4 · British Columbia

CHAPTER 4: BRITISH COLUMBIA

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KEY FINDINGS

- **Transportation systems in British Columbia have demonstrated vulnerability to extreme weather and changes in climate.** Impacts of particular concern include those associated with:
    - Extreme precipitation, such as atmospheric river (Pineapple Express) events, affecting road and rail networks, marine transportation lanes, and airport facilities;
    - Sea level rise and storm surge, increasing the risks of flooding and damage to fixed coastal infrastructure, including Vancouver International Airport, Sandspit Airport on Haida Gwaii, and the Port of Vancouver;
    - High winds, affecting marine transportation lanes; and,
    - Visibility issues, affecting airport operations, particularly in the British Columbia interior.
- **Land transportation routes within British Columbia often occupy restricted corridors through mountains and along coastlines.** In these settings, flooding (associated with extreme precipitation or snowmelt) and slope failures have resulted in infrastructure failures to road and rail systems in the past. Events that have affected one of these modes have typically also affected the other.
- **While previous efforts to reduce climate risks to transportation systems were often reactive, and based on historical information, there is indication that this is changing**. Transportation entities are now inclined to become involved in broader future focused climate change studies and to incorporate these finding into their systems.
- **Climate change vulnerability assessments and revised and updated infrastructure design criteria can improve planning and adaptation efforts for British Columbia's transportation infrastructure.** The provincial government has conducted vulnerability assessments for highway systems and continues to monitor and assess sea level rise. The British Columbia Ministry of Transportation and Infrastructure is one of the first jurisdictions to require infrastructure design work for the ministry to include climate change implications.
- **Given the interconnectedness of transportation networks in British Columbia, there is opportunity to share research, risk analysis, and adaptation best practices across modes.**

1.0 INTRODUCTION

British Columbia is Canada's third-largest and most westerly province, encompassing more than 95 million hectares of land and freshwater (10% of Canada's land surface) and 27,200 km of coastline (KnowBC, 2016). Its geography is rugged – vast, snow-covered mountain ranges stretch along the coast and through eastern and southern regions of the province, while the central interior and northeast are characterized by valleys and broad plains. Provincial transportation systems must contend with many shoreline inlets, tight corridors traversing mountain ranges with few major passes, and long distances between population centres. Economic activity and opportunity is distributed across the province, as are populations and transportation networks.

As part of the Pacific Rim, British Columbia's transportation network provides a key link between North America and Asia and facilitates the movement of people and goods to support provincial, national, and international trade. In this context, British Columbia requires aviation, marine, road, and rail infrastructure that is resilient, effective, and efficient. While infrastructure in British Columbia is designed to withstand certain types of weather and climate conditions, building and maintaining a viable transportation system in the context of projected changes in climate – including temperature, precipitation, patterns of extreme weather, and other variables – is essential. Transportation systems in the province demonstrate vulnerability to both extreme weather events and incremental changes in climate conditions. While difficulties persist in identifying the location and criticality of infrastructure vulnerabilities and communicating them to decision-makers, progress is evident in advancing climate adaptation broadly.

This chapter examines the interactions and vulnerabilities of transportation infrastructure and operations to changes in weather and climate in British Columbia. It has a strong focus on engineering approaches to climate adaptation in the transportation sector. The science and practice of adaptation is a relatively new undertaking in the engineering field, with the consideration of future climate conditions remaining a challenge and new way of thinking for engineering professionals (see Box).

ADAPTING ENGINEERING PRACTICES TO CLIMATE CHANGE

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

Due to the newness of this field and current limitations of climate models in providing information to engineering designers, many questions cannot yet be answered. For example, a particular climate parameter like extreme wind will have a significant effect on the future functionality and safety of a bridge being designed today. Anticipating how this parameter may behave 75 years from now is a level of uncertainty most engineering designers have not had to deal with before.

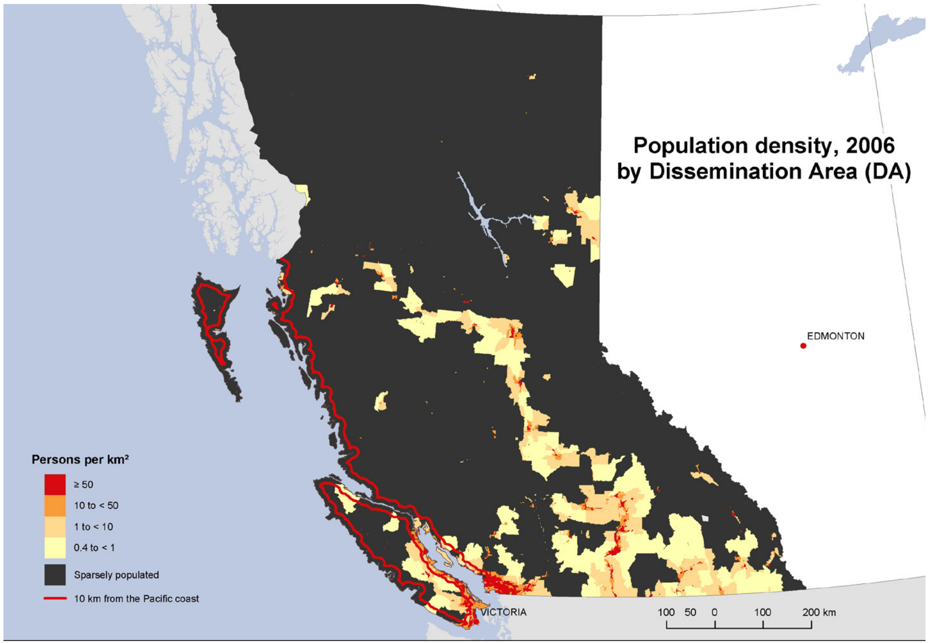
It will take time for engineers to develop procedures and processes to adequately deal with climate change, and maximize the likelihood that infrastructure being constructed today remains safe and effective for public use for the whole of its design life.

1.1 POPULATION

As of October 2014, British Columbia had a population of 4.7 million (Government of British Columbia, 2015a). The population is growing and becoming more urban, with the greatest growth in Greater Vancouver (Government of British Columbia, 2015b). In 1981, 22% of British Columbia's population resided in rural areas and by 2011 this had declined to 14% (Statistics Canada, 2011). While the total number of rural residents remained relatively constant over that period, at around 600,000, urban population grew from 2.1 million to 3.8 million.

Most of the province's population is concentrated in southern coastal areas (Figure 1). The Capital City of Victoria on southern Vancouver Island has a population of 327,000, while Greater Vancouver on the southern mainland of the province has a population of 2.4 million and comprises almost 60% of the province's population (Government of British Columbia, 2015b).

Figure 1: 2006 British Columbia Population Densities. The large population centres are located on the south coast, while mountainous and northern areas are very sparsely populated. (Source: Statistics Canada)



1.2 ECONOMY

In 2013, British Columbia had a Gross Domestic Product (GDP) of $215 billion, which represents about 13% of Canada's GDP (Statistics Canada, 2011). Historically, British Columbia's economic activity was based around natural resources including forestry, mining and fishing. While these sectors are still important, the service sector has grown in importance, now accounting for four out of five jobs. Key service sectors include: finance, insurance, real estate, transportation, retail and wholesale trade, tourism, education, and manufacturing.

British Columbia's economy depends heavily on trade, including international and interprovincial imports and exports (Table 1). Trade within the Asian Pacific region has increased significantly since 2001. With the growth of China as a global manufacturing centre, demand for British Columbia's natural resources has increased. In 2011 British Columbia exported more to the Pacific Rim than to the United States.

Increased demand from China and India have challenged British Columbia's transportation infrastructure to meet these emerging opportunities. This infrastructure has played a key role in international trade due to its strategic location. For example, Prince Rupert, Canada's closest port to the Asia Pacific Rim, saves up to 68 hours of shipping time compared to locations to the south, such as Long Beach in Los Angeles (Port of Prince Rupert, 2014).

Table 1: International and interprovincial trade in British Columbia in 2013. (Source: Statistics Canada, 2015a)

Trade Element		Value	Percentage of Provincial GDP
Exports	International	$49.2 billion	23%
	Interprovincial	$35.7 billion	17%
Imports	International	$57.8 billion	27%
	Interprovincial	$41.8 billion	19%

1.3 GEOGRAPHY

British Columbia's unique landscape strongly influences the province's transportation systems (Figure 2). Ground transportation routes generally follow river routes and mountain passes, rather than the straight-line alignments typical of many other areas of Canada. Thus, routes can be circuitous and often involve significant changes in elevation.

British Columbia includes ten ecoprovinces, defined as part of a provincial ecoregion classification system (Figure 3). Ecoprovinces are areas with consistent climate processes, oceanography, relief and regional landforms. Each has a unique climate and they exhibit different sensitivities to projected climate changes. The ecoprovinces generally align with the physiographic features of the province, as do the major transportation corridors. With this understanding, it is possible to evaluate how climate change trends in British Columbia may affect transportation systems based on generalized climate change projections for relevant ecoprovinces within the province.

Figure 2: Physiological features of British Columbia. (Source: Encyclopedia of British Columbia and KnowBC.com)

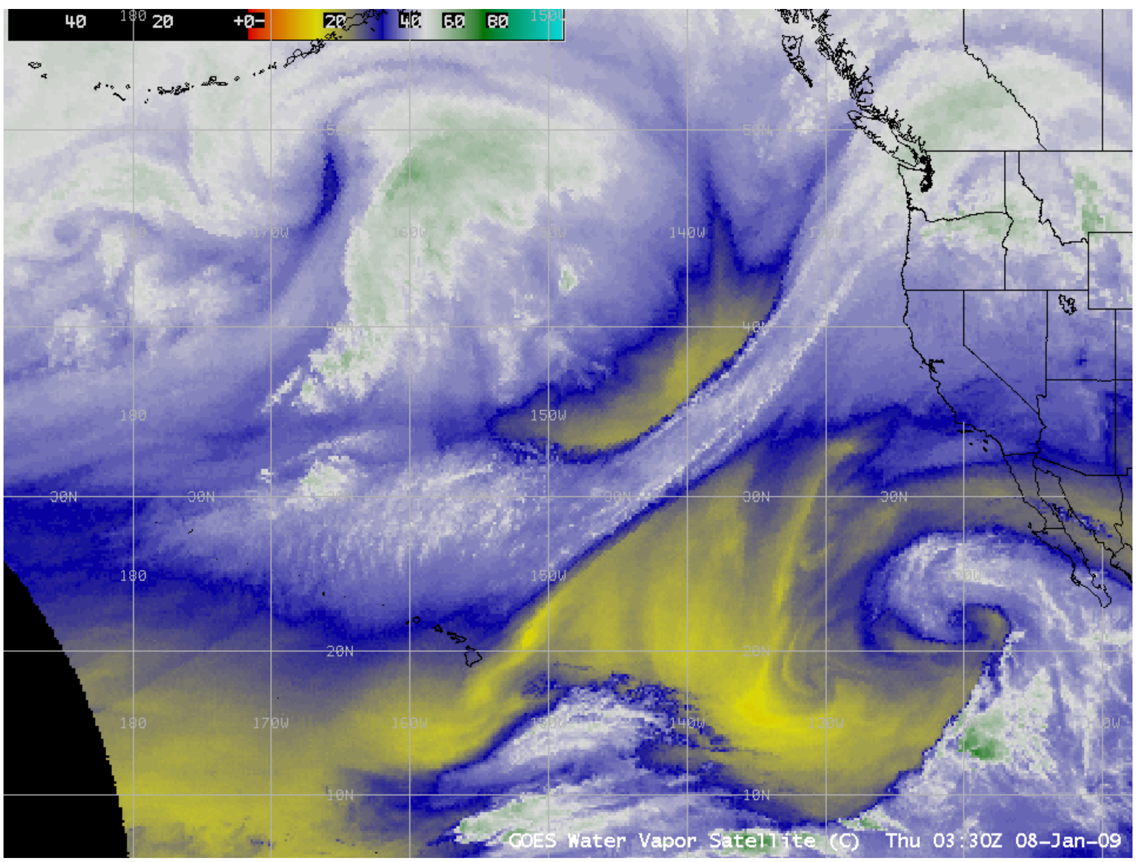
Figure 3: Ecoprovinces of British Columbia: Climatic zones of British Columbia. (Source: British Columbia Ministry of Transportation and Infrastructure)

2.0 CLIMATE

British Columbia's diverse landscape, including major mountain ranges, and proximity to the Pacific Ocean, strongly influence climate regimes in different parts of the province (Pacific Climate Impacts Consortium, 2013a). An important aspect of British Columbia's climate is a phenomenon known as "atmospheric rivers" that are associated with very heavy precipitation, and have had significant impacts on transportation systems. Atmospheric rivers are long narrow streams of high water vapour concentrations in the atmosphere that move moisture from tropical regions towards the poles across the mid latitudes. Pineapple Express is a term used to characterize an atmospheric river with origins in the western Pacific, east of Hawaii, flowing to and affecting the West Coast of North America between British Columbia and California (Figure 4). Atmospheric rivers are typically several hundred kilometers wide and thousands of kilometers long, and contain between 3 cm and 6 cm of water vapour in the middle of the stream (Pacific Climate Impacts Consortium, 2013a).

Atmospheric rivers occur most frequently in the fall and winter in British Columbia. Their impacts are greatest on coastal areas when the moist water vapor laden air rises over the Coast Mountains, resulting in intense precipitation. The impacts have been significant, for example, the January 2009 extreme event shown in Figure 4 lasted two days and cost nearly $16 million, while another two-day event in June 2011 resulted in flooding and cost more than $85 million. In 2012, 15 registered flooding events affected over 100 communities in British Columbia (Pacific Climate Impacts Consortium, 2013a).

Figure 4: Atmospheric River striking British Columbia on January 8, 2009. The colours in the image below represent "water vapour" in the middle to upper layers of the atmosphere. The shades of white to green are moist to cloudy and the shades of blue to yellow indicate increasingly dry areas. (Source: Cooperative Institute for Meteorological Satellite Studies / University of Wisconsin – Madison)



2.1 OBSERVED TRENDS

The Pacific Climate Impacts Consortium has done extensive work characterizing the current climate, identifying trends, and projecting future climate conditions for many regions in British Columbia. These reports provide an analysis of trends across the province for the period 1901 through 2009 (Table 2). Over this period, British Columbia has experienced shifts in both temperature and precipitation. These trends have accelerated since the 1950s. Overall, temperature across the province has increased by 0.18 °C per decade since 1951, an overall increase of 1°C. At the same time, the province has experienced generally wetter spring, summer, and autumn periods and significantly drier winters.

Table 2: Temperature and precipitation trends in British Columbia by ecoprovince. (Source: Pacific Climate Impacts Consortium, 2013b)

Ecoprovince	Temperature Trends (°C per Decade)		Precipitation Trends (mm/season per Decade)			
			1901–2009		1951–2009	
	1901–2009	1951–2009	SSA	W	SSA	W
Central Interior	0.13	0.20	3	3	3.7	-3
Southern Interior Mountains	0.12	0.16	5	4	7.7	-12
Taiga Plains/Boreal Plains	0.22	0.25	3.3	2	2.3	-1
Sub Boreal Interior	0.19	0.25	3.7	3	3.3	-3
Northern Boreal Mountains	0.16	0.21	3	4	2.3	-5
Georgia Depression	0.12	0.20	4.7	6	5	-13
Southern Interior	0.12	0.21	4.3	3	6.7	-6
Coast and Mountains	0.13	0.18	3	8	8	-6
Provincial Average	0.13	0.18	3.33	3.67	4.33	-5.44

SSA = Spring, Summer, Autumn
W = Winter

Relative sea level (relative to land height), has also been changing in British Columbia, with significant variability across coastal areas. For example, during the past 50 years, sea level rose by 3.1 cm at Victoria and 2.0 cm at Vancouver, but decreased by 8.4 cm at Tofino (Vadeboncoeur, 2016). A number of factors contribute to changes in ocean levels, including atmospheric and oceanographic effects, such as storm surges and climate-variability cycles (e.g., Pacific decadal oscillation) (Vadeboncoeur, 2016). One of the dominant factors affecting relative sea-level change in British Columbia is vertical land motion, which can be attributed to a combination of tectonic activity (interactions of the Juan de Fuca and Pacific oceanic plates with the North American plate), glacial isostatic adjustment (the ongoing movement of land that was once covered by glaciers from the last ice age), and changes in ice-mass in the Coast Mountains and Gulf of Alaska (Vadeboncoeur, 2016). Other factors that contribute to regional variability in sea levels include the influence of melting glaciers on nearby ocean waters and ocean surface topography alterations due to changes to ocean currents (Vadeboncoeur, 2016).

In addition to posing a long-term threat of coastal flooding, sea-level rise increases the risk of storm-surge flooding. Deeper water increases the height and energy of waves. Extreme high water levels, which typically occur as storm surges are superimposed on high tides, can be particularly destructive to coastal infrastructure.

2.2 PROJECTED CHANGES

The Plan2Adapt tool (Pacific Climate Impacts Consortium, 2013c), developed by the Pacific Climate Impacts Consortium, provides generalized climate change projections for British Columbia for three time horizons as well as for each of the ecoprovince designations based on a standard set of climate model projections (Tables 3 and 4). Projections are broadly consistent with observed climate trends (see Section 2.1). Overall, the climate in British Columbia will shift over the next 80 years with upwards of 2.7 °C of annual warming, wetter winters, generally drier summers and significantly longer frost-free periods.

Table 3: Projected changes in selected climate variables for the province of British Columbia for three time periods – the 2020s, 2050s and 2080s. Projected changes are relative to the historic baseline 1961-1990. The ensemble median is a mid-point value, chosen from a set of 15 Global Climate Model (GCM) projections for each of A2 and B1. (Source: Pacific Climate Impacts Consortium, 2013c)

Climate Variable	Season	Projected Change from 1961-1990 Baseline Ensemble Median		
		2020s (2010-2039)	2050s (2040-2069)	2080s (2070-2099)
Mean Temperature	Annual	+1.0	+1.8 °C	+2.7 °C
Precipitation	Annual	+4%	+6%	+9%
	Summer	+0%	-1%	+0%
	Winter	+4%	+8%	+13%
Snowfall	Winter	-2%	-10%	-12%
	Spring	-30%	-58%	-70%
Frost-Free Days	Annual	+10 days	+20 days	+30 days

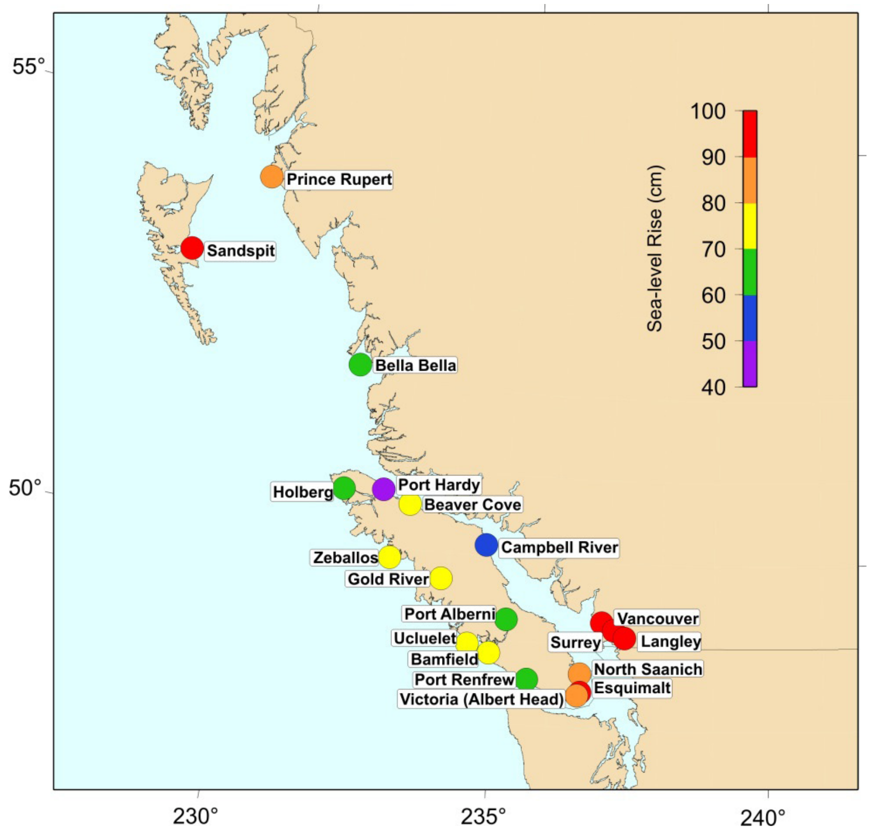
Table 4: Projected changes in selected climate variables by the 2080s for ecoprovinces in British Columbia. "+" denotes increase, "-" denotes decrease. (Source: Pacific Climate Impacts Consortium, 2013c)

Ecoprovince	Mean Annual Temperature Increase	Precipitation				Frost Free Days	Summary
		Annual	Summers	Winters	Snowfall		
Central Interior	+2.6	+	-	+	-74%	+35	Warmer, wetter winters Much drier summers
Southern Interior Mountains	+2.7	+	-	+	-69%	+34	Warmer, wetter winters Much drier summers
Taiga Plains	+3.0	+	+	+	-75%	+21	Warmer, wetter winters and summers
Boreal Plains	+2.8	+	No Change	+	-75%	+21	Warmer, wetter winters No change summer precipitation
Sub-Boreal Interior	+2.6	+	No Change	+	-75%	+30	Warmer, wetter winters No change summer precipitation
Georgia Depression	+2.6	+	-	+	-54%	+26	Warmer, wetter winters Drier summers
Southern Interior	+2.8	+	-	+	-75%	+37	Warmer, wetter winters Much drier summers
Coast and Mountains	+2.4	+	-	+	-71%	+35	Warmer, wetter winters Much drier summers

Climate change is not only associated with warming conditions, but also more extreme weather events such as high intensity rainfall (Murdock and Sobie, 2013). The Pacific Climate Impacts Consortium preliminary analysis indicates that the frequency of Pineapple Express events will increase by 2041-2070 with the largest increases on the coast. The average number of atmospheric river days per year is projected to approximately double at most locations, including the interior.

Projected changes in sea level in British Columbia (Figure 5) are similar to historic patterns (Section 2.1). The greatest amounts of sea level rise are projected to occur along the southern mainland and southeast Vancouver Island. The least amount of sea level rise is projected in areas where there is significant tectonic uplift, a non-climatic influence, described above in Section 2.1. Projections vary according to emissions scenarios, and changes in relative sea level could be negligible at some sites under a low emissions scenario.

Figure 5: 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; Atkinson et al., 2016). See Vadeboncoeur (2016) for additional information on sea-level projections. (Source: Natural Resources Canada)



3.0 OVERVIEW OF BRITISH COLUMBIA'S TRANSPORTATION SYSTEM

The British Columbia transportation system encompasses a variety of different modes, including roads and highways, rail, marine, air, and urban transit systems. The diverse hubs and networks related to these various modes act together to provide a cohesive transportation system that supports the people and economy of the Province of British Columbia, as illustrated in Figures 6 and 7. The alignment of the major transportation corridors and hubs along coastlines and within mountain passes and corridors is evident.

This chapter focuses on roads, rail, marine and air, with urban transit systems discussed in Chapter 9. While this chapter discusses each transportation mode individually, it is important to understand that they are heavily integrated. Weather impacts that adversely affect one mode of transportation can also have negative impacts on other modes.

3.1 ROADS

British Columbia has over 46,000 km of roads, including provincial highways (12,700 km) and side roads (33, 300 km) (British Columbia Ministry of Transportation and Infrastructure, 2014e; Figure 7), in addition to other municipal and federal roads. There are also over 2,800 bridges within the road system (British Columbia Ministry of Transportation and Infrastructure, 2014e).

Figure 6: Principle transportation infrastructure in British Columbia, including permafrost zones.

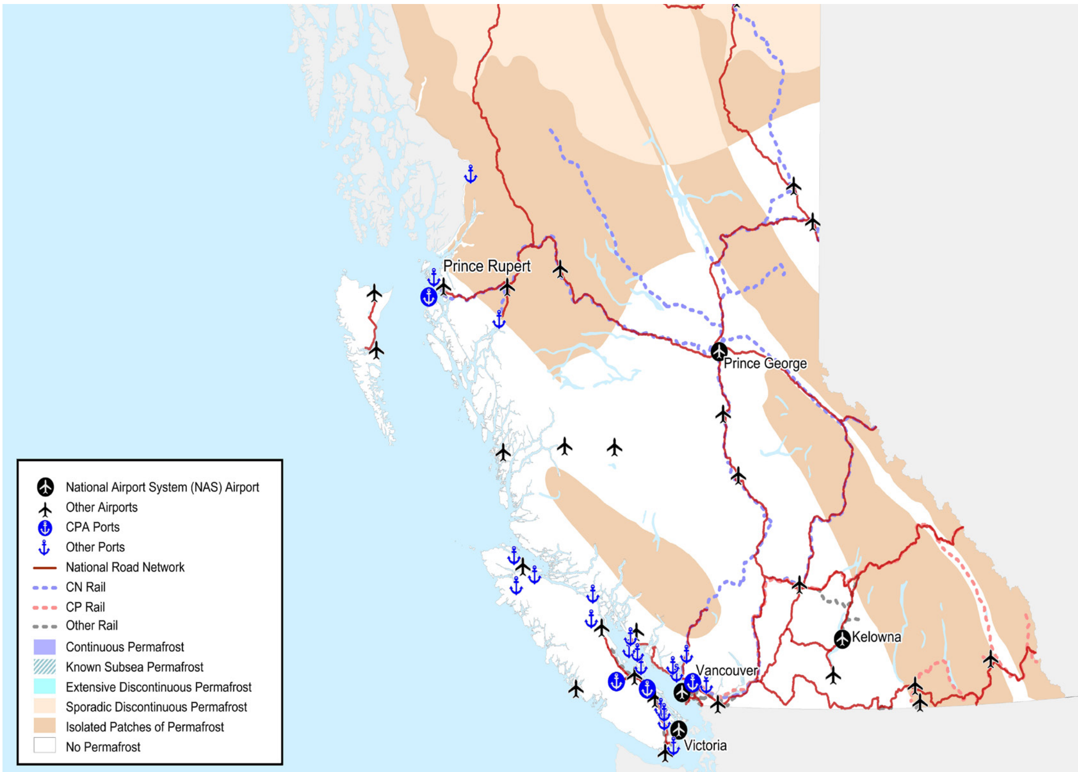
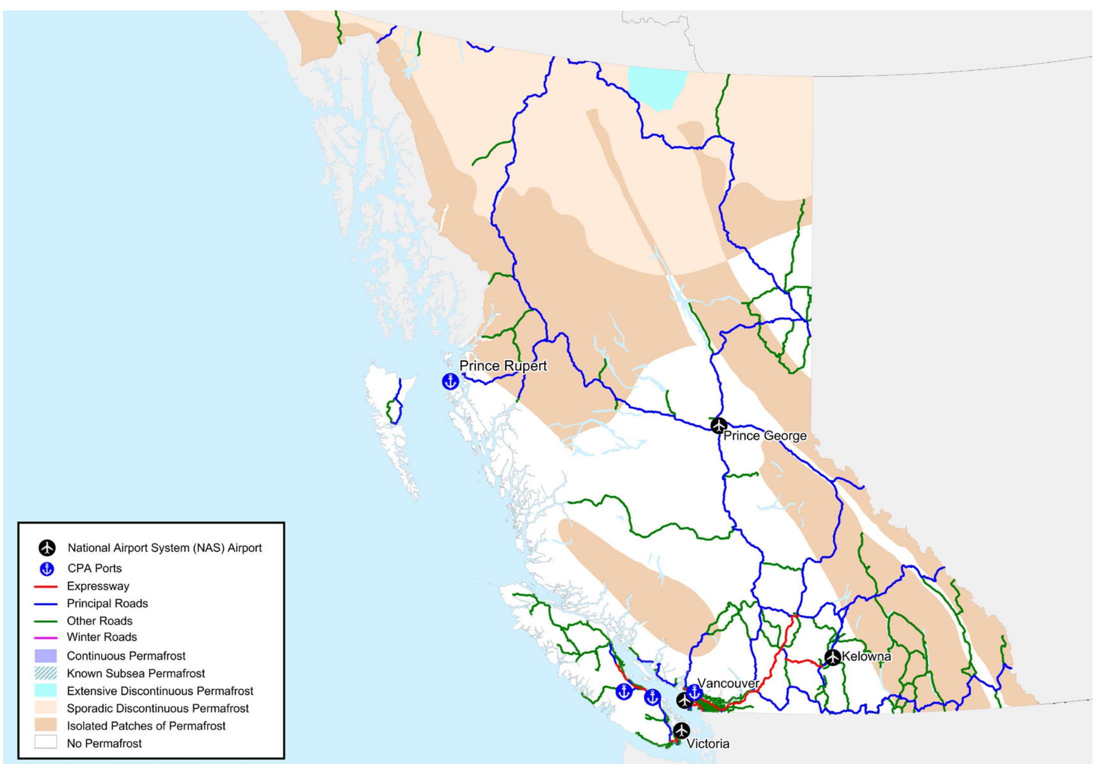


Figure 7: Road infrastructure in British Columbia.



In 2013, there were three million registered on-road vehicles in British Columbia, representing 13 percent of the Canadian total on-road vehicle registrations that year. This includes 2.7 million light-duty vehicles (automobiles, SUVs and lighter trucks), or approximately one vehicle for every 1.7 people in the province (Statistics Canada, 2015b). The province's population is, therefore, highly dependent upon the road system. Climate-induced interruptions in road service can have a significant impact on the lives and livelihood of the people of British Columbia.

3.2 RAIL

British Columbia has approximately 6,500 kilometers of railway (Figure 6), primarily served by Canadian National (CN) Rail (~4,400 km) and Canadian Pacific (CP) Rail (~1,720 km). Regional railways comprise another 402 km of track. This extensive infrastructure is designed to facilitate the efficient flow of goods through the Asia Pacific Gateway. The railways provide 24-hour, year-round service to port and terminal networks in Vancouver and Prince Rupert.

CN's main rail routes in British Columbia run from Vancouver to Edmonton, Alberta from Fort Nelson to Vancouver, and from Prince Rupert to Edmonton. CN Rail employs three Intermodal terminals in the province, located in Vancouver, Prince George, and Prince Rupert (CN, 2015). CN also operates an intermodal service from Prince Rupert, British Columbia to Whittier, Alaska. Called the AquaTrain, rail cars are loaded onto a barge directly and transported. Alaska is completely dependent on CN Rail AquaTrain service for its freight transport, as this service is connected to all Alaskan Freight train routes (Alaskarails, 2015). CP's main rail route runs from Vancouver to an Intermodal Terminal in Calgary, Alberta, and the company has one intermodal terminal in Vancouver (CP, 2015).

In 2013, the British Columbia rail system moved 63 million tonnes of commodities, representing over 20 percent of the Canadian total (Statistics Canada, 2015c). Of these, the principal commodities, by tonnage, were coal, lumber and wood products, sulphur, cement, automobiles, and wheat. Many of the commodities reflect the resource-based nature of the British Columbia economy, and indicate the impact of trade with the Pacific Rim.

In addition to freight services, VIA Rail offers passenger services along two corridors, from Toronto, Ontario to Vancouver (The Canadian) (Via Rail, 2015a) and from Jasper, Alberta to Prince Rupert, British Columbia (Western Canada) (Via Rail, 2015b).

3.3 AIR

There are 39 airports in British Columbia which are federally certified for passenger service, in addition to 251 registered land-based airports, aerodromes, heliports and water aerodromes (Transport Canada, 2015; Government of British Columbia, 2016a). Certified airports include Vancouver, the second busiest airport in Canada, Victoria the tenth busiest and Kelowna the eleventh busiest (Travel BC, 2016). (See Figure 6 for principle airports). Vancouver International Airport (YVR) handles over 19 million passengers and more than 256, 900 tonnes of cargo in 2014 (Vancouver Port Authority, 2014). Airport expansion plans are expected to increase capacity.

3.4 MARINE

British Columbia has three international ports, four regional ports, and 40 local ports (see Figure 6 for principle ports). Port Metro Vancouver is Canada's largest and busiest marine port, representing trade in excess of $187 billion annually with more than 160 countries (Port Metro Vancouver, 2014), and adding approximately $10.5 billion to the national economy (Government of British Columbia, 2011a). The three container ports in Vancouver, Prince Rupert and Nanaimo are interconnected with rail and road systems, as are major ports at Kitimat and Squamish. The ports of Stewart, Port Alberi, and Victoria have only road connections. Prince Rupert is the terminus of the Pacific Gateway Northern Corridor with capacity of 750,000 TEUs – container shipments are measured in 20-foot equivalent units, or TEUs, which represent one standard-sized shipping container (Government of British Columbia, 2011b; World Bank Group, 2016)). Vancouver is the terminus of the Pacific Gateway Southern Corridor handling upwards of 2.9 million TEUs of container traffic annually (Port Metro Vancouver, 2015a).

In 2010, the province's marine ports handled:

- 85 million tonnes of cargo traffic; and
- 2.86 million TEUs of container traffic *(Government of British Columbia, 2011c)*.

Principal exports, by tonnage were coal, forest products, grain, potash, petroleum products, and metals, minerals, and chemicals. Principal imports included: automobiles, household goods, construction materials, machinery, produce, base metals, and beverages. British Columbia's marine ports also handle a significant volume of passenger traffic. For example, in 2014 the Port of Vancouver handled 812,000 cruise ship passengers (Port Metro Vancouver, 2015b).

Ferries are another key element of the province's marine transportation system. 7.7 million vehicles were transported by ferry through the province's ferry system in 2014, representing 19.8 million passengers on 171,000 sailings (British Columbia Ferry Services Inc., 2015). BC Ferries, formerly a crown corporation and now a commercial organization, has 35 vessels and 47 ports of call providing passenger and cargo services to coastal locations in British Columbia. Ferry connections to the United States from British Columbia include the Alaska Marine Highway System, providing transport between Prince Rupert and South East Alaska. In the South, vessels between British Columbia and Washington State provide service to coastal and island locations. Inland Ferries transport passengers and cargo across rivers and lakes on the mainland. Other vessels such as water taxis also provide transport to various locations.

The next section discusses historic climate impacts, future climate risks and adaptation practices as they relate to road, rail, air and marine transport in British Columbia. Discussion of historic impacts includes several case studies of specific climate events.

4.0 ROAD SYSTEMS

4.1 HISTORIC CLIMATE IMPACTS

British Columbia highways have exhibited clear vulnerability to extreme rain events that have caused road washouts, mudslide blockages and bridge closures. Heavy precipitation can cause flooding in rivers and creeks and may also trigger debris flows that can block roads, and clog culverts leading to road washouts. Debris can also accumulate at bridge structures, potentially leading to bridge failures. In some instances, these events can isolate communities from their principle lines of supply.

Three events, which all resulted in washouts of road infrastructure systems, are highlighted here to illustrate the climate sensitivities of British Columbia's highway infrastructure. The locations of these events have subsequently been the focus of detailed vulnerability assessments by the British Columbia Ministry of Transportation and Infrastructure (see Section 4.2).

BELLA COOLA - SEPTEMBER 2010

On September 25th and 26th, 2010 an intense frontal system stalled over the Central British Columbia coast, bringing heavy rainfall exceeding the 1-in-200 year rainfall of 200 mm (TranBC, 2016). The rainfall resulted in washouts and rock falls which, along with flooding, closed Highway 20 between Tatla Lake and Bella Coola (Figure 8). The route was impassable at 12 locations, as 12.5 kilometres of Highway were damaged, underwater or simply gone. The impact of the road closure on local communities was made worse by other consequences of the storm as residents depended on diesel to generate electricity for heat, water and other vital services. Highway access to Tatla Lake and Bella Coola was not fully restored for 17 days and resulted in transportation repair costs of $45 million.

Figure 8: Bella Coola: Highway 20 Flood Impacts – Sallompt Road bridge approach washout.
(Source: British Columbia Ministry of Transportation and Infrastructure)

PINE PASS - JUNE 2011

Fifteen sites along Highway 97 in the Pine Pass were damaged during a 1-in-100-year rainfall event on June 25th and 26th, 2011 (British Columbia Ministry of Transportation and Infrastructure, 2014a). Damages included road washouts and flooding (overtopping) of bridges (Figure 9). The storm affected the entire Peace Region of British Columbia, with major floods and washouts damaging more than 280 sites on about 140 roads. Road access, north of Prince George was closed, restricting tourist travel between British Columbia and Alaska. Transportation infrastructure repairs arising from this storm took through the summer of 2012 to complete and resulted in repair costs of $80 million.

Figure 9: Pine Pass: Highway 97 Flood Impacts – Blocked road access between Pine Pass and Chetwynd. (Source: British Columbia Ministry of Transportation and Infrastructure)

STEWART - SEPTEMBER 2011

In early September 2011, 333 mm of rain fell in the Stewart region of British Columbia, including 111 mm of rainfall in a single 24-hour period (Fraser Basin Council, 2015). The event caused significant flooding and resulted in road washouts and bridge failures, including a failure of the bridge at Bitter Creek (Figure 10). Washouts and the damage at this bridge closed 61.5 km of Highway 37A from Stewart to the Meziadin Junction with Highway 37. The bridge failure isolated the town of Stewart from the rest of British Columbia, stranding 117 tourists and vehicles. Tourists needed to be air-lifted to Prince Rupert while vehicles were shipped out of the region by barge. A temporary bridge was constructed by the British Columbia Ministry of Transportation and Infrastructure, which was later replaced by a permanent structure. Transportation damages arising from this storm event resulted in $7 million in response costs and $11 million in repair costs that continued through the summer of 2012 to complete.

Figure 10: Stewart: Highway 37A Flood Impacts – Bitter Creek bridge failure. (Source: British Columbia Ministry of Transportation and Infrastructure)

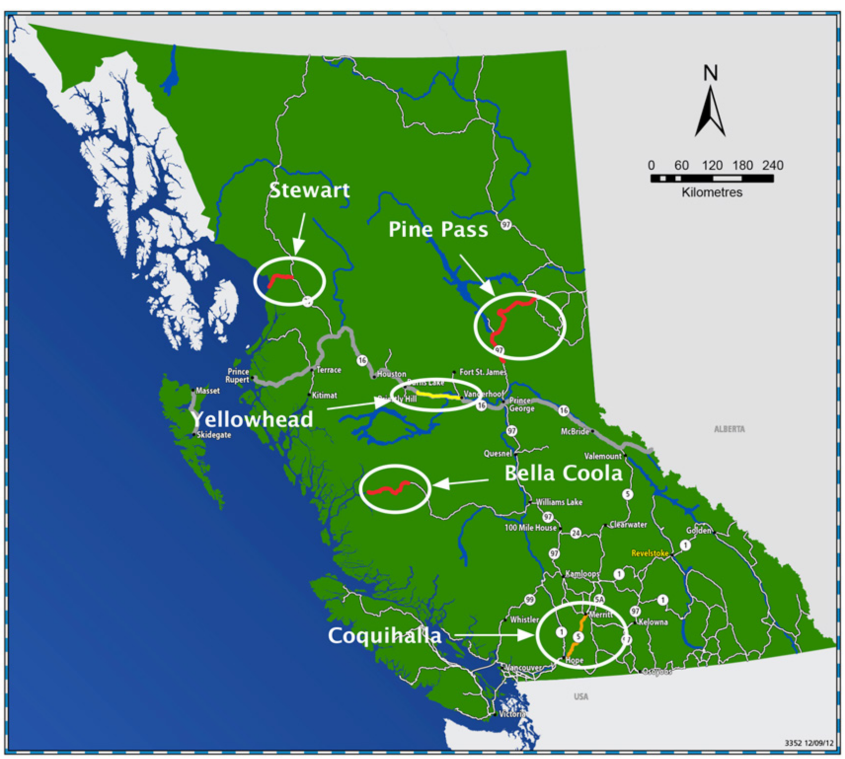
4.2 FUTURE CLIMATE RISKS

The British Columbia Ministry of Transportation and Infrastructure has completed five assessments using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol (see Box) to determine vulnerability to road transportation infrastructure in British Columbia from future changes in climate, and identify potential adaptation measures (Table 5, Figure 11) (British Columbia Ministry of Transportation and Infrastructure, 2014b). The assessments covered a broad range of geographic and climatic conditions.

Table 5: British Columbia Ministry of Transportation and Infrastructure vulnerability assessments. (Source: British Columbia Ministry of Transportation and Infrastructure, 2014b)

Ecoprovince	Highway	Location	Date completed
Southern Interior	Coquihalla Highway (B.C. Highway 5)	Between Nicolum River and Dry Gulch	June 2010
Sub-Boreal Interior	Yellowhead Highway 16	Between Vanderhoof and Priestly Hill	April 2011
Coast and Mountains	Highway 20	Bella Coola region	Sept. 2013
Coast and Mountains	Highway 37A	Stewart region	Sept. 2013
Sub-Boreal Interior	Highway 97	Pine Pass Region	Sept. 2013

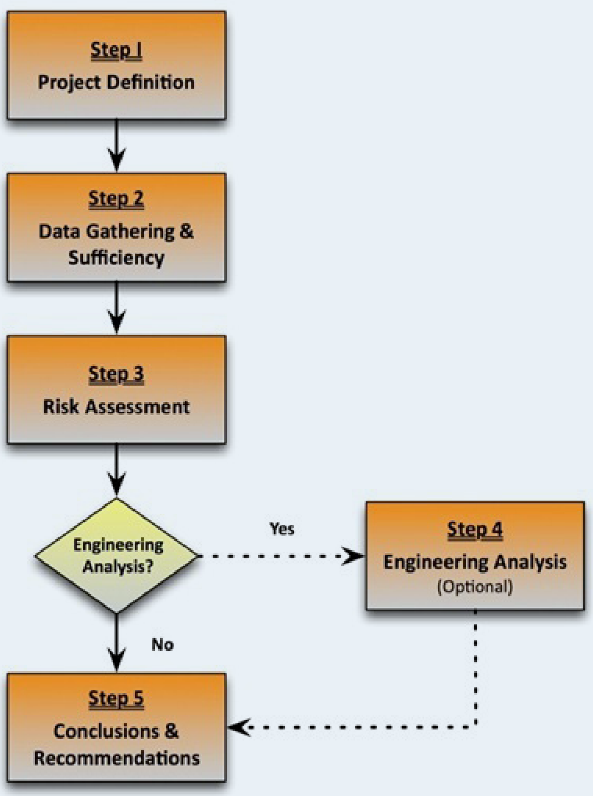
Figure 11: Locations of British Columbia Ministry of Transportation and Infrastructure Climate Change Vulnerability Assessments. (Source: British Columbia Ministry of Transportation and Infrastructure)



The **Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol**, led by Engineers Canada, was developed as a 5-step process to analyze the engineering vulnerability of individual infrastructure systems based on current climate and future climate projections (see Figure 12). Since 2012, the PIEVC Protocol has been applied to a wide variety of infrastructure types, including roads and airports.

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

Figure 12: Engineers Canada PIEVC Protocol Process. (Source: Engineers Canada)



The Coquihalla and Yellowhead highway assessments considered a very broad range of infrastructure components and climate parameters, including:

- High and Low temperatures;
- Freeze / Thaw cycles;
- Frost / Frost Penetration;
- Rainfall - Total Annual; Extreme High; Sustained
- Snow Frequency; Snow Storm / Blizzard;
- Rain on Snow; Hail / Sleet; Rain on Frozen Ground;
- High Wind / Downburst;
- Rapid Snow Melt; Snow Driven Peak Flow Events (Freshet);
- Ice / Ice Jams; and
- Ground Freezing.

Results of these two assessments identified a common vulnerability - the impact of extreme rainfall, such as high-intensity, short-duration (HISD) rainfall events, on highway drainage infrastructure (see Box). This risk was more pronounced on the Coquihalla Highway study location, where the increasing future intensity and frequency of atmospheric river events was identified as a very significant vulnerability. A similar pattern of risk was identified for the Yellowhead Highway (British Columbia Ministry of Transportation and Infrastructure, 2014c).

As a result of these findings, and in consideration of recent extreme precipitation events in British Columbia that had damaged highway infrastructure, the remaining three highway assessments focused on extreme rainfall and other drainage challenging events.

CALCULATING EXTREME RAINFALL VALUES FOR INFRASTRUCTURE VULNERABILITY ASSESSMENTS

Extreme rainfall event design values are not always readily available for vulnerability assessments, especially for older infrastructure or through climate projection work. The values used for vulnerability assessments depend on the infrastructure system design, which in the past has relied on historical climate information for extreme events. They can vary significantly depending upon the location, topography, local and historical weather and climate conditions and the infrastructure involved. For example, the Coquihalla Highway assessment identified an extreme rainfall intensity event as >76 mm of rain over a period of 24 hours, while the Yellowhead Highway and highways 20, 37A and 97 assessments used 24 hour rainfall values of >35 mm and >98 mm, respectively, to define extreme rainfall. While the general projections outlined in Section 3 provide a starting point for this type of analysis, they are only the first step of a more focussed analysis necessary to answer questions about specific infrastructure systems.

Table 6: Summary of Findings from British Columbia Ministry of Transportation and Infrastructure Vulnerability Assessments. (Source: British Columbia Ministry of Transportation and Infrastructure, 2014b)

Vulnerability Assessment	Summary of Findings
Coquihalla	All high level vulnerabilities identified for this highway segment were associated with HISD events. HISD events also dominated the medium vulnerability outcomes.
Yellowhead	80% of the higher vulnerability items were related to HISD events. Other vulnerability factors identified included: • Bridge structure sensitivities to high temperature; • Sensitivity to freeze/thaw impacts on winter maintenance; and • Sensitivities to spring freshet impacts on culvert systems.
Bella Coola	Higher vulnerabilities were associated with the impact of freshet conditions on protection works and bridge end fill. Within the medium vulnerability category, 27% were related to HISD events. The remainder were associated with freshet events. These events are seen to challenge protection works, stabilization works and drainage elements in a very similar fashion to HISD events.
Stewart	Same results as Bella Coola; 26% of vulnerabilities related to HISD events.
Pine Pass	High vulnerabilities were associated with the impact of freshet conditions and HISD events on protection works and bridge end fill and third party utilities. Of the high vulnerabilities, five were directly related to HISD events while the others were associated with freshet conditions. Within the medium vulnerability category, 53% were related to HISD events. The rest were associated with freshet events. These events are seen to challenge protection works, stabilization works and drainage elements in a very similar fashion to HISD events.

All five highway segments examined also exhibited vulnerability to snowmelt driven peak flow events (freshet conditions). Such conditions generated risk profiles very similar to those associated with extreme precipitation – with generally increased risk of failure of drainage appliances, culverts and stabilization works (British Columbia Ministry of Transportation and Infrastructure, 2014b). These and other potential vulnerabilities identified through the assessments are listed in Table 6).

4.3 ADAPTATION PRACTICES

As a result of its climate change vulnerability studies, the provincial Ministry of Transportation and Infrastructure now requires infrastructure design work for the Ministry to include climate change implications. This includes a design criteria sheet where the designer indicates climate design baseline information, any additional climate change factors, and how the design will accommodate these climate changes over the infrastructure's service life. British Columbia is one of the first jurisdictions to require specific climate change adaptation measures to be included in infrastructure design work.

The Ministry of Transportation and Infrastructure also provides tools which can reduce safety risks to road users posed by extreme weather. Its DriveBC program aims to improve highway safety, by providing better real-time travel information for provincial highways on extreme weather conditions, road work, and closures. Since the program started in 2005, it has become the Ministry's most popular online tool (British Columbia Ministry of Transportation and Infrastructure, 2015).

5.0 RAIL TRANSPORT

5.1 HISTORIC CLIMATE IMPACTS

Severe weather conditions that affect freight rail services in British Columbia can significantly affect the transportation of goods in Canada and potentially international trade. The rail industry in British Columbia has a long history of managing the effects of weather conditions on its operations. A review of Transportation Safety Board of Canada (TSB) reports reveals an ongoing and evolving pattern of rail incidents associated with climate events, in particular high precipitation events in British Columbia's transportation corridors. The British Columbia rail system has experienced incidents related to extreme precipitation, spring runoff and drainage. These events can undermine railroad beds and are significant factors contributing to mud and rockslides that impact rail systems and equipment.

Three weather-related incidents, associated with varying degrees of infrastructure damage, environmental impacts and injuries to railroad personnel, are highlighted here and could be used as a foundation to evaluate the potential for climate change to exacerbate conditions that have historically led to interruptions in rail services. All three incidents arose from precipitation and drainage issues.

CONRAD – MARCH 1997

On March 26, 1997, a Canadian National (CN) train encountered a large roadbed depression near Conrad, British Columbia and derailed. The CN locomotive engineer and conductor were fatally injured, fourteen freight cars and two locomotives were damaged beyond repair and 1,200 feet of track and siding was destroyed (Figure 13). Leaking fuel ignited and resulted in a fire that made firefighting difficult and required helicopter water-bombing to contain.

Figure 13: Conrad, British Columbia train derailment. Collapse of the railroad subgrade was caused by extreme precipitation. (Source: Transportation Safety Board of Canada)

The investigation report for this incident provides extensive detail about the preceding weather conditions that led to this derailment (Transportation Safety Board of Canada, 1998). The key points from this analysis indicate that the period between October 1996 and March 1997 was the wettest six-month period in 59 years. March 26, 1997 was the 41st day of runoff from melting snow in the region. However, the rate of melting snow suddenly increased between March 17 and 19 when a rain on snow event occurred. The report concluded that the depression was caused by:

1. High seasonal runoff that was not managed by drainage systems above the adjacent Trans-Canada Highway; and
2. Water saturating the ground through the highway fills, infiltrating and destabilizing the railroad subgrade, which then collapsed.

KOMO – NOVEMBER 2009

On November 17, 2009, a Canadian Pacific (CP) freight train travelling west between Boston Bar and Vancouver struck a debris slide consisting of rock, mud and trees. The locomotive and three cars loaded with copper concentrate derailed (Figure 14). The locomotive engineer and conductor sustained non-life-threatening injuries. At the time of the incident, the area was experiencing very heavy rainfall, caused by an atmospheric river event.

The slide occurred during a period of heavy rain (Transportation Safety Board of Canada, 2010). Large volumes of water transited through a highway culvert located above the affected track. While the culvert had sufficient capacity to handle the water volume, diversion features downstream of the culvert were overtopped and significant volumes of water established an alternate channel that impacted the train tracks at a location where there were no culverts. The diversion resulted in rock, debris and mud being carried downslope and onto the track below.

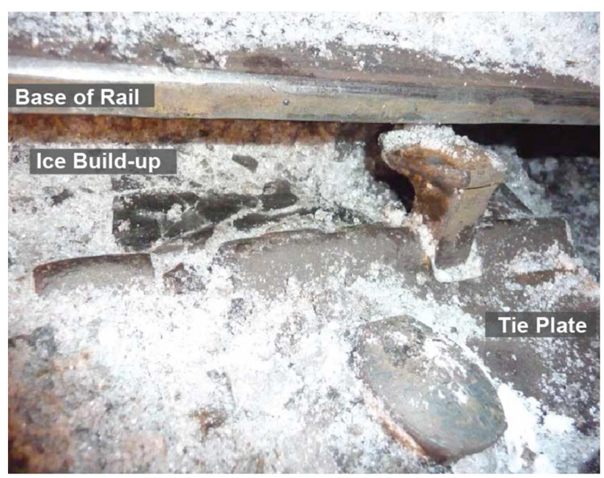
Figure 14: Komo, British Columbia train derailment caused by debris flow onto train tracks. (Source: Transportation Safety Board of Canada)

FERNIE – MARCH 2011

On March 8, 2011, twenty-seven rail cars loaded with coal derailed near Fernie, British Columbia. There were no injuries.

The TSB attributed the failure to rail rollover, resulting in excessive wide gauge (Transportation Safety Board of Canada, 2012). The rail gauge canted outward as a result of ice build-up between the base of the rail and the tie plates (Figure 15). The area had experienced numerous freeze-thaw cycles over the previous four weeks, which drew snowmelt water to the base of the rail through the pumping action of passing trains. The TSB report also notes *that between February 11 and 20, the ambient temperature was above 0°C during the day and below freezing at night. There were 23 millimetres of rain, between February 11 and 14, followed by snow accumulation of about 58 centimetres between February 15 and 17. After February 17, through the end of the month, the temperature was below freezing and as low as -32°C.* While this incident was attributed to freeze-thaw, the root cause was high levels of snow, contributing to snow-melt accumulation at the base of the tracks. This, combined with cycling between temperatures above and below the freezing point, contributed to the failure.

Figure 15: Fernie, British Columbia rail track showing ice build-up. (Source: Transportation Safety Board of Canada)



There are many other examples of incidents that demonstrate the sensitivity of rail transport in British Columbia to extreme precipitation. High-level summaries of ten other similar incidents over the period 1995 to 2009 are presented in Table 8.

Table 8: Summary of British Columbia rail incidents related to weather conditions (1995-2009).

Date	Location	Description	Citation
Jan 1995	Procter	• CP freight train struck fallen rock near Procter. Three locomotives and two cars derailed and fell 125 feet into Kootenay Lake. • Two fatalities due to drowning. • Sulphur and diesel fuel spilled into lake. • Attributed to pressure from tree roots, freeze/thaw cycles and surface runoff.	TSB Report No. R95V0017 Procter – Jan 20. 1995
May 1998	Creston	• CP freight train encountered roadbed depression, derailing three locomotives and eight gondola cars. • Silver/lead concentrate and diesel fuel were released, and later recovered. • Attributed to record rainfall, performance of drainage system, steep side hill slope and susceptibility of subgrade fill to water changes.	TSB Report No. R98V0100 Creston – May 31, 1998
Nov 2004	Ruby Creek	• CN train hit rockslide. • Fuel tank on locomotive ruptured resulting in fuel oil spill into Fraser River.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A
Dec 2004	Glen Valley	• CN train stuck by mudslide. Eight cars derailed.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A
Aug 2005	Lasha	• Landslide struck CN train. Nine cars derailed.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A
Oct 2005	Yale	• CN freight train hit landslide. Two locomotives and seven flat cars derailed. Locomotive leaked fuel oil beside Fraser River. One crewmember sustained injuries requiring hospitalization.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A
Jan 2006	Albion	• Two locomotives of a CP train derailed upright as a result of a landslide.	TSB Report No. R09V0235 Komo – Nov 17, 2009, , Appendix A
Jan 2007	Lasha	• CN train struck landslide derailing two locomotives and first car.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A
Jan 2007	Inkitsaph	• CN train locomotive derailed upon striking landslide.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A
Jul 2008	Lasha	• Four cars loaded with ethylene glycol derailed when struck by a mudslide.	TSB Report No. R09V0235 Komo – Nov 17, 2009, Appendix A

5.2 FUTURE CLIMATE RISKS

As rail corridors in British Columbia tightly parallel highway routing, with transportation corridors sharing mountain passes and routing along rivers, it is not uncommon for drainage failure events on one system to also negatively affect the other. In several of the case studies considered previously, failures on road system components resulted in mudslides onto the rail system. Therefore, severe weather events that negatively affect one system may have simultaneous impacts on others.

Climate change work by British Columbia's Ministry of Transportation and Infrastructure indicates that in these same corridors, highways will continue to be affected by intense precipitation events leading to drainage component failure and slope instability, and that these events are anticipated to increase both in frequency and intensity into the future. Given the close proximity between road and rail in British Columbia and the history of sequential and coincident failure of these systems, it is reasonable to project similar patterns of vulnerability for the rail system.

5.3 ADAPTATION PRACTICES

While specific references to rail companies conducting climate change assessment and adaptation work in British Columbia were not identified in the literature, it was observed that rail companies in British Columbia are making considerable effort to address the impacts of severe climate events, including extreme precipitation. The recommendations that arise from these investigations and follow up activities are very similar to those that may arise from focussed climate change assessment analyses. The forensic analysis conducted as part of the TSB investigation process is a critical input to climate change adaptation assessment, such as the work conducted by the British Columbia Ministry of Transportation Infrastructure for the province's highway system. Examples of these actions are listed in Table 9.

Table 9: Example follow-up actions from TSB Reports.

Date	Location	Follow Up	Citation
Jan 1995	Procter	CP: • Provided employees instruction on basic rock slope inspection, principles of rock slope stability, and methods for stabilization and protection; • Extended annual rock slope inspections; • Initiated aerial inspections to evaluate rock slope features at higher elevations; • Established a procedure to evaluate and catalogue a broader range of mitigative measures for rock slope instability.	TSB Report No. R95V0017 Procter – Jan 20. 1995
Mar 1997	Conrad	CN: • Constructed additional surface drainage works at Conrad, and installed a prototype washout detector; • Used aerial photographs to identify sites at Thompson/ Fraser geologically similar to Conrad; inspected those sites and installed drainage improvements; • Conducted geotechnical subsurface investigations at selected locations and installed instruments (pneumatic piezometers) to measure groundwater pressures; • Developed a slope-monitoring assessment procedure to report all incidents related to rockslides and landslides to the geotechnical department for action or for data to assess long-term stability of soil slopes.	TSB Report No. R97V0063 Conrad – Mar 26, 1997

Date	Location	Follow Up	Citation
May 1998	Creston	CP: • Provided training on rock and soil slope stability to track maintenance supervisors; • Initiated a new culvert inspection policy requiring that culvert inspections be carried out annually; • Contracted the services of World Weather Watch for a warning system to provide detailed, accurate weather forecasts, and notification of severe weather, referenced to track mileage and station; and • Instructed railway safety inspectors to focus on drainage issues and review railway maintenance practices in territories susceptible to slope instability.	TSB Report No. R98V0100 Creston – May 31, 1998
Nov 2009	Komo	CN and CP: • Monitor Fraser Canyon corridor and conduct regular inspections by geotechnical engineers/geologists; and • Engage in research to improve detection of rock falls and slides. CN: • Installed an Emergency Slope Washout System in the Komo area. • Implemented a protocol for local supervisors to contact CN and CP during rain events, periods of extraordinary runoff, and other potentially damaging weather systems and to notify railway contacts of any specific problems.	TSB Report No. R09V0235 Komo – Nov 17, 2009
Mar 2011	Fernie	CP: • Installed rolled tie plates and new rail at the derailment site; and • Moved the 30 mph speed sign to ensure that trains complete braking prior to reaching this curve, reducing the lateral loading on the curve. TSB: • Established a minimum frequency requirement for the electronic geometry inspection of all tracks.	TSB Report No. R11V0057 Fernie – Mar 8, 2011

Many of these sample actions are the type of recommendations that arise from focused vulnerability assessments. Actions cover a range of research, monitoring, procedural, maintenance, reporting and engineering activities. From this, we can conclude that rail companies in British Columbia are conducting activities to reduce climate risks (see Box). The TSB and rail companies extrapolate from forensic analyses of climate related failure events to establish generalized actions and approaches to mitigate the risk of such events throughout the rail system in general.

RAIL INDUSTRY APPROACH TO CLIMATE CHANGE (MICHAEL GULLO, RAILWAY ASSOCIATION OF CANADA, PERSONAL COMMUNICATION, 2015)

Railway capital investments address a variety of issues and challenges, including how extreme weather events such as flash flooding, avalanches, washouts, and freezing~~,~~ can lead to service disruptions within and around the railway network. To ensure the efficient movement of traffic, railways invest significantly in track infrastructure upgrades, execute seasonal readiness plans, test natural hazard warning systems, undertake regular rail inspections, and ensure processes are in place to mitigate against, and to recover from, severe weather situations. A variety of technologies are applied to determine the status of rail infrastructure and the landscape it traverses, including:

- Radar interferometer to measure track stability,
- Vulnerability assessment of risk area and GIS mapping,
- Landslide mapping; temporal and spatial,
- Geotechnical assessment of slopes,
- Laser movement detection system,
- Fiber optic detection for slope movement,
- River hydraulic studies; and,
- Beaver dam assessment and management.

For planning and operations, the rail sector generally uses short-term weather forecasts/ considerations, rather than long-term climate projections. Rail companies are concerned about climate change in terms of the potential for more frequent and/or intense severe weather phenomena, as these may cause catastrophic risk to the railway network and its operations. The Railway Association of Canada and the American Association of Railroads have both established Environment Committees that include extreme and inclement weather events within their mandates.

As with other transportation modes, the rail sector requires a scientific and fact-based approach to help them identify where climate change impacts are expected to occur in the short, medium and long term. With this knowledge, adaptation efforts within the sector can be targeted, and ultimately more strategic.

6.0 AIR TRANSPORT

6.1 HISTORICAL CLIMATE IMPACTS

Climate affects air transportation systems in many ways, including: 1) accidents where weather conditions have contributed to the causes; 2) service interruptions that have been caused by weather; and, 3) impacts on physical infrastructure systems.

WEATHER-RELATED ACCIDENTS

The air industry has a long history of managing and coping with weather conditions and has established standard procedures for accessing weather forecast information and incorporating that information into flight planning (Klock and Mullock, 2001). Impacts of severe weather are normally managed through avoidance practices, resulting in flight delays and through advancements in technology that incorporate advanced aircraft instrumentation systems. The result is a very low frequency of weather-related accidents.

In British Columbia, only seven aircraft incidents with weather related contributing factors over the last thirteen years have been of sufficient magnitude to warrant TSB investigation (Table 10).

Table 10: Summary of Aircraft Incidents Related to Weather Conditions.

Date	Incident	Contributing weather factors
Jun 6, 2002	Collision with Terrain, Needle Peak, BC (Transportation Safety Board of Canada, 2003)	Adverse weather in mountainous terrain
Jan 19, 2005	Control Difficulty Due to Airframe Icing, Kelowna, BC (Transportation Safety Board of Canada, 2005)	Severe in-flight icing conditions
Mar 8, 2006	Runway Overrun—Collision with Terrain, Powell River, BC (Transportation Safety Board of Canada, 2007)	Downwind conditions on approach; hydroplaning
Feb 7, 2008	Loss of Visual Reference / Collision with Terrain, Golden, BC (Transportation Safety Board of Canada, 2008)	Poor visibility
Mar 17, 2012	Runway Excursion, Blue River, BC (Transportation Safety Board of Canada, 2013c)	Deteriorating weather
Jun 1, 2012	Loss of Visual Reference and Collision with Terrain, Terrace, BC (Transportation Safety Board of Canada, 2013b)	Poor visibility
Aug 13, 2012	Collision with Terrain, Kelowna, BC (Transportation Safety Board of Canada, 2013a)	High-density altitude conditions and reduced visibility.

The TSB reports demonstrate that, historically, weather is rarely the sole cause of aircraft incidents. Rather, it is weather conditions and pilot error combined which led to an incident. Furthermore, the relative scarcity of weather-related aircraft incidents indicates that the air sector has effective, ongoing management strategies and technological development to accommodate severe weather conditions, and will not fly when conditions are unsafe.

WEATHER-RELATED SERVICE DISRUPTIONS

Weather-related delays and cancellations in air transportation services can be very disruptive to individuals and the Canadian economy, as they can have ripple effects across the national airport system. Causes include thunderstorms, fog, snow, and icing. In mountainous regions of the British Columbia interior weather-related fog and visibility issues can be problematic. Varying topography can result in very different weather conditions in close proximity. For example, the West Kootenay Regional Airport in Castlegar experiences frequent flight delays due to low ceilings and the surrounding mountains while the Trail Regional Airport, roughly 40 km south of Castlegar, offers better weather conditions and greater reliability in scheduled flights. Navigation technologies can play an important role in reducing weather-related delays. For example, the Northwest Regional Airport in Terrace, in the Coastal Mountains, often experiences weather conditions very similar to the West Kootenay Regional Airport, but has far fewer weather related cancellations. This can be attributed to Instrument Landing Systems (ILS) employed at the Terrace Airport that are not installed at West Kootenay. These systems can cost well in excess of $1 million to install, and are often considered uneconomic for smaller airports.

Changes in parameters affecting airport operations, and that can result in flight delays and cancellations, include extreme weather, storm surge and sea level rise over time. Fortunately airports in British Columbia can handle most snowstorm events, with the occasional service delay. Having appropriate snow removal equipment and staff can help to manage this type of event.

Visibility issues are more problematic. While Vancouver International Airport has an advanced ILS (enabling landing and departures in visibility conditions as low as 600 feet), not every airport in British Columbia is equipped with ILS. While other management options such as Required Navigation Performance may be available, they often require ongoing cooperation between regional airports and air carriers. The main approach to visibility issues is flight cancellation or diversion to alternative airports. This can inconvenience passengers, and over the long-term, potentially compromising regional growth.

IMPACTS ON PHYSICAL INFRASTRUCTURE SYSTEMS

Coastal airports may be exposed to the hazards of storm surge and sea level rise (see Box). For example, the low elevation of Vancouver International Airport's physical infrastructure could potentially be affected by storm surge and sea level rises over time. This airport is a major regional, national, and international hub, and disruption of service could have wide-ranging impacts on air mode reliability in British Columbia and elsewhere. The airport is located on Sea Island, close to sea level, and is also in the Fraser River floodplain where there is flooding potential from heavy precipitation affecting river flow, plus Pacific Ocean storm surge and changing conditions from sea level rise. A dyke system, approximately 15 km long, currently protects Sea Island. The Airport Authority has an ongoing program to manage the dykes and regularly assesses flood risk, while working in collaboration with federal, provincial, and local governments to define appropriate dyke elevations (Marion Town, Vancouver Airport Authority, personal communication, 2015). Other relevant measures at Vancouver Airport include ensuring the airport has an in-to-wind runway in virtually all wind conditions; and investments in pavement snow and ice control and de-icing, to ensure aircraft can safety operate in severe weather conditions.

SANDSPIT AIRPORT

Transportation infrastructure and operations at Sandspit Airport, Haida Gwaii, are susceptible to winter storms and associated storm surges with potential increases and attendant issues as sea levels rise over time. The runway is located across the 'spit' and heavy and frequent winter storms have caused severe wave damage to riprap revetment, which is a sloping structure made of rocks or other material, protecting the shore. Overtopping of the revetment has become more frequent in recent years, with damage and repairs occurring on an annual basis, including marine debris and driftwood on the runway and damage to airfield lights and pavement (Figure 16). The airport is also located within the Pacific Flyway, a route for migratory birds. Airport operators have observed changes over the last decade in migratory and resident birds that also affect management of the airport.

Figure 16: Sandspit runway from December 2011. The end of the runway was subject to severe wave overtopping during a significant storm event, with a sea surge approximately 1 metre above runway elevation. A 250 m section of damaged riprap needed to be re-constructed.

In light of these changes, the airport needs to continuously adapt its operations to ensure continued safety. The vulnerability of Sandspit Airport may need to be further assessed, along with new management approaches and practices, as the frequency and magnitude of storm surge events will increase as a result of sea level rise.

Written with input from Transport Canada staff, Pacific Region Office.

6.2 FUTURE CLIMATE RISKS

While visibility is an ongoing concern for British Columbia airports, it is presently unclear how climate change will affect the situation. The vulnerability assessments of highways by the British Columbia Ministry of Transportation and Infrastructure noted that current climate models cannot project changes in visibility conditions in the complex landscape of the British Columbia Interior Mountains. This issue has been identified by the Pacific Climate Impacts Consortium as a topic for further work, specifically to address transportation risks in the British Columbia interior.

Warmer and wetter winters in future might suggest a decline in snow-related air travel delays: however, projections of changes in the frequency and intensity of snowfall events over a shorter winter season remain uncertain. This represents another area where additional modeling work to assess the nature, form, frequency and intensity of future snowfall events for major British Columbia airports would be valuable.

Sea-level rise, and associated increases in storm-surge flooding, is a threat to operations at both Vancouver International Airport and Sandspit Airport (plus river flooding at Vancouver International Airport). As part of the Vancouver International Airport Authority's work to support the Airport Master Plan 2057, the Airport Authority is assessing climate change impacts on airport operations. The objective of this work will be to review and gain a better understanding of anticipated climate change impacts specific to Sea Island. Further work is expected to include the identification and quantification of possible risks associated with climate change impacts to airport operations. The results of these studies will culminate in adaptation plans from which any infrastructure improvements would be incorporated and funded through the Airport Authority's capital program.

6.3 ADAPTATION PRACTICES

The air sector manages weather conditions on an ongoing basis, adjusting practices as changes in weather phenomena are observed. In this sense, for many airports (with exceptions, such as Vancouver International Airport), adaptation tends to be primarily reactive, rather than performed in anticipation of future changes. At the same time, aircraft technology is evolving with more frequent use of instrument landing systems and other innovations allowing aircraft to fly safely in less than ideal conditions.

While there is very little information available regarding climate change risk assessment studies for air transportation in British Columbia, this does not mean that these studies are not being undertaken, as they may not be published or available in the public domain. For example, there has been a commitment to undertake a climate change risk assessment for the Vancouver International Airport that addresses risks of sea level rise and implications for the ongoing review and renewal of dike systems.

7.0 MARINE TRANSPORT

As a coastal province, and a major national hub for both passengers and goods, weather events that affect British Columbia marine transportation systems can have significant provincial and national impacts. As with aviation, impacts of concern include:

- Accidents where weather conditions have contributed to the causes;
- Service interruptions caused by weather; and,
- Impacts on physical infrastructure systems.

7.1 HISTORICAL CLIMATE IMPACTS

The marine sector has a long history of managing and coping with weather conditions and has established standard procedures for accessing weather forecast information and incorporating that information into voyage planning. As a result, impacts of severe weather are normally managed through avoidance practices (resulting in delays) and through improvements in technology that incorporate advanced weather monitoring and navigation systems. For example, Environment and Climate Change Canada maintains an extensive network of weather forecasting areas, observation sites and marine weather radio frequencies for the British Columbia coastline (Government of Canada, 2016). The system provides ongoing weather information to the marine sector and provides warnings of inclement weather that may affect marine transportation systems. This has resulted in weather-related marine accidents being relatively uncommon in British Columbia. A limited review of TSB reports suggests that any weather-related marine incidents involve strong components of human error.

Seaports in British Columbia must be able to handle high winds and heavy rainfall, normally at the same time. In 2014, four percent of British Columbia ferry sailings were delayed due to weather. High winds are a common cause of delays, with heavy rain another factor (British Columbia Ferry Services Inc., 2016). While the percentage is not large, it nonetheless represents 6,600 of the year's sailings being disrupted by weather conditions. Severe weather can not only result in delayed or canceled sailings, but can also affect physical infrastructure systems. For example, on November 3, 2015, high winds pushed the Queen of Nanaimo (ferry service between Vancouver Island and the Mainland) out of position, causing it to crash into and damage a private floating dock (CBC News, 2013). However, to date damage to physical infrastructure systems arising from weather related events has been relatively rare.

7.2 FUTURE CLIMATE RISKS

While wind is a key parameter in climate change forecast work, predicting the nature and intensity of short duration wind events is technically difficult and models are not good at simulating surface winds (Engineers Canada, 2008; Griffin et al., 2010). Specific studies aimed at assessing the impact of changes in high wind intensity and frequency on marine sector operations have not been identified. Existing practices that utilize a sophisticated network of weather monitoring and forecasting facilities may be sufficient to address future risks. Nonetheless, a changing climate may result in an increase in cancellations and delays, with economic implications. This is an area for further study.

Preliminary analysis (see Section 2.2) indicates a likely increase in the frequency of atmospheric river events by 2041-2070, with the largest increases on the coast. The average number of atmospheric river days per year is projected to approximately double at most locations, including the interior. Specific marine sector studies or activities to assess the impact of changing precipitation intensity and frequency on marine sector operations in British Columbia were not identified.

Studies are underway to examine flooding scenarios based on spring snow melt, coastal storm surge, king tides and sea level rise flooding for areas around the Fraser River, where a number of port facilities are located. These studies are being developed under a Lower Mainland Flood Management Strategy that involves a number of entities including municipal and provincial governments, the Fraser Basin Council and others such as Port Metro Vancouver (Kerr Wood Leidal, 2015). As part of this Strategy, the Fraser Basin Council is proposing to examine the vulnerability of key infrastructure, such as ports, rail, airports, highways, emergency or major road networks, and BC Hydro substations, to flooding.

Previously, the province completed studies assessing the impact of flooding from sea level rise and climate change on the Fraser River (Fraser Basin Council, 2014), and also published guidelines for the management of coastal flood hazard land use and sea dykes (Ausen Sandwell, 2011). As well, the British Columbia Professional Engineers and Geoscientists have published professional practice guidelines for flood assessments in a changing climate (Association of Professional Engineers and Geoscientists of British Columbia, 2012). The Ministry of Forests, Lands and Natural Resource Operations provides coastal flood hazard maps that indicate the impact of sea level rise for the entire provincial coastline for the year 2100 (Government of British Columbia, 2016b). The maps clearly indicate that by 2100, the region around Port of Vancouver will be a high flood hazard area, presenting risks to port infrastructure facilities that may disrupt the flow of goods and services into and out of the southern Pacific Gateway Corridor.

7.3 ADAPTATION PRACTICES

The extensive network of weather monitoring stations and forecasting services for the marine sector in British Columbia represents a primary response to reducing climate risks. The sector adjusts practices to accommodate inclement weather and may benefit from adjusting future practices to accommodate weather changes. The longer term risks to coastal infrastructure including ports, associated with sea-level rise are recognized by the provincial government. It has implemented a concrete plan of action that includes monitoring, and specific requirements for maintaining and upgrading sea dykes.

8.0 PROVINCIAL CLIMATE ADAPTATION PRACTICES

The Government of British Columbia has been working to better prepare the province to adapt to a changing climate. This includes a province-wide plan *Preparing for Climate Change: British Columbia's Adaptation Strategy*, which aims to build a foundation of knowledge and tools, make adaptation a part of the Government's decision-making, and assess risks and implement priority adaptation actions in key climate sensitive sectors (British Columbia Ministry of Environment, 2010).

Of specific relevance to transportation, British Columbia Ministry of Transportation and Infrastructure has developed a set of notional best practices based on the outcomes from their climate change vulnerability assessments of British Columbia highway systems (British Columbia Ministry of Transportation and Infrastructure, 2014e). These notional best practices are generally applicable to all transportation infrastructure systems, and are grouped into three primary categories: data, personnel; and, process (see Box).

BRITISH COLUMBIA MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE - CLIMATE ADAPTATION PRACTICES

The notional best practices developed by the British Columbia Ministry of Transportation and Infrastructure include the specific practices identified below. To view the full best practices document, please visit: http://www.th.gov.bc.ca/climate_action/documents/MoTI-Climate%20Adaptation_Best%20Practices.pdf

Data

- Keep weather and climate data up to date
- Establish monitoring programs
- Always consider the impact of extreme precipitation events
- Consider combinations and sequences of events
- Identify sources for robust climate change information
- Ensure that projections are based on ensembles of climate model outputs

Personnel

- Strive for balance between computational methods and professional judgement
- Identify, monitor and manage climate change issues
- Establish multidisciplinary climate change review teams
- Work with qualified climate and meteorological professionals

Process

- Provide vulnerability assessment tools and appropriate training
- Use risk management to address uncertainties
- Incorporate climate change adaptation measures into planning cycles
- Mandate consideration of climate change in ongoing activities

9.0 INFORMATION AND KNOWLEDGE GAPS THAT CONSTRAIN DECISION-MAKING

This assessment has identified the following gaps in knowledge and information to advance adaptation decision-making related to transportation systems in British Columbia.

- **Extreme Precipitation Events.** Extreme precipitation events are the primary climate-related concern for road and rail transportation systems in British Columbia. Work is ongoing to characterize the future nature, frequency and intensity of such events. This work could be expanded with a focus on ensuring that decision makers have sufficient information and tools to inform system design, operation and maintenance for future extreme weather and climate conditions. Additionally, further work to characterize conditions that affect marine transportation and to project future precipitation event frequency and intensity would be useful.

- **Sea Level Rise Impacts on Coastal Infrastructure Systems.** Sea level rise and storm surge pose risks to coastal infrastructure in British Columbia, particularly to Vancouver International Airport, Sandspit Airport and Port Metro Vancouver. The Province of British Columbia has an active program to assess these risks and provide guidance to decision makers regarding adapting to sea level rise. Risk assessments will continue to be a key tool in ensuring that the owners and operators of critical coastal infrastructure facilities in British Columbia have the appropriate information to build, adjust and maintain infrastructure that is adaptable to sea level rise.

- **Marine Wind Events.** High winds can lead to sailing cancellations and delays within the marine transportation system. Climate change projections of high wind event frequency and intensity are not reliable. More work in this area would provide decision makers with a better foundation to plan and implement operational changes to adapt to changes in high wind event frequency and intensity.

- **Visibility Issues in the Interior.** Visibility can have significant impacts on road and airport operations in the British Columbia interior. While these issues are being managed, the causes of low visibility (fog) in the interior, and particularly the likely future changes in conditions that lead to these events, are not well understood. More knowledge about these weather effects could aid decision makers in implementing new systems and procedures to adapt to anticipated changes.

Climate change adaptation in all transportation marine modes in British Columbia has generally been reactive, with issues being addressed only after impacts have been observed. However, recent vulnerability assessments have examined longer-term climate change issues for some infrastructure. These studies of climate change and its effects on infrastructure will allow operators to better anticipate issues, and encourage the development of contingencies to adapt facilities, assets and operations to the risks posed by a changing climate. Given the contribution of rail, air and marine sectors to the provincial and national economies, additional climate change vulnerability assessments in all modes could be beneficial.

10.0 CONCLUSION

This chapter has demonstrated the vulnerability of British Columbia's transportation system to extreme weather and the changing climate, described practices to reduce these risks, and identified potential areas for additional work. The province's transportation network is critical for the effective movement of people and goods through airports, ports, rail, and roads – both within the province and between North America and Asia. However, many of British Columbia's transportation corridors, which traverse mountainous terrain and coastlines, are vulnerable to disruption and even failure resulting from climate events.

This chapter also indicates that infrastructure operators in British Columbia are primarily responding to failures, rather than anticipating and preparing for change. As a result, infrastructure impacts could be more severe than if proactive adaptive measures had been taken. Along with more robust data collection tools for climate and weather variables, and effective guidelines for data modeling and interpretation, proactive approaches (i.e. vulnerability assessments, infrastructure design requirements) could offer transportation decision-makers a stronger foundation for adaptive decisions. Sharing studies of climate vulnerability among operators and modes may improve learning and could benefit the transportation system as a whole.

The British Columbia Ministry of Transportation has assessed the vulnerability of several of the province's highways to climate change, and is one of the first jurisdictions to require that road infrastructure design work for the ministry consider climate change implications. This is an important indicator that adaptation efforts in British Columbia's transportation sector are advancing, though more work remains to be done.

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