moncton, New Brunswick; see Chapter 9) (AMEC Inc., 2011). For example:

- The Confederation Bridge, which connects PEI to the Canadian mainland in New Brunswick, was built to accommodate a one metre rise in sea levels over 100 years. The bridge was also designed to allow ice blocks to pass safely underneath (Gregg, 2010).
- The Prince Edward Island Department of Transportation is rebuilding the Souris bridge one metre higher, due to sea level rise projections (Government of Prince Edward Island, 2015).
- Nova Scotia's provincial government recently rebuilt its 100-series highways further inland from their original coastal locations to provide safer and faster corridors; as a result, these highways are much less sensitive to coastal hazards (Finck, 2013).
- The New Brunswick Department of Transportation rebuilt and raised a bridge on the main road into Pointe-du-Chêne to accommodate future sea-level rise (Daigle, 2011).
- Relocation of the section of Trans-Canada Highway along the Chignecto Isthmus has been discussed as a potential long-term adaptation solution, but is presently considered too costly (see Case Study 5).

### OPERATIONAL AND MAINTENANCE PRACTICES

Operators are also adapting to challenging weather conditions. For example, one trucking company in Newfoundland, experiencing more frequent repairs due to difficult road and weather conditions, has found a creative way to ensure business continuity (Fleming, 2014). Towing trucks to the company's facility in Corner Brook is expensive and time consuming; therefore, the company now strategically leaves replacement parts in customers' homes and businesses along its routes (Fleming, 2014). When minor repairs are required (i.e. tires, springs, and lights), drivers contact the closest facility to request delivery or replacement of the appropriate parts. The company's connections to local communities make this approach possible.

Governments are investing in proactive maintenance to reduce climate risks to transportation infrastructure. For instance, to reduce spring flood risks in rural New Brunswick resulting from periods of rapid warming and snowmelt, the federal government invested $1.7 million in 2015 to proactively remove snow from the roadways of eight vulnerable First Nations communities. As many as 800 truckloads of snow per day were removed from critical infrastructure (including roadways) in some communities. Regional snowfall in winter 2014 broke local records and contained higher-than-normal water content, making snow difficult for communities to remove (Water Canada, 2015; Aboriginal and Northern Development Canada, 2015).

# 5.0 RAIL TRANSPORTATION: IMPACTS AND ADAPTATIONS

## 5.1 PAST IMPACTS AND FUTURE RISKS

Rail infrastructure in Atlantic Canada is affected by a changing climate and extreme weather in many of the same ways as roads. For example, flooding (caused by extreme precipitation, storm surge, and ice jams) has resulted in impacts on both modes (Environment Canada, 2010), and snowstorms that inundated roadways in St. John's, Newfoundland in 1959 and Prince Edward Island in 1989 also buried and stranded trains (Environment Canada (2013b).

### STORM SURGE, COASTAL EROSION, AND SEA-LEVEL RISE

Coastal rail lines in Atlantic Canada are vulnerable to flooding, washouts, and damage associated with storm surge and erosion, which can sometimes result in derailments. For example, in 2003 Hurricane Juan resulted in 1.5-2 m storm surges at Halifax Harbour that severely eroded shoreline, washed-out railway tracks (Figure 8), and washed several rail cars into the ocean at the Dartmouth rail yard (Bowyer, 2003a). Similarly, Hurricane Igor in 2010 caused rail-line damage, washout, and closures – these were especially pronounced in Newfoundland (Curtis and Ehrenfeld, 2012).

**Figure 8: Debris on rail track at Dartmouth Point the morning after Hurricane Juan.** Run-up was 1.64 m above the highest water level recorded at the Halifax tide gauge across the harbor, and water levels remained unusually high at the time of photography. (Source: Natural Resources Canada)

In 1974, a wind storm accompanied by high seas washed-out 30 m of railway track and derailed two diesel trains at Cape Ray, Newfoundland (Heritage Newfoundland and Labrador, n.d.). Coastal erosion has resulted in damaged tracks, slower speeds, operational delays, and rail closures in Atlantic Canada, affecting the movement of goods such as paper, coal, lumber, petroleum products, and chemicals (Genesee and Wyoming, Inc., n.d.). These disruptions have negative impacts on local industries (including intermodal facilities) due to delayed shipping, production, and refinement, and foregone profits/revenues.

Slope failures in coastal areas have affected the Quebec North Shore and Labrador Railway (QNS & L) (Batterson et al., 1999; CBC News, 2014b), and will continue to pose risks in future (Spooner et al., 2013; Evan et al., 2005). Similarly, the Cape Jack section of the Cape Breton and Central Nova Scotia Railway (CBNS) has experienced severe erosion around coastal sections of track (Stephen Newson, Province of Nova Scotia, personal communication, 2015; CBC News, 2014a).

Looking forward, an area of considerable concern is the Chignecto Isthmus, which is vulnerable to flooding and where flood risks will increase significantly throughout the 21 century as a result of sea-level rise (Webster et al., 2011) (Figure 9; see Case Study 5).

**Figure 9: CN Rail in the Chignecto Isthmus.** Embankments form part of the region's dyke network. (Source: EOS Eco-Energy Inc.)

## EXTREME PRECIPITATION

There are many documented incidents of heavy precipitation events affecting rail transport in Atlantic Canada. For example, on August 31, 2007, heavy rain caused a number of culverts to fail along CBNS rail in Cape Breton, Nova Scotia, as well as wash-outs along many sections. The track was closed for approximately three weeks for repair and replacement, disrupting freight movement (Stephen Newson, Province of Nova Scotia, personal communication, 2015). In total, the incident cost the railway more than $500,000 (Province of Nova Scotia, 2007a, 2007b).

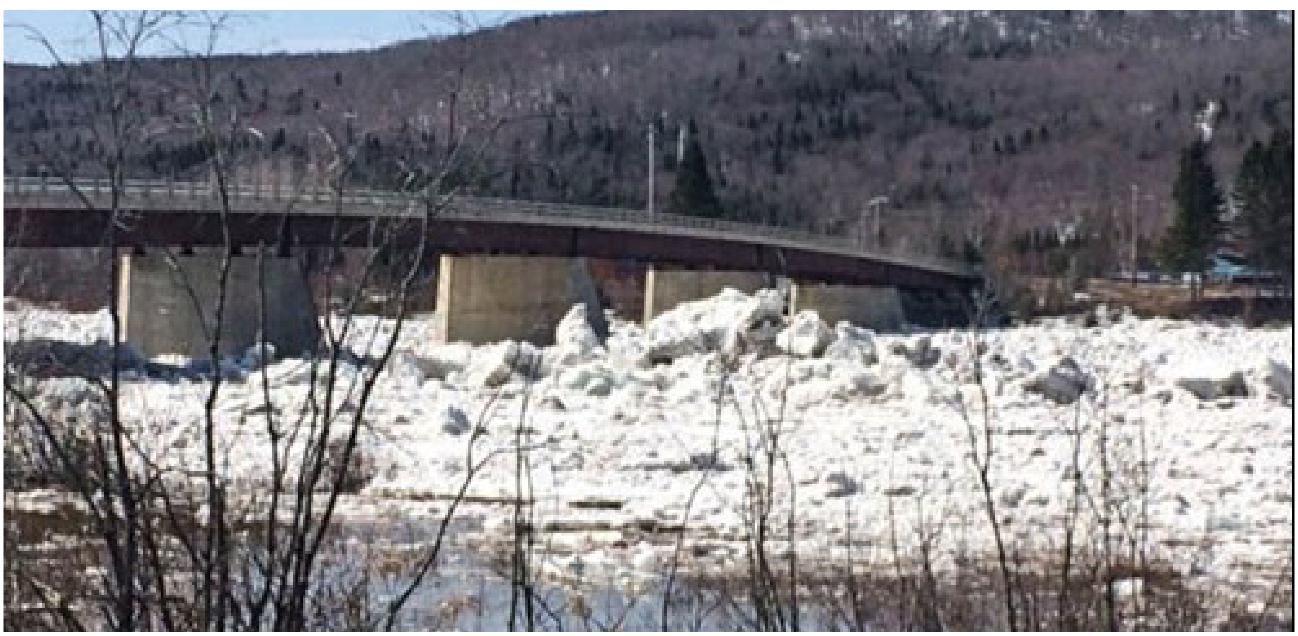
In April 2003, culverts beneath a rail line in Ellershouse, Nova Scotia washed out during a large storm event (Stephen Newson, Province of Nova Scotia, personal communication, 2015). Similarly a severe tropical storm in December 2010 caused significant damage to rail infrastructure near Fredericton, New Brunswick, as extreme precipitation washed-out rail bridges and undermined rail beds (Environment Canada, 2013c). Future increases in the intensity, duration, and frequency of extreme precipitation (Bush et al., 2014) would result in even more severe impacts.

Heavy snow also disrupts rail movements in Atlantic Canada. For instance, snowstorms in Nova Scotia during winter 2015 delayed the movement of goods and services by rail from multimodal facilities to North American markets, proving costly for operators (Henderson, 2015; Cuthbertson, 2015). Heavy snow will continue to affect rail movements in Atlantic Canada, at least over the short term.

## ICE-JAM FLOODING

Inland flooding associated with snowmelt and ice jams[8] have caused major damage to rail systems. Floods involving ice jams tend to be more damaging to infrastructure than open-water events, particularly to bridges. For example, during a February 1970 flood on the Saint John River, New Brunswick, a series of ice jams on six rivers resulted in the destruction of 32 bridges (both road and rail) and damage to 124 others (see Figure 10) (Government of New Brunswick, 2012).

**Figure 10: Spring ice jam at a rail bridge on the Saint John River.** (Source: New Brunswick Power, 2015)



[8] An ice jam is a temporary ice blockage of a river, formed by the accumulation of ice fragments that build up to restrict the flow of water. Ice jams form during both the freeze-up and breakup periods, but it is usually breakup jams that have the greater flooding potential. Over two thirds of total provincial flood damage costs in the Saint John River basin are due to ice-related events (Environment Canada, 2013a).

In April 1987, an ice jam caused the collapse of the Perth-Andover railway bridge, during a severe spring flooding event in New Brunswick. Loaded rail cars had been placed on the bridge to hold back the ice jam and prevent flooding downstream, a practice that had been successfully employed during a less-severe spring flood event in 1976; however in 1987, the pressure of the ice and floodwaters caused the bridge to fail (Environment Canada, 2010). In future, the likelihood of ice-jam flooding may increase as the timing of seasonal change becomes more variable from year to year (Government of New Brunswick, 2014).

### TEMPERATURE

Increasing average air temperatures and changing extremes pose uncertain risks to rail transportation in Atlantic Canada. Hot and cold temperature extremes cause rail tracks to expand or contract, and can lead to train derailments (Dobney et al., 2008; Peterson et al., 2008; Nova Scotia Department of Transportation and Infrastructure Renewal, 2014). Extreme summer heat can result in rails buckling as they expand beyond reasonable design limits (Dobney et al., 2008), causing "sun kinks". Historically this has not been a common problem in the Atlantic provinces (Stephen Newson, Province of Nova Scotia, personal communication, 2015). However, the region has experienced incidents caused by, or exacerbated by, rapid temperature changes. For example, the investigation into a derailment in Pictou County, Nova Scotia in June 2014 indicated that track buckling "produced by a sudden and unusual fluctuation of rail temperature and accumulated steel stress" was a significant contributor (Province of Nova Scotia, 2014). Extreme temperature change is also considered to have been a major factor in a main-track derailment in Milford, Nova Scotia in 2002 (Transportation Safety Board of Canada, 2003). The frequency of these events – and the probability of a serious accident – is likely to increase as temperatures rise in the 21st century (Dobney et al., 2008).

## 5.2 ADAPTATION PRACTICES

While documented examples are limited, rail operators in Atlantic Canada have made efforts to reduce future climate risks. For example, an emergency culvert and aboiteaux[9] system in Hantsport, Nova Scotia was constructed to accommodate increased water flow through culvert systems under rail tracks (Figure 11). The overflow openings allow excess water during extreme precipitation or flooding situations to drain from the culvert via an alternate route. This prevents culvert blowouts during periods of heavy flow (Stephen Newson, Province of Nova Scotia, personal communication, 2015).

**Figure 11: Overflow aboiteaux at Hantsport, Nova Scotia.** (Source: Danika Van Proosdij)

[9] This refers to a series of protective dykes around low-lying farmland to prevent tidal inundation (Hatvany, 2002).

In the past, the general solution to erosion under rail lines was to replace fallen or sunken rock. However, due to the increasing frequency of repairs and associated costs, this method may no longer be sufficient or effective (Stephen Newson, Province of Nova Scotia, personal communication, 2015). Physical barriers, such as dykes have also been used to protect rail infrastructure from the effects of storm-surge flooding, and erosion, but these protections may not be sufficient in future. Adaptation options are currently being examined for dyke systems in the Chignecto Isthmus, for example (Case Study 5).

One practice that has been used to increase the resilience of rail infrastructure vulnerable to temperature extremes is to replace continuously welded rail (CWR) with shorter segments, which have joints allowing track to expand and contract (Lim et al., 2003). (CWR, which has longer rail segments, generally reduces track maintenance costs and increases the average service life of rail components under moderate temperature conditions). For example, following the June 2014 derailment in Pictou, 300 feet of CWR from the point of derailment was replaced with 39-foot track panels that are easier to maintain and replace in the event of stress caused by heat or temperature fluctuations. Additionally, the company conducted a stress test on the rail line, and employees reviewed rail maintenance requirements. To prevent similar events in the future, the railway has developed a new technical training program, and train speeds have been restricted to 40 km/h during summer months and may be further restricted to as low as 16 km/h when warranted by extreme heat conditions (Province of Nova Scotia, 2014).

## 6.0 MARINE TRANSPORTATION

### 6.1 PAST IMPACTS AND FUTURE RISKS

Marine transportation in Atlantic Canada has long been affected by adverse climate conditions and storms, disrupting operations and damaging vessels, ports, and navigation infrastructure. These impacts are particularly challenging for Newfoundland and Labrador, which relies heavily on marine transportation for resupply and connectivity (CBC News, 2015b, 2015c). Over the past century, improved forecasting and monitoring technologies have considerably reduced risks to marine operators from extreme weather. However, ports and vessels remain vulnerable to a number of future risks associated with a changing climate. Lost productivity from weather-related disruptions in Atlantic Canada's marine transportation sector is estimated to total millions of dollars annually (Catto et al., 2006).

#### PRECIPITATION, EXTREME WEATHER, STORM SURGE, AND SEA-LEVEL RISE

Hurricanes have caused major damage to marine infrastructure and vessels in the past. During Hurricane Juan,  storm surges of 1.5-2 m and wind gusts up to 230 km/h, damaged coastal wharves and other port infrastructure in Halifax Harbour, blew containers off ships, snapped weather buoys, and sank and damaged vessels (Bowyer, 2003a Bowyer, 2003b). "White Juan", a hurricane-force nor'easter in February 2004 (five months after the hurricane), resulted in 10-15 m waves and a storm surge that further damaged ports in Nova Scotia (Environment Canada, 2013a). In 1995, during Hurricane Luis, a 30 m wave struck an ocean liner off the coast of Newfoundland (Environment Canada, 2013b).

Rising sea levels and increased storm surge are also expected to pose greater risks over the course of the 21st century (Bush et al., 2014). Sea-level rise in the range of 70-100 cm is projected for many key coastal locations in Atlantic Canada by 2100 (Savard et al., 2016); and in some cases, higher tides and storm surges could inundate and damage wharves, terminals, and loading equipment in the absence of adaptive action (Andrey and Mills, 2003). Figures 12a and 12b illustrate the extent of possible inundation for Halifax Harbour in 2100, based on two sea-level rise scenarios (high- and low-probability). In some locations sea-level rise could permit the entry of ships with greater drafts and heavier cargo loads (Andrey and Mills, 2003).

**Figure 12a: Flooding extent/depth in Halifax Harbour associated with a 10-year return level event and a 0.57 m rise in global sea level (highly plausible).** For these projections, it is assumed that frequency and intensity of storms remains unchanged in future. (Source: Forbes et al., 2009)

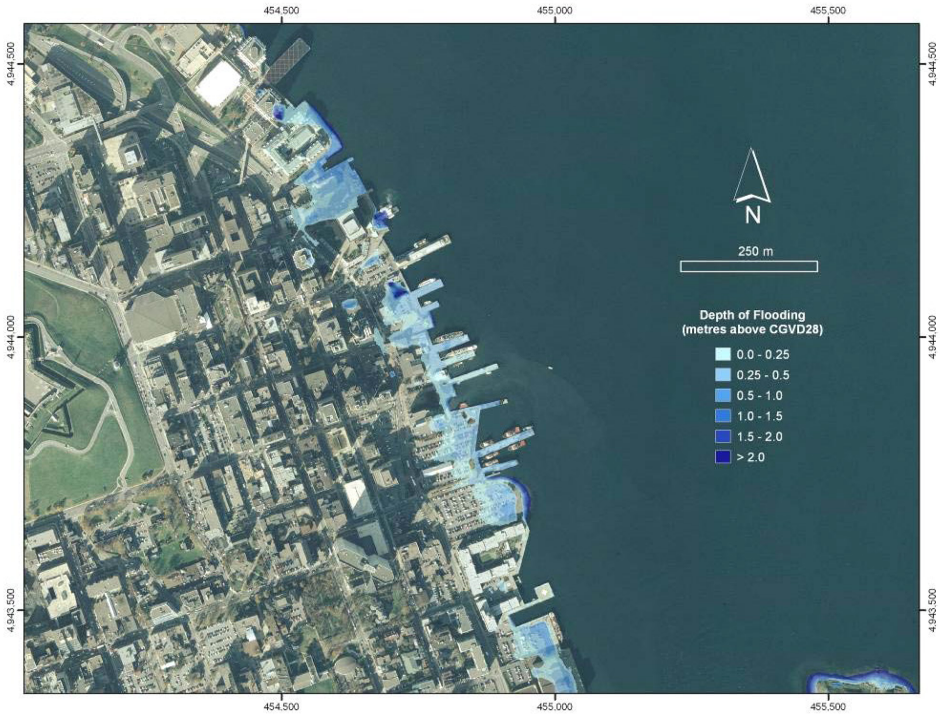
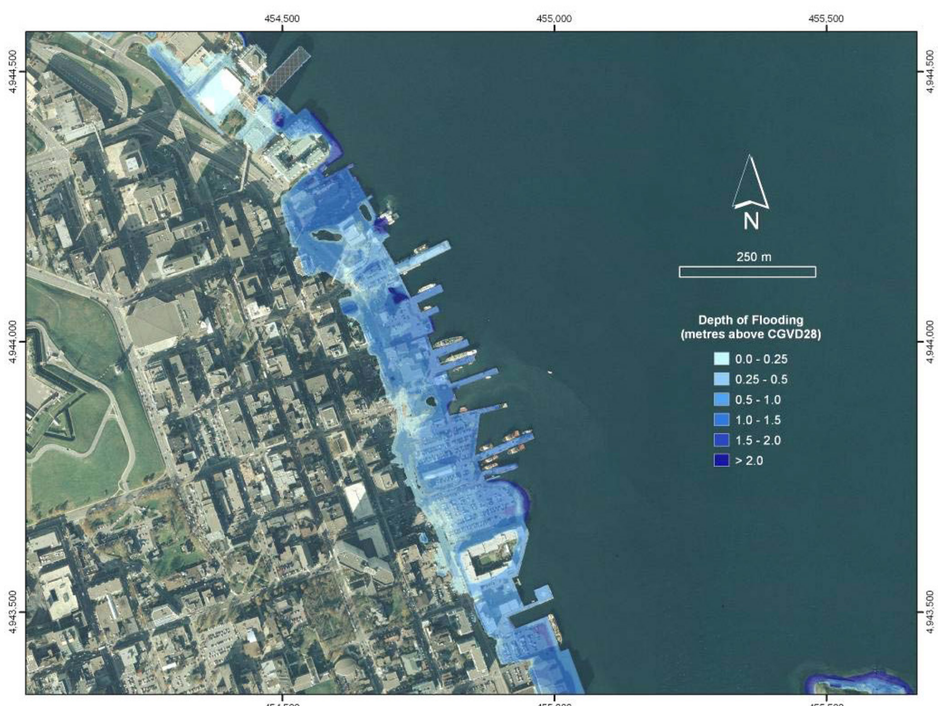



**Figure 12b: Flooding extent/depth in Halifax Harbour associated with a 50-year return level event and a 1.3 m rise in global sea level (lower probability).** For these projections, it is assumed that frequency and intensity of storms remains unchanged in future. (Source: Forbes et al., 2009)



### SEA ICE AND WIND

High winds have been a source of costly delays for ferries servicing Newfoundland, Labrador, and Nova Scotia (CBC News, 2015b; Cape Breton Post, 2015; Catto et al., 2006). When combined with earlier seasonal break-up and fragmentation of sea ice, winds pose additional navigation hazards. For instance, in the winter of 2015, ice blown into the Strait of Belle Isle resulted in lengthy delays and frustration for passengers attempting to travel between Newfoundland and Labrador (CBC News, 2015b). Similarly, increasing easterly wind strength in Channel-Port aux Basques, Newfoundland may threaten the reliability of ferry transportation in the area, an important crossing point from the island to the mainland (Catto et al., 2006).

High winds will continue to pose risks to vessels and ports, based on projected increases to the frequency of extreme weather events. At the same time, warmer summer weather and the decreasing extent and duration of sea ice will offer potential benefits to commercial shipping, the cruise industry, and eco-tourism via an extended Maritime shipping season (Andrey and Mills, 2003; Leys, 2009; Savard et al., 2016).

CASE STUDY 3

## CASE STUDY 3: PLANNING FOR FUTURE EXTREME WEATHER CONDITIONS AT HALIFAX HARBOUR

The Province of Nova Scotia, with support from Natural Resources Canada has been conducting a case study on the impacts of climate change on coastal transportation infrastructure in Halifax Harbour. Researchers are using cost-benefit analysis to assess vulnerabilities to changing climate parameters and adaptation options. Analysis focuses on marine shipping and intermodal transfers to truck and rail. This includes an investigation of how rail delays resulting from extreme weather or infrastructure damage might affect the delivery of goods to marine ports. The results of this study were not yet available at the time of writing this assessment.

Variables under consideration in the study included sea-level rise, storm surge, and coastal subsidence. Maps and computer models were used to visualize potential impacts on the system. Volunteer participants in the study included CN rail and major port operators. This cost-benefit analysis will help to demonstrate the impacts of climate change on businesses near Halifax Harbour.

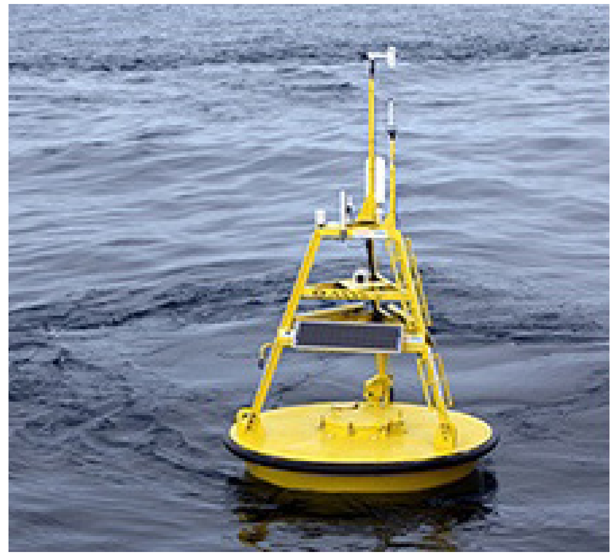
*Written with input from Shawn MacDonald (Climate Change Unit, Government of Nova Scotia).*

### 6.2 ADAPTATION PRACTICES

Atlantic Canada's marine ports and operators have employed a number of practices to improve their resilience to climate and extreme weather risks. One example is Bay Bulls Harbour (Figure 13), an economic hub in eastern Newfoundland that is proximate to St. John's and the productive fishing grounds of the Grand Banks. In 2010, Hurricane Igor caused extensive damage to the wharf. When the wharf was reconstructed, the community elected to include adaptive measures to better withstand future storm conditions. Sea-level rise, storm surges, and extreme weather were considered. As a result, the new wharf was built 0.5 m higher than previously, its directional orientation was changed, and a breakwater of 1.5 m was constructed to provide increased protection. Bay Bulls and its economic assets are now better-prepared for higher-intensity weather conditions (Office of Climate Change, Energy Efficiency and Emissions Trading, 2013). There are an increasing number of cost/benefit analyses demonstrating that capital and other expenditures undertaken to reduce risks of infrastructure damage result in long-term cost savings (see Case Study 5).

**Figure 13: Bay Bulls Harbour, Newfoundland.** (Source: Government of Newfoundland and Labrador Office of Climate Change and Energy Efficiency)

**Figure 14: SmartAtlantic buoy in St. John's, Newfoundland.** (Source: Fisheries and Marine Institute of Memorial University)



An under-explored area of adaptation is the application of new technologies to reduce climate risk. For example, the Fisheries and Marine Institute of Memorial University of Newfoundland and the Institute for Ocean Research Enterprise of Halifax have created the SmartAtlantic Alliance to further modernize Canada's marine navigation system by providing accurate and real-time meteorological and hydrological data. Data generated by SmartAtlantic buoys (Figure 14) is used to produce high-resolution forecasts of weather and sea conditions, and for scientific research. The technology is currently in use at seven Atlantic ports (see Case Study 4) and allows the marine transportation industry, commercial and recreational boaters, researchers, and interested members of the public to access real-time, online data about regarding weather and directional wave information at these locations. It is designed to optimize efficiency without compromising navigational safety, and to enhance the reliability of port operations in a variety of weather and climatic conditions (Government of Canada, 2014; New Brunswick Department of Transportation and Infrastructure, 2015).

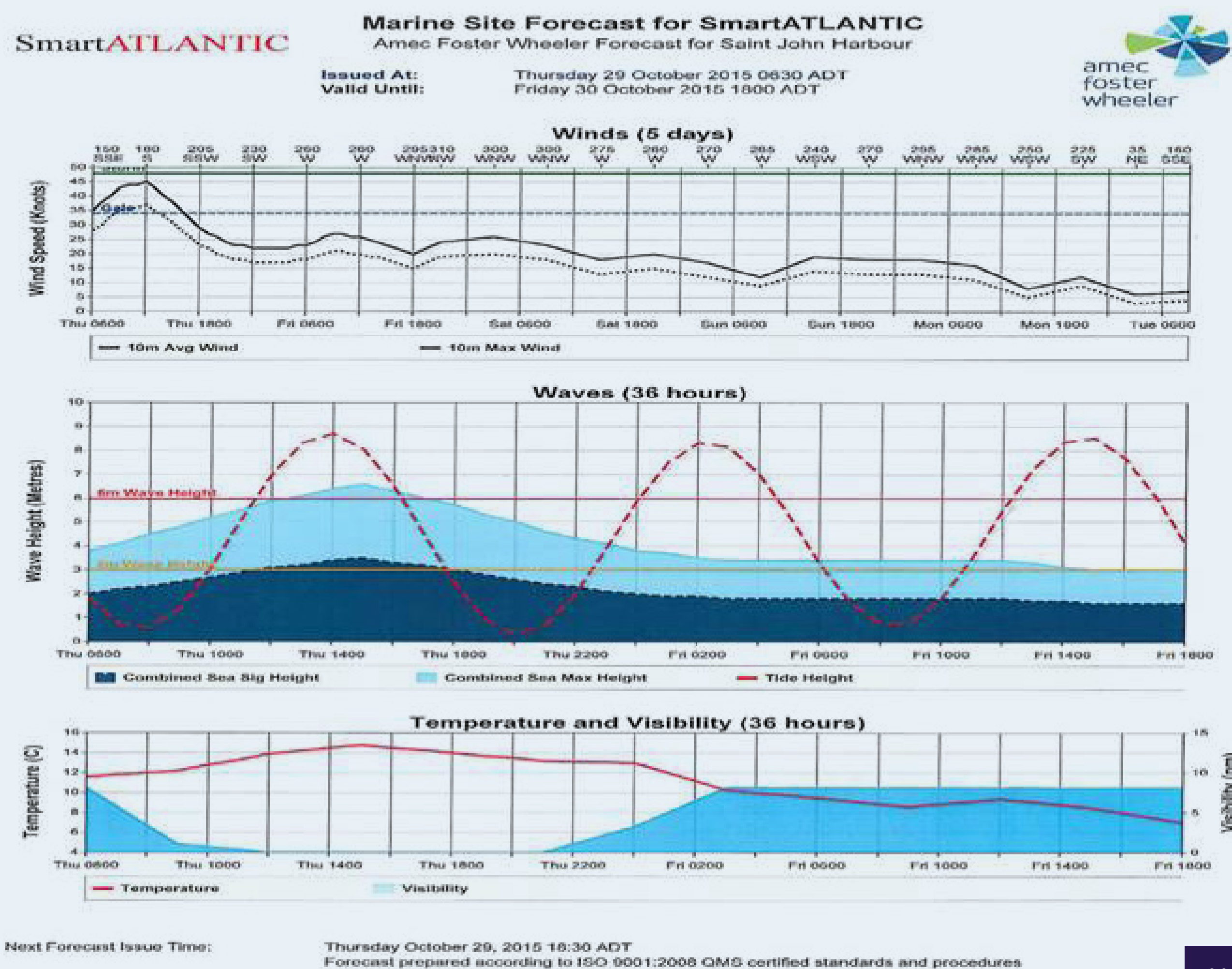
# CASE STUDY 4: CLIMATE CHANGE ADAPTATION AT PORT SAINT JOHN

Port Saint John is Atlantic Canada's largest port by tonnage. It connects global markets to central Canada by rail and road, and serves regionally-important industries such as potash, petroleum, and tourism (i.e. the cruise industry). Climate-related impacts and disruptions to the port's operations negatively affect the regional and national economy, as well as the Port's profitability. Port operators have identified a number of risks to infrastructure and operations related to extreme, variable and/or changing climatic conditions. Spring flooding has been particularly problematic.

Sea-level rise and storm surges pose increasing risks to port infrastructure, designed for a 100-year lifespan. In late 2015-early 2016, Port Saint John experienced an unusually high number of strong wind events, producing storm surges in the inner harbour. During one particularly strong event on October 29, 2015 (the peak of which coincided with an extra high tide), infrastructure sustained approximately $20,000 in damages (Chris Hall, Port Saint John, personal communication, 2016).

Several actions, implemented and planned by the Port as part of its modernization efforts, are expected to make the port more resilient to variable and changing climatic conditions, and more reliable for shippers and mariners. For example, the "SmartAtlantic" inshore weather buoy was recently launched, along with a wave forecasting tool. Figure 15 provides an example of the forecasting output from Saint John Harbour's SmartAtlantic buoy. This data accurately predicted the storm-surge event on October 29, 2015.

**Figure 15: SmartAtlantic buoy output for Saint John Harbour (October 29, 2015).** (Source: Chris Hall, Port Saint John)



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The Port is also undertaking long-term planning for its infrastructure as part of a port modernization plan. A preliminary engineering study in support of these efforts explicitly accounted for future sea level rise, based on high-resolution models for the Upper Bay of Fundy (Dupont et al., 2005).

*Written with input from Chris Hall (Port Saint John) with additional information provided by Tyler O'Rourke (Port Saint John).*

# 7.0 AIR TRANSPORTATION

## 7.1 PAST IMPACTS AND FUTURE RISKS

Practitioners suggest that on the whole, airports in the Atlantic region are well-equipped to function during difficult weather conditions. However, extreme weather events and storms, including heavy rain, snowfall, and strong winds, can result in flight delays and cancellations, associated economic losses, and passenger inconvenience. Flight delays are especially problematic for Newfoundland (CBC News, 2015b, 2015c), which relies on aviation (as well marine transportation) for connectivity.

Airports aim to keep facilities open in all weather conditions, especially for medical emergency services that require the use of runways and airport facilities. The challenge for airports is to provide efficiency of service while ensuring safe operations during extreme weather conditions. Atlantic airports are particularly concerned with rising operating costs accompanying more variable and severe weather conditions (Helen MacInnis, J.A. Douglas McCurdy Sydney Airport, personal communication, 2015; Andrew Isbill, Fredericton Airport Authority, personal communication, 2015).

### PRECIPITATION AND STORMS

Precipitation, including rain, snow, and freezing rain on runways can compromise the friction and visibility necessary for planes to take off and land. Operational costs can also rise significantly in response to freezing rain events and extreme snowfall (Helen MacInnis, J.A. Douglas McCurdy Sydney Airport, personal communication, 2015).

Increasingly frequent storm events (and associated precipitation and flooding) in the 21st century could lead to further losses in revenue due to operational disruptions. These types of delays could also increase operating costs, associated with requirements for more aircraft, facility maintenance and the improvement of supporting infrastructure, such as access roads and drainage facilities (Transportation Research Board, 2008).

While storm surges, erosion and sea-level rise pose risks to regional coastal infrastructure, most airports in Atlantic Canada are built on relatively high ground, which reduces vulnerability to coastal flooding.

Drainage systems are usually effective in reducing flood risks to runways. However, extreme precipitation events have, in some instances, flooded airport service/access roads and parking lots in Atlantic Canada. In some cases, these floods have delayed and cancelled flights, as was the case at Halifax Stanfield International Airport during a strong nor'easter in December 2014 (CBC News, 2014c).

Increased frequency of lightning storms and hurricanes are also a concern for some airports in Atlantic Canada, given their potential to disrupt operations and pose safety risks (for instance, by reducing visibility during landing and take-off). While data to support the increasing frequency of these storms are not captured in the historical record, Sydney airport has documented an increase in frequency over the short term (Helen MacInnis, J.A. Douglas McCurdy Sydney Airport, personal communication, 2015).

#### WIND

High winds can result in cancelled, delayed or redirected flights when cross winds are too strong for aircraft to safely take off or land (United Kingdom Department for Transport, 2014). Wind can also damage equipment on the ground. For instance, in 2012, high winds tipped over an array (part of the instrument landing system) at the J.A. Douglas McCurdy Sydney Airport in Nova Scotia, affecting landing operations and requiring NAV CANADA to make unexpected and costly repairs (Helen MacInnis, J.A. Douglas McCurdy Sydney Airport, personal communication, 2015).

Power outages accompanying windstorms can create major problems for air transportation. For example, when Hurricane Arthur hit the Maritimes in the summer of 2014, Fredericton International Airport lost power and had to rely on a backup generator (Andrew Isbill, Fredericton Airport Authority, personal communication, 2015). The generator allowed the airport to continue with some operations, although operators had concerns about its potential failure. More frequent high-intensity wind events would increase risks associated with these impacts, although projections indicate that daily average wind speeds are not likely to increase significantly in the Atlantic region (Loder et al., 2013).

#### TEMPERATURE

Atlantic aviation is also vulnerable to changing temperatures. Increasing freeze-thaw cycles pose risks to runway stability, while extreme heat and cold reduce aircraft engine performance and fuel efficiency (Transportation Research Board, 2008).

Increasing turbulence as a result of higher-temperature conditions (increased air density) is expected to affect flights in the North Atlantic by mid-century. The proportion of flight time for transatlantic journeys spent in conditions of "moderate-or-greater turbulence" is likely to increase 40-170 percent by mid-century, resulting in longer trip times, greater fuel consumption, and more greenhouse-gas emissions (Williams and Joshi, 2013).

### 7.2 ADAPTATION PRACTICES

Adaptation actions at Atlantic airports are not well documented in the public domain. However, Atlantic aviation faces many of the same climate risks as operators in other Canadian jurisdictions (including extreme weather events and temperature extremes). Thus, many of the practices outlined in other chapters of this report apply to Atlantic Canada. General risk avoidance practices include standard procedures for accessing weather forecasts and planning flights, and for advanced aircraft instrumentation systems.

## 8.0 MULTI-MODAL RISK ASSESSMENTS AND COST-BENEFIT ANALYSES

Some initiatives in Atlantic Canada have considered the vulnerability of the region's transportation network with a multimodal lens. These include risk assessments and cost-benefit analyses of climate change impacts and adaptation options for transportation infrastructure.

### 8.1 RISK ASSESSMENTS

In 2012, the Department of Fisheries and Oceans (DFO) completed an expert-based risk assessment of infrastructure, waterways, and biological systems in the Atlantic Large Aquatic Basin (LAB), which includes the Newfoundland Labrador Shelf, Scotian Shelf/Slope, and the Gulf of Maine (Department of Fisheries and Oceans, 2013). The assessment process identified and rated six key risks based on "risk exposure" (vulnerability to impacts) on 10- and 50-year horizons. Risks relevant to transportation include increased demand for emergency services, infrastructure damage, and changes to the navigability of waterways. Of these, it was determined that the greatest risks are posed to infrastructure by changing climate conditions over both timescales. Authors note that this assessment's methodology can be applied to smaller-scale risk assessments of ports and coastal transportation systems in Atlantic Canada.

Public and private institutions are developing tools to assist in the assessment of climate change risks. For example, the "CoastaL Impact Visualization Environment" (CLIVE) tool, created in partnership by the University of Prince Edward Island (UPEI) and Simon Fraser University, offers a "virtual tour" of likely coastal erosion and storm-surge impacts on Prince Edward Island. CLIVE is operated by a game controller and allows the user to "fly" over Prince Edward Island's coastline, examining past and future sea levels (at 30, 60, and 90 year future intervals). This tool also quantifies sea-level rise risks, including land area lost. This tool is useful for assessing transportation infrastructure vulnerability to coastal changes in order to better plan for changes in maintenance, structure, or location over the short and long term (Office of the Vice-President, Research, 2015).

### 8.2 COST-BENEFIT ANALYSIS

Some practitioners in the region are undertaking cost-benefit analyses of adaptation options in order to ensure the benefits of a given option outweighs the costs associated with climate change. The costs of direct (damages) and indirect (disruptions and closures) climate impacts on transportation systems can be significant. At the same time, adaptation efforts can be costly – infrastructure is expensive to build, and changing operational practices can cause short-term delays, confusion, and other inefficiencies (Füssel, 2007). Case Study 5 summarizes a cost-benefit analysis of climate impacts and adaptation options for the Chignecto Isthmus.

CASE STUDY 5

## CASE STUDY 5: ADAPTING TO FLOODING AND STORM-SURGE RISKS IN THE CHIGNECTO ISTHMUS

The Chignecto Isthmus is one of Canada's most important transportation corridors, and the sole land bridge joining mainland Canada (New Brunswick) with Nova Scotia. Marsh areas within the Isthmus had dykes installed in the 1700s for agriculture. Since that time, significant infrastructure has been built within this area, including the Trans-Canada Highway, the CN Railway, and electricity-transmission lines serving Nova Scotia. Trade through the Isthmus is conducted by both road and rail, carrying an estimated value of $50 million per day and $20 billion annually.

Recent studies demonstrate the vulnerability of the region to sea-level rise and storm-surge flooding (Webster et al., 2011, Lieske and Bornemann, 2012; and Webster et al., 2012). By 2100, 38 km of dykes, 19 km of rail, and 19 km of the Trans-Canada Highway could be severely affected by flooding in a 1-in-100 year storm event (Figure 16). However, there has been a lack of information on the economic costs associated with these impacts in the Chignecto region.

A collaborative cost-benefit analysis (CBA) of adaptation options (including maintaining the status quo) was undertaken to assess the economic consequences of sea-level rise and storm surge on significant infrastructure (highways, rail, agricultural dykes, and electricity) and trade in the Isthmus. The project features collaboration among the Provinces of New Brunswick and Nova Scotia and Natural Resources Canada. The CBA had three objectives:

- Build on existing local assessments of climate change impacts and adaptation options, adding economic analysis to the discussion.
- Quantify economic costs associated with flood-related damages to the transportation corridor in order to demonstrate the benefits (monetary and otherwise) associated with potential adaptation options.
- Support decision-makers in the selection of informed adaptation investments.

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Six adaptation options were assessed (see Table 3). These options mainly focus on changes that could be made to the management of agricultural dykes in the Isthmus, which currently protect farmland against tidal flooding, and provide secondary protection for roads, rail, and infrastructure. However, the dykes are not designed to withstand severe storm events. Summaries of adaptation options are presented below. A key assumption in the study was that no option could result in increased risks or damages to the communities and municipal infrastructure of Sackville and Amherst.

**Figure 16: 100-year flood event (in blue) for the Chignecto Isthmus in 2070 in relation to road, rail, and electrical transmission infrastructure.** (Source: MacDonald and Webster, Applied Geomatics Research Group)

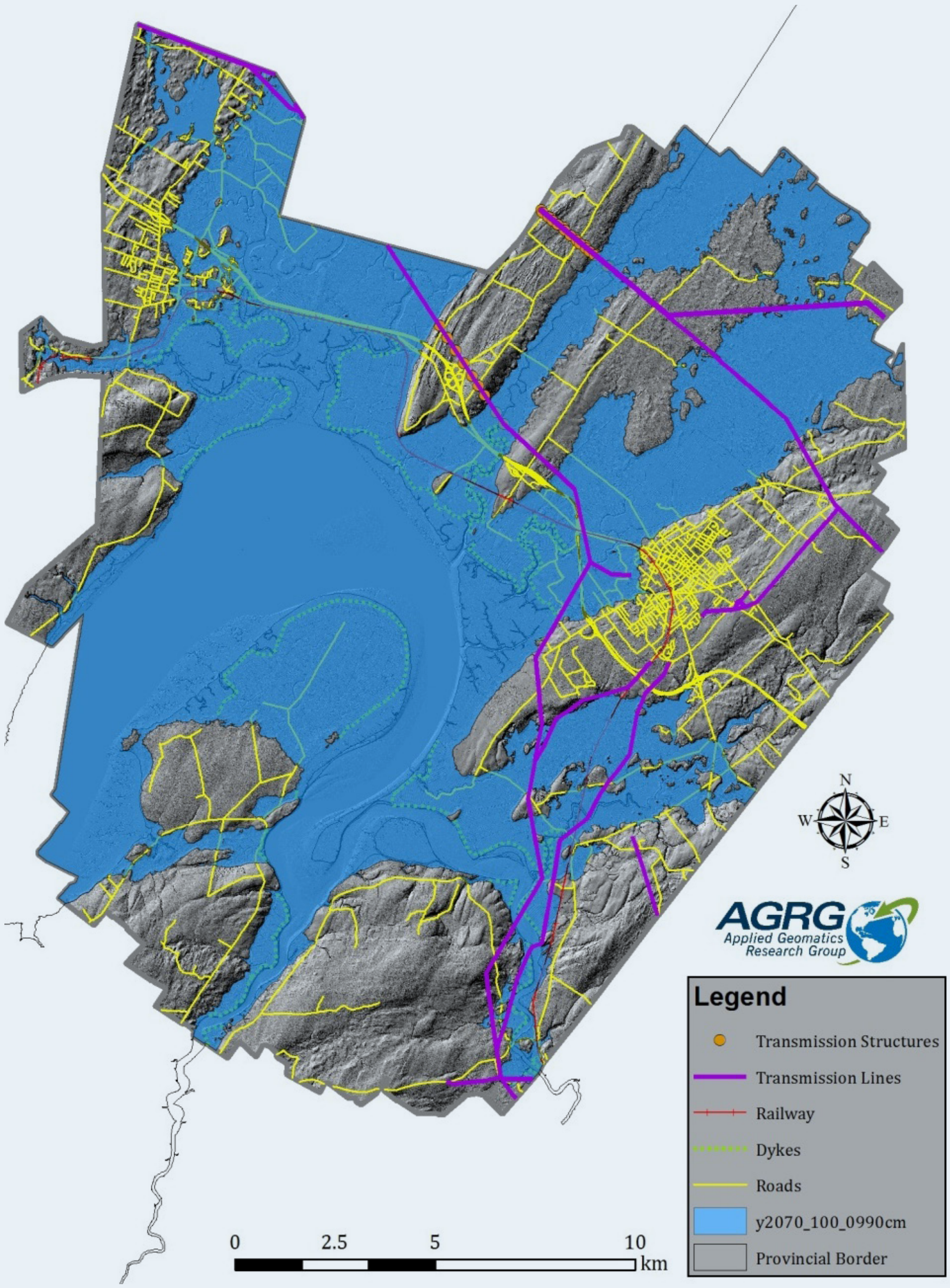


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**Table 3: Adaptation options evaluated in the Chignecto Isthmus CBA.**

| Option Number | Adaptation Option | Description |
|---|---|---|
| 1 | Agricultural dykes, existing location | Raising/topping-up dykes in existing locations to 10 m. Public infrastructure not protected behind dykes. |
| 2 | Agricultural dykes, shortened | Combination: Topping-up dykes and rebuilding to 10 m in existing locations, but shortened in certain sections. Raise infrastructure. |
| 3 | Engineered dykes, existing location | Build engineered dykes on top of existing dykes, engineered to 2070, 1-in-100-year events (10 m). |
| 4 | Engineered dykes, shortened, protect public infrastructure only | Shorten dykes, build engineered dykes on top of existing dykes, as well as new stretches, engineered to 2070, 1-in-100-year events (10 m); raise rail that is not being protected by existing dykes. |
| 5 | Engineered dykes, shortened protect all infrastructure | Shorten dykes, build engineered dykes on top of existing dykes, as well as new stretches, engineered to 2070, 1-in-100-year events (10 m). |
| 6 | Re-route the Trans-Canada Highway (50km) | Re-route a vulnerable 50 km stretch of the Trans-Canada Highway. |

## RESULTS

**The CBA is a high-level analysis intended to provide strategic direction on adaptation options – not to inform operational-level decision-making or costing.**

The cost of impacts associated with climate change over the period from 2015 to 2064 in today's dollars is estimated at $124 million. When potential trade loss is incorporated, this cost rises to $435 million.

The preferred adaptation option is an approach involving engineered dykes designed to protect against flooding associated with a 1-in-100 year storm event in 2070 (Option 3). Dykes would be shortened (compared to their current length) and protect all infrastructure (road, rail and electricity). The cost of the preferred option is estimated at approximately $93 million and its Net Present Value – calculated as the difference between the benefits of adaptation and costs of climate change impacts (discounted for evaluation in dollars today at 4 percent) – is estimated at $31 million. When lost trade due to climate change impacts is broadly accounted for, the Net Present Value of the preferred option grows to $278 million.

In this case, the cost of taking no adaptation action exceeds the costs associated with infrastructure renewal.

Lessons learned from the project relate to the challenges of integrating divergent stakeholder interests – however, practitioners believe the project has allowed for information-sharing around a common threat. Given that agricultural and transportation departments have typically worked separately, the process is likely to provide a more coordinated approach to the future management of the Isthmus. This study highlights the value of the dykes, and has challenged all stakeholders to think collaboratively and critically about how assets are protected in the Chignecto region.

*Written with input from Jeff Hoyt (Government of New Brunswick) and Sabine Dietz (Aster Group Environmental Services).*

## 9.0 INFORMATION GAPS AND CONCLUSIONS

Several gaps and barriers related to climate change adaptation in Atlantic Canada's transportation sector are evident. First, there is an absence of vulnerability assessments and comprehensive data specific to transportation in the Atlantic region. While risk assessment protocols have been applied to identify climate vulnerabilities in some cases, it is not known which specific roads, rail, airports and ports are most and least vulnerable. In addition, for certain important weather conditions such as fog and wind, there is little relevant, published climate data and literature from which to draw conclusions. Wind and fog have major impacts on marine and air navigation in the Atlantic region, so further research could better inform planning and operations.

The research conducted for this chapter also suggests that the risks to assets and operations posed by extreme weather events are more salient to public and private infrastructure managers than those related to long-term changes in climate parameters (i.e. sea-level rise, increased ambient temperatures). Greater attention is given by municipalities, practitioners, and infrastructure operators (i.e. Halifax Harbour, Port Saint John) to the increasing frequency of extreme weather events over other, longer-term impacts. This is not surprising, given limited public resources and the high costs incurred by flooding and other catastrophic events.

Likely for this same reason, practitioners and researchers conducting risk assessments and adaptation planning in Atlantic Canada acknowledge challenges in engaging stakeholders. The relevance of climate change to business owners can be difficult to explain – sea-level rise is a long-term process that does not fit neatly into conventional business cycles.

Despite some of these difficulties, this chapter has identified a number of tangible adaptation efforts in the transportation sector, just one sector among many in Atlantic Canada considering how to adapt to emerging climate risks (Atlantic Climate Adaptation Solutions Association, 2016). Climate change adaptation is a growing issue on the transportation agenda, and climate risks are spurring investment and planning. Practitioners are aware that the demand for transportation services will change in response to physical damages and service disruptions caused by changing climate conditions, and actions taken to enhance economic access to new or expanded markets will alter the supply and demand of freight in the region. Ensuring an efficient and resilient transportation infrastructure through collaboration and adaptation will be important to reduce impacts and maximize benefits from a changing climate.

# 10.0 ANNEX

Tables A1-A4: Temperature and precipitation projections by province for the Atlantic region up to 2100 over three time horizons (2016-2035, 2046-2065, and 2081-2100). Seasonal periods include winter (December-February), spring (March-May), summer (June-August), and autumn (September-November). Data was derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) global climate model under an ensemble of RCP2.6, RCP4.5, and RCP8.5 scenarios (Canadian Climate Data and Scenarios, 2015). These data reflect uncertainty associated with these projections by presenting a range of values from the 25th-75th percentiles of CMIP5 outputs. The median value (50th percentile) appears in brackets following the range.

**Table A1: Temperature and precipitation projections for New Brunswick.**

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | Near term 2016-2035 | Mid-century 2046-2065 | Late-century 2081-2100 |
| **RCP 2.6 (Low-emissions scenario)** | Precipitation (%) | Winter | +1.1-10.1 (+4.8) | +1.0-12.4 (+6.7) | +0.9-9.9 (+3.5) |
| | | Spring | +1.4-8.5 (+5.4) | +2.1-10.2 (+5.9) | +2.2-10.5 (+7.3) |
| | | Summer | -3.4-+5.8 (+2.8) | -2.7-8.6 (+1.1) | -0.6-10.1 (+3.9) |
| | | Autumn | -1.9-+4.6 (+1.9) | -2.7-+4.2 (+0.6) | -2.8-+6.1 (+2.7) |
| | Temperature (˚C) | Winter | +0.8-1.4 (+1.1) | +1.3-2.3 (+1.7) | +1.4-2.7 (+2.1) |
| | | Spring | +0.6-1.2 (+0.9) | +0.8-2.0 (+1.6) | +0.7-2.0 (+1.2) |
| | | Summer | +0.8-1.4 (+1.0) | +1.0-2.1 (+1.5) | +0.8-1.8 (+1.4) |
| | | Autumn | +0.9-1.4 (+1.0) | +1.2-2.3 (+1.6) | +1.0-2.0 (+1.5) |
| **RCP 4.5 (Intermediate-emissions scenario)** | Precipitation (%) | Winter | -0.7- +10.1 (+5.2) | +3.6-15.2 (+8.9) | +7.0-19.1 (+11.9) |
| | | Spring | -0.6-+8.8 (+4.1) | +3.9-13.2 (+10.1) | +6.1-19.1 (+12.5) |
| | | Summer | -2.2-+8.2 (+3.0) | +0.2-9.1 (+3.9) | -0.7-+11.3 (+4.5) |
| | | Autumn | -2.5-+5.9 (+1.1) | -0.8-+9.5 (+5.9) | -3.1-+6.7 (+1.4) |
| | Temperature (˚C) | Winter | +0.7-1.8 (+1.3) | +2.0-3.3 (+2.7) | +2.9-4.3 (+3.5) |
| | | Spring | +0.6-1.5 (+1.0) | +1.4-2.5 (+1.8) | +1.8-3.2 (+2.7) |
| | | Summer | +0.7-1.4 (+1.1) | +1.5-2.6 (+2.1) | +2.0-3.5 (+2.5) |
| | | Autumn | +0.9-1.5 (+1.1) | +1.7-2.6 (+2.1) | +2.2-3.6 (+2.5) |

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | **Near term** | **Mid-century** | **Late-century** |
| | | | **2016-2035** | **2046-2065** | **2081-2100** |
| **RCP 8.5 (High-emissions scenario)** | Precipitation (%) | Winter | -0.2-+11.3 (+5.8) | +6.0-17.3 (+11.4) | +13.1-28.6 (+19.0) |
| | | Spring | +0.1-7.3 (+3.4) | +6.1-15.1 (+10.6) | +12.0-23.0 (+16.6) |
| | | Summer | -2.3-+6.6 (+3.2) | -1.3-+9.9 (+4.2) | -1.1-+14.8 (+7.8) |
| | | Autumn | -4.2-+3.7 (-0.4) | -1.0-+10.4 (+3.5) | +1.2-10.3 (+4.3) |
| | Temperature (˚C) | Winter | +1.0-1.9 (+1.4) | +3.0-4.4 (+3.6) | +5.6-7.3 (+6.4) |
| | | Spring | +0.8-1.5 (+1.0) | +2.2-3.5 (+2.7) | +4.2-6.0 (+4.6) |
| | | Summer | +1.0-1.6 (+1.2) | +2.4-3.7 (+3.0) | +4.4-6.3 (+5.4) |
| | | Autumn | +1.0-1.8 (+1.3) | +2.5-3.8 (+3.1) | +4.4-6.2 (+5.1) |

**Table A2: Temperature and precipitation projections for Newfoundland and Labrador.**

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | **Near term** | **Mid-century** | **Late-century** |
| | | | **2016-2035** | **2046-2065** | **2081-2100** |
| **RCP 2.6 (Low-emissions scenario)** | Precipitation (%) | Winter | -2.4-+8.1 (+3.2) | -0.1-+11.8 (+5.8) | +1.0-12.9 (+6.3) |
| | | Spring | +1.2-10.2 (+5.3) | +1.7-13.3 (+8.1) | +2.7-13.3 (+7.9) |
| | | Summer | -0.2-+7.3 (+3.5) | +0.8-9.8 (+4.8) | +0.3-8.8 (+4.3) |
| | | Autumn | +0.7-8.1 (+4.3) | +1.1-9.0 (+5.3) | +1.9-9.8 (+6.0) |
| | Temperature (˚C) | Winter | +0.8-1.8 (+1.3) | +1.4-3.0 (+2.2) | +1.3-3.3 (+2.3) |
| | | Spring | +0.4-1.2 (+0.8) | +0.7-1.9 (+1.2) | +0.5-1.9 (+1.1) |
| | | Summer | +0.5-1.2 (+0.8) | +0.7-1.8 (+1.2) | +0.6-1.7 (+1.2) |
| | | Autumn | +0.7-1.3 (+1.0) | +1.0-2.1 (+1.6) | +0.9-2.1 (+1.5) |

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | **Near term** | **Mid-century** | **Late-century** |
| | | | **2016-2035** | **2046-2065** | **2081-2100** |
| **RCP 4.5 (Intermediate-emissions scenario)** | Precipitation (%) | Winter | -0.3-+11.7 (+5.0) | +2.9-16.1 (+9.5) | +6.5-20.8 (+14.5) |
| | | Spring | +0.7-11.5 (+6.0) | +3.8-13.7 (+8.5) | +5.1-17.4 (+10.5) |
| | | Summer | -0.6-+7.8 (+3.3) | +0.7-10.7 (+5.1) | +2.2-10.5 (+5.9) |
| | | Autumn | -0.6-+7.2 (+3.2) | +3.3-10.2 (+7.2) | +2.7-10.7 (+7.1) |
| | Temperature (˚C) | Winter | +0.8-2.0 (+1.3) | +2.2-3.7 (+2.9) | +2.9-4.9 (+4.1) |
| | | Spring | +0.4-1.2 (+0.8) | +1.1-2.3 (+1.6) | +1.6-2.8 (+2.1) |
| | | Summer | +0.5-1.3 (+0.8) | +1.2-2.3 (+1.7) | +1.5-3.0 (+2.2) |
| | | Autumn | +0.8-1.3 (+1.0) | +1.5-2.5 (+1.8) | +1.9-3.3 (+2.3) |
| **RCP 8.5 (High-emissions scenario)** | Precipitation (%) | Winter | +0.6-10.6 (+4.8) | +6.5-20.7 (+12.0) | +14.2-34.8 (+23.0) |
| | | Spring | +0.8-9.0 (+5.4) | +5.6-15.8 (+10.2) | +12.0-28.5 (+18.9) |
| | | Summer | -1.7-+7.9 (+3.5) | +2.2-11.2 (+6.6) | +5.3-18.6 (+11.5) |
| | | Autumn | +0.2-7.2 (+3.8) | +4.0-11.5 (+7.8) | +7.2-18.9 (+12.2) |
| | Temperature (˚C) | Winter | +1.0-2.2 (+1.5) | +3.4-5.2 (+4.3) | +6.5-9.0 (+7.7) |
| | | Spring | +0.5-1.4 (+1.0) | +2.0-3.1 (+2.4) | +3.8-6.0 (+4.7) |
| | | Summer | +0.8-1.3 (+1.0) | +1.9-3.2 (+2.5) | +3.9-5.9 (+4.6) |
| | | Autumn | +0.9-1.5 (+1.2) | +2.3-3.5 (+2.7) | +4.2-6.2 (+4.8) |

**Table A3: Temperature and precipitation projections for Nova Scotia.**

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | Near term 2016-2035 | Mid-century 2046-2065 | Late-century 2081-2100 |
| **RCP 2.6 (Low-emissions scenario)** | Precipitation (%) | Winter | -0.1-6.2 (+2.8) | -2.2-+7.0 (+2.5) | +0.3-7,8 (+3.0) |
| | | Spring | +1.7-8.0 (+4.0) | +0.9-10.1 (+3.6) | +1.9-9.8 (+6.6) |
| | | Summer | -3.9-+7.3 (+2.8) | -3.8-+8.0 (+2.2) | -2.9-+9.2 (+2.6) |
| | | Autumn | -1.8-+4.2 (+1.5) | -2.7-+5.0 (+1.7) | -2.1-+6.5 (+2.2) |
| | Temperature (˚C) | Winter | +0.7-1.3 (+1.0) | +1.1-2.1 (+1.5) | +1.0-2.5 (+1.9) |
| | | Spring | +0.6-1.2 (+0.9) | +0.8-1.9 (+1.4) | +0.7-1.9 (+1.3) |
| | | Summer | +0.7-1.2 (+0.9) | +1.0-1.8 (+1.5) | +0.9-1.8 (+1.3) |
| | | Autumn | +0.8-1.3 (+1.0) | +1.1-2.1 (+1.5) | +1.0-1.8 (+1.4) |
| **RCP 4.5 (Intermediate-emissions scenario)** | Precipitation (%) | Winter | -1.8-+6.1 (+2.8) | +2.9-9.3 (+5.4) | +4.1-14.4 (+8.7) |
| | | Spring | -0.8-+7.6 (+3.5) | +2.8-13.7 (+8.1) | +4.0-16.5 (+8.6) |
| | | Summer | -2.2-7.6 (+3.0) | -3.6-9.2 (+4.4) | -1.3-9.8 (+6.4) |
| | | Autumn | -0.9-+6.3 (+2.7) | -1.3-+9.1 (+4.8) | -3.7-+9.1 (+3.8) |
| | Temperature (˚C) | Winter | +0.7-1.6 (+1.2) | +1.7-2.9 (+2.3) | +2.4-3.7 (+2.9) |
| | | Spring | +0.6-1.4 (+1.0) | +1.5-2.2 (+1.7) | +1.8-2.9 (+2.5) |
| | | Summer | +0.7-1.5 (+1.0) | +1.5-2.4 (+1.9) | +1.9-3.2 (+2.4) |
| | | Autumn | +0.8-1.4 (+1.1) | +1.6-2.5 (+1.9) | +2.1-3.5 (+2.4) |

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | Near term 2016-2035 | Mid-century 2046-2065 | Late-century 2081-2100 |
| **RCP 8.5 (High-emissions scenario)** | Precipitation (%) | Winter | +0.6-6.7 (+3.7) | +6.5-12.5 (+8.3) | +14.2-21.1 (+13.9) |
| | | Spring | +0.5-8.6 (+4.4) | +3.8-13.8 (+7.6) | +7.3-18.1 (+12.8) |
| | | Summer | -4.5-+5.8 (+1.7) | -2.2-+8.5 (+4.3) | -3.0-+15.3 (+6.8) |
| | | Autumn | -4.6-+4.0 (-0.3) | -1.8-+8.8 (+4.0) | -0.6-8.6 (+3.7) |
| | Temperature (˚C) | Winter | +.9-1.6 (+1.3) | +2.5-3.6 (+3.0) | +4.7-6.2 (+5.4) |
| | | Spring | +0.7-1.4 (+1.0) | +2.1-3.2 (+2.5) | +3.9-5.5 (+4.4) |
| | | Summer | +0.9-1.5 (+1.1) | +2.2-3.4 (+2.7) | +4.1-6.6 (+4.9) |
| | | Autumn | +0.9-1.6 (+1.2) | +2.3-3.6 (+3.0) | +4.2-6.0 (+4.8) |

**Table A4: Temperature and precipitation projections for Prince Edward Island.**

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | Near term 2016-2035 | Mid-century 2046-2065 | Late-century 2081-2100 |
| **RCP 2.6 (Low-emissions scenario)** | Precipitation (%) | Winter | +1.2-8.7 (+3.0) | -2.3-8.8 (+5.2) | +2.1-8.0 (+5.3) |
| | | Spring | +1.3-7.8 (+5.6) | +1.1-9.8 (+6.2) | +4.1-9.8 (+7.7) |
| | | Summer | -3.7-+8.1 (+0.6) | -4.3-+7.7 (+1.9) | -1.4-+6.6 (+2.7) |
| | | Autumn | -3.3-+4.0 (+1.6) | -5.2-+5.5 (+0.9) | -3.3-+5.5 (+2.8) |
| | Temperature (˚C) | Winter | +0.8-1.6 (+1.1) | +1.3-2.5 (+1.7) | +1.3-2.9 (+2.1) |
| | | Spring | +0.7-1.2 (+0.9) | +0.9-2.1 (+1.5) | +0.9-2.3 (+1.3) |
| | | Summer | +0.7-1.3 (+0.9) | +1.0-2.1 (+1.6) | +0.8-1.9 (+1.4) |
| | | Autumn | +0.8-1.3 (+1.0) | +1.1-2.2 (+1.5) | +1.0-1.9 (+1.4) |

| Climate scenario (Representative Concentration Pathway) | Climate variable | Season | Projected change from 1986-2005 baseline (25th- 75th percentiles; 50th percentile in brackets) | | |
|---|---|---|---|---|---|
| | | | Near term | Mid-century | Late-century |
| | | | 2016-2035 | 2046-2065 | 2081-2100 |
| RCP 4.5 (Intermediate-emissions scenario) | Precipitation (%) | Winter | -1.2-+8.1 (+5.3) | +2.5-11.3 (+7.5) | +5.1-15.1 (+10.8) |
| | | Spring | -2.0-+7.9 (+3.1) | +3.3-14.3 (+8.5) | +6.6-20.4 (+8.8) |
| | | Summer | -3.1-+9.4 (+3.1) | -1.4-+12.2 (+3.9) | -2.1-+9.8 (+6.1) |
| | | Autumn | -0.3-+5.5 (+1.6) | -0.3-+8.1 (+5.0) | -4.7-+9.5 (+1.9) |
| | Temperature (˚C) | Winter | +0.8-1.8 (+1.3) | +1.8-3.2 (+2.7) | +2.7-4.1 (+3.4) |
| | | Spring | +0.8-1.4 (+1.1) | +1.6-2.6 (+1.7) | +1.9-3.1 (+2.5) |
| | | Summer | +0.7-1.4 (+1.1) | +1.6-2.5 (+2.0) | +2.0-3.3 (+2.5) |
| | | Autumn | +0.8-1.5 (+1.0) | +1.6-2.6 (+2.1) | +2.0-3.4 (+2.5) |
| RCP 8.5 (High-emissions scenario) | Precipitation (%) | Winter | +1.4-9.3 (+5.3) | +3.4-13.8 (+10.7) | +8.3-22.1 (+17.1) |
| | | Spring | +0.7-8.7 (+5.2) | +4.0-13.1 (+9.0) | +8.6-22.5 (+14.9) |
| | | Summer | -6.0-+5.9 (+2.5) | -2.4-+9.4 (+5.4) | -1.8-+15.6 (+6.3) |
| | | Autumn | -4.2-+3.6 (-0.6) | -3.0-+8.5 (+3.8) | +0.4-+8.6 (+3.7) |
| | Temperature (˚C) | Winter | +1.0-1.8 (+1.4) | +2.7-4.1 (+3.4) | +5.3-6.7 (+6.0) |
| | | Spring | +0.8-1.6 (+1.1) | +2.1-3.3 (+2.6) | +4.3-6.0 (+4.7) |
| | | Summer | +1.0-1.6 (+1.2) | +2.4-3.4 (+2.8) | +4.2-6.0 (+5.3) |
| | | Autumn | +0.9-1.6 (+1.2) | +2.3-3.7 (+2.9) | +4.2-6.0 (+4.8) |

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