LA GRANDE ALLIANCE

PRE-FEASIBILITY STUDY – PHASES II & III – TRANSPORTATION INFRASTRUCTURE

TECHNICAL NOTE 9
CLIMATE CHANGE

FINAL VERSION

DATE: MARCH 25, 2024

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EXECUTIVE SUMMARY

The objective of this technical Note 9 is to document the shifts in climate change over the lifetime of the infrastructure planned under The Grand Alliance. This assessment takes into account short-term (2021-2050) and long-term (2051-2080) climate projections and considers two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios - RCP 4.5 and RCP 8.5.

La Grande Alliance proposed infrastructures includes port, roadways, and railways in northern Quebec, along the southern coast of Hudson Bay and farther inland. La Grande Alliance Study Area lies within a subarctic environment, which is rugged, forested, and glaciated (WWF, 2022; Agriculture and Agri-food Canada, 1995). The study area has:

- Cold winters and cool summers, which are projected to increase in temperatures;
- Sporadic permafrost, which is projected to experience ongoing degradation due to increasing temperatures and liquid precipitation regimes;
- Moderately dry conditions, which are projected to become wetter with increases in extreme precipitation events;
- Substantial snow accumulation, which is projected to remain relatively unchanged in the near future;
- Days with freezing rain, which are projected to nearly double;
- High wind gusts and sustained wind velocities, which are projected to nearly triple in some cases;
- A moderate number of fire spread days (i.e., days when weather conditions are favorable to the spread of wildfires), which are projected to increase up to three days per year in the more northern Eastern Subarctic zone of the study area;
- Riverine flooding, which requires further characterization but may potentially increase in the future;
- Coastal flooding, which is a short-term consideration but projected to ultimately decrease in the future due to land uplift.

The purpose is to assess if and how the climate hazards can impact and influence the infrastructure components included in the proposed Grande Alliance Studies. Overall, eight climate hazards are selected for the region and should be considered in further assessments:

1. Extreme Cold
2. Extreme Precipitation
3. Freezing Rain
4. Land Instability
5. High Winds
6. Wildfires
7. Riverine Flooding
8. Coastal Flooding

These climate hazards have the potential to interact with the infrastructure components included in La Grande Alliance proposed infrastructures and should be further studied. Three data gaps are identified (linked to riverine flooding, geotechnical knowledge, permafrost distribution and melt, and wind). In addition to remedying the data gaps, proposed next steps include a climate resilience assessment following the applicable provincial laws, while being aligned with ISO 31000 and ISO 14091 standards for risk management and climate change adaptation to better quantify the level of risk for each climate-infrastructure interaction.

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1 INTRODUCTION

The objective of this technical Note 9 is to document the shifts in climate change over the lifetime of the infrastructure planned under The Grand Alliance. This assessment takes into account short-term (2021-2050) and long-term (2051-2080) climate projections and considers two Intergovernmental Panel on Climate Change (IPCC) emissions scenarios - RCP 4.5 and RCP 8.5.

The purpose is to assess if and how the climate hazards can impact and influence La Grande Alliance proposed infrastructures.

2 HISTORICAL CLIMATE AND NATURAL ENVIRONMENT

The study area for La Grande Alliance proposed infrastructures spans large areas in Quebec, both along the southern coast of Hudson Bay and farther inland to the south and east. All parts of the proposed infrastructures lie within the Eastern Taiga Shield ecozone, which is a subarctic landscape with rugged terrain that is generally level, covered in coniferous forest, and interrupted by peatlands, glacial features, and rivers (WWF, 2022; Agriculture and Agri-food Canada, 1995).

For this climate portrait and assessment, data for multiple climate parameters are retrieved from the Prairie Climate Centre's Climate Atlas of Canada (2019). Unless otherwise indicated, they are from the large Lac Mistanukaw grid cell, which was selected to represent the study area's climate because it is relatively central (Figure 2-1).

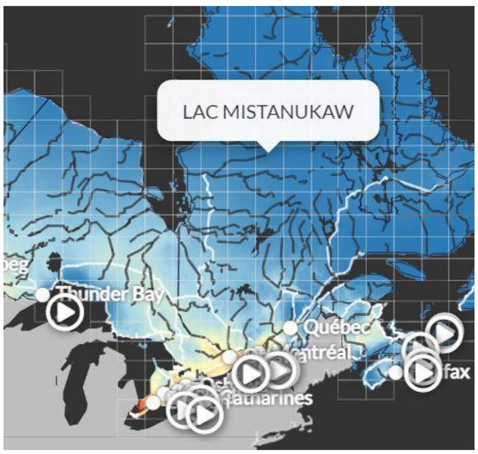

Figure 2-1 Lac Mistanukaw grid cell
Lac Mistanukaw's coordinates are approximately 54.7779, -72.6324, which are encompassed in the grid cell. Image captured from the Prairie Climate Centre's Climate Atlas of Canada (2019).

2.1 TEMPERATURE

Historical conditions in La Grande Alliance study area represent a relatively cold climate. Historical mean annual temperatures are approximately -4°C, mean winter temperatures are very low (-21°C on average), and mean summer conditions are relatively cool (approximately 11°C; Prairie Climate Centre, 2019). Very cold days are relatively common with temperatures dropping below -30°C approximately 38 days per year and the average lowest minimum temperature reaching approximately -42°C every year (Prairie Climate Centre, 2019). Very warm days are rare with temperatures essentially not rising above 30°C at the highest (Table 3-1).

2.2 PERMAFROST AND FREEZE-THAW CYCLES

La Grande Alliance's latitude places it within a zone of sporadic permafrost (as of 2010; Figure 2-2), meaning that 10 to 50% of the land surface overlies permafrost, which is permanently frozen ground (at or below 0°C for at least two years; University of Calgary, 2016). In areas that do experience freeze-thaw cycles, which are expressed as the number of days when the air fluctuates between freezing and non-freezing temperatures, historical models indicate an average of approximately 55 cycles per year (Table 3-1; Prairie Climate Centre, 2019).

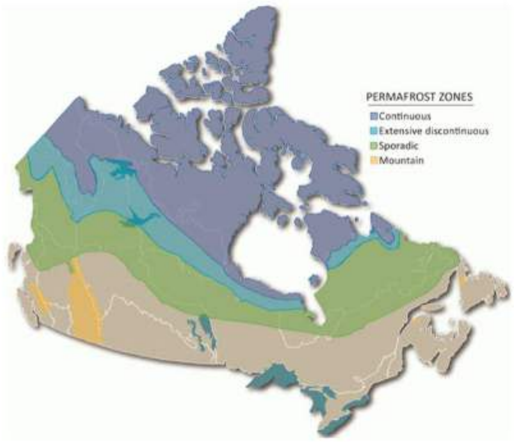

Figure 2-2 Permafrost zones
Delineation of permafrost in Canada, showing La Grande Alliance study area in a Sporadic zone. Map from (Smith S. , 2010) and adapted from (Heginbottom et al., 1995).

2.3 PRECIPITATION

For general context, southern areas in Canada are typically warmer and wetter while areas to the north are typically colder and dryer. La Grande Alliance study area lies near Canada's mid latitudes and, in addition to being relatively cold, it is moderately dry. The historical mean of maximum precipitation occurring in one day is approximately 21 mm, although these events are not common in the region with less than one occurrence per year (Table 3-2; Prairie Climate Centre, 2019).

Intensity-duration-frequency (IDF) curves provide a good representation of extreme rainfall events. Historical IDF models calculate 17 mm of precipitation in 15 minutes and 72 mm in 24 hours in La Grande Alliance study area, both with a 50-year return period, which is a 2% likelihood of occurring each year (University of Western Ontario et al., 2022). Although these amounts are modelled for a coastal climate station in the region (Kuujjuarapik), model outputs from an inland station (Nitchequon) are similar (suggesting the coastal influence on precipitation regimes in La Grande Alliance study area is minimal).

Figure 2-3 Kuujjuarapik and Nitchequon climate stations
Kuujjuarapik's coordinates are approximately 55.2847, -77.7625 and Nitchequon's coordinates are approximately 53.3963, -70.8557. Image captured from the Prairie Climate Centre's Climate Atlas of Canada (2019).

Snow and ice are common in La Grande Alliance's study area. The region can accumulate a substantial amount of snow by spring, with a historical maximum extreme snow depth of 124 cm (April; Kuujjuarapik Airport climate station). This value is retrieved from the Canadian 1981-2010 Climate Normals database (2021) and is the average depth in a representative area.

Finally, freezing rain occurs from October to May. Observed and modelled historical averages calculate 3.6 days per year with freezing rain events at least one hour long. For comparison, this is less than Eastern (8 days) and Southern (5 days) Ontario annual averages (Cheng et al., 2012).

2.4 WIND

Wind can vary horizontally and vertically with different directions and velocities, and it can be sustained or happen in gusts. In La Grande Alliance study area, the maximum sustained wind speed recorded is 97 km/h (November 9, 1957; Government of Canada, 2021). The same database reports the maximum recorded wind gust speed as 113 km/h on that same day and an annual average of 15.4 days with winds above 52 km/h and of 2.9 days above 63 km/h. The same database reports the most frequent wind directions as southeast from December to March, north from April to June, west from July to September, and south for October and November (Kuujjuarapik Airport Climate Station ID: 7103536).

2.5 WILDFIRES

La Grande Alliance study area spans the Eastern subarctic and the Eastern James Bay fire zones (Figure 2-4). The more northern zone, the Eastern subarctic, has a baseline median of two fire spread days while the more southern zone, the Eastern James Bay, has a baseline median of one fire spread day[1]. In addition, smoke from active fires in other parts of the country (e.g., northwestern Ontario) can cause elevated levels of particulate matter in the air, which can reduce the visibility and air quality.

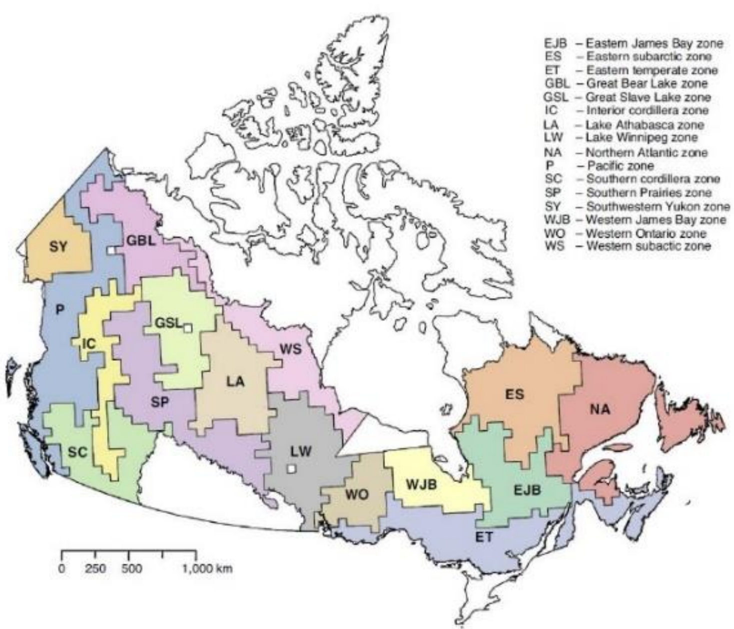

Figure 2-4 Fire Zones
Delineation of fire zones in Canada, showing La Grande Alliance Study area in the Eastern Subarctic and Easter James Bay zones. Map from (Wang, et al., 2017) and adapted from (Boulanger et al., 2012).

[1] A fire spread day occurs when weather conditions are favorable to the spread of wildfires in terms of temperature, dryness, and wind regimes.

2.6 COASTAL AND RIVERINE FLOODING

Flooding can be caused by short-duration extreme rainfall events, river breaching, and ocean submersion. In Canada, riverine floods are typically caused by extreme and long-lasting precipitation, melting snow or ice (including rain-on-snow events), and/or river ice jams (Bonsal et al., 2019). However, no indication of trends in water high and low flows is available for La Grande Alliance study area (MELCC, 2022). This absence indicates a data gap.

Coastal flooding is a dangerous hazard that is expected to increase along most of Canada's coasts due to a combination of sea level rise and land subsidence (Bush & Lemmen, 2019). However, much of Canada's North Coast region, including the coastal parts of La Grande Alliance Study area, are not experiencing sea level rise due to glacial isostatic adjustment (uplift of the land; Climatedata.ca, 2021). As such, there are ongoing reductions in extreme-water-level events but short-term potential for events given changes in sea ice extent and duration, while storm intensity remains similar as the recent past (Ford et al., 2016).

2.7 LANDSLIDES

Landslide occurrence depends on characteristics and conditions such as slope, precipitation, permafrost, geology, vegetation, and distance to rivers and coasts. La Grande Alliance proposed infrastructures are situated in the Canadian Shield region, which is a relatively flat area with thin sediment cover. As such, landslide susceptibility is considered as low and not likely to substantially increase as a climate hazard over time (Bobrowsky & Dominguez, 2012).

A recent landslide along the Great Whale River in La Grande Alliance study area (April 22, 2021, 8 km upstream of Whapmagoostui/Kuujjuarapik) has been deemed too far south to be caused by degraded permafrost and too deep to be caused by the effects of climate change. Rather, the massive slide (second largest in Quebec over 150 years of recordkeeping) in a relatively coastal area was caused by deep and sensitive clay deposits, which are not as common farther inland (Bell, 2021).

Given that climate change is not considered a driver of these landslides, future landslide projections for La Grande Alliance study area will not be outlined in this report. Refer Technical Note 10 for more information about landslides in the study area.

3 CLIMATE PROJECTIONS

Changes in climate in the natural environment are inevitable and likely to increase in the future. A baseline level of climate change is unavoidable given greenhouse gas (GHG) emissions that have already occurred; however, the severity of future change will depend on ongoing global action to reduce GHG emissions.

The most used scenarios of future change are named Representative Concentration Pathways (RCPs), which were established in the preparation of the fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). These scenarios provide a range of potential trajectories of climate change based on a range of net global emissions. The RCPs are named according to their radiative forcing values (i.e., the change in net irradiance in the troposphere due to external drivers) in the year 2100: 2.6, 4.5, 6.0, and 8.5 Wm^{-2} (van Vuuren et al., 2011). This assessment considers RCP 4.5, which is a scenario of moderate climate change mitigation that represents the most optimistic but feasible case today, and RCP 8.5, which is the most pessimistic trajectory considering to mitigation measures implemented at global scale (van Vuuren et al., 2011).

Given that changes will occur over the lifespan of La Grande Alliance proposed infrastructures, this assessment considers climate projections for the short-term (2021-2050) and the long-term (2051-2080).

3.1 TEMPERATURE

Temperature projections for La Grande Alliance study area show warming conditions in both RCP 4.5 and RCP 8.5 over the short and long terms. Winter temperatures are increasing more than summer temperatures over both time periods in both scenarios (Table 3-1; Prairie Climate Centre, 2019).

3.2 PERMAFROST AND FREEZE-THAW CYCLES

The increase to mean annual temperatures exceeding -1°C over the long-term in both RCP 4.5 and RCP 8.5 scenarios not only indicates rising temperatures (Table 3-1), but also presents the likelihood of permafrost degradation (Brown, 1967). Given increasing temperatures in the La Grande Alliance study area, it is likely that the discontinuous permafrost will thaw and disappear over the upcoming century (Smith & Burgess, 2004).

Additionally, the annual number of freeze-thaw cycles in the region is projected to decline 10-15% from the historical baseline over the short and long terms in RCP 4.5 and RCP 8.5 (Table 3-1; Prairie Climate Centre, 2019).

Table 3-1 Temperature and freeze-thaw cycle projections

		RCP 4.5		RCP 8.5	
CLIMATE INDICATOR	HISTORICAL	SHORT	LONG	SHORT	LONG
Mean annual temperature (°C)	-4	-2	-0.8	-1.6	0.9
Average lowest minimum temperature (°C)	-42	-38	-36	-38	-33
Number of days below -30°C	38	22	13	19	6
Average highest maximum temperature (°C)	28	29	31	30	32
Number of days above +30°C	0.2	0.8	1.6	1	3.5
Annual number of freeze-thaw cycles	55	51	48	49	46

Historical baselines and short- and long-term projections for select temperature indicators under RCP 4.5 and RCP 8.5 scenarios. Red text denotes warmer conditions relative to the previous time period. Uncertainty ranges not indicated but would be considered in detailed climate change adaptation risk assessment.

3.3 PRECIPITATION

Precipitation can fall as rain, snow, freezing rain, and other variations between water and ice. In addition to the inclement conditions when precipitation falls rapidly and intensely, it can cause flooding, stress from a heavy (snow) load, or damage and danger from ice. Extreme precipitation levels in La Grande Alliance study area, represented by both a coastal (Kuujjuarapik) and inland (Nitchequon) climate station and Lac Mistanukaw grid square, are projected to increase in both scenarios over the short and long terms (Table 3-2; University of Western Ontario et al., 2022).

According to Derksen et al. (2019), snow cover and snow load are likely to remain relatively unchanged in Canada's north, including La Grande Alliance study area (a loss as low as 2.5% in snow accumulation or a gain as much as 2.5% per decade). Increased snowfall is expected to be offset by increasing temperatures that shorten the accumulation season.

According to Cheng et al. (2011), there will likely be an increase and a shift in the distribution of freezing rain over a typical year. The number of freezing rain days is expected to increase substantially in winter (December, January, and February) and moderately (November, March, April, and May) or only slightly (October) in the shoulder seasons (Table 3-2; Cheng et al., 2011).

Table 3-2 Extreme precipitation projections

			RCP 4.5		RCP 8.5	
LOCATION	CLIMATE INDICATOR	HISTORICAL	SHORT	LONG	SHORT	LONG
Lac Mistanukaw (Figure 2-1)	Max 5-day precipitation (mm)	40	43	45	43	46
Kuujjuarapik (coastal; Figure 2-3)	IDF curve, 15-min, 1:50 return period (mm)	17.3	20.6	21.3	20.0	23.7
	IDF curve, 24-hr, 1:50 return period (mm)	72	76.1	78.1	73.7	86.9
Nitchequon (inland; Figure 2-3)	IDF curve, 15-min, 1:50 return period (mm)	17	21.3	22.7	21.5	23.1
	IDF curve, 24-hr, 1:50 return period (mm)	69	78.8	83.6	79.8	85.3
Hudson Bay region (VI zone)	Freezing rain days – Dec, Jan, Feb	0.7	No data	No data	1.1	1.4
	Freezing rain days – Nov, Mar, Apr, May	2.5	No data	No data	3.0	3.1
	Freezing rain days – Oct	0.4	No data	No data	0.4	0.4
	Freezing rain days – Annual	3.6	No data	No data	4.5	4.9

Historical baselines and short- and long-term projections for precipitation indicators under RCP 4.5 and RCP 8.5 scenarios. Lac Mistanukaw data are from (Prairie Climate Centre, 2019), Kuujjuarapik and Nitchequon data are from (ClimateData.ca, 2021), and Hudson Bay (VI) data are from (Cheng et al., 2011). Red text denotes more precipitation relative to the previous time period. Uncertainty ranges not indicated but would be considered in detailed climate change adaptation risk assessment.

3.4 WIND

Wind projections are indirect models based on daily temperature and precipitation; therefore, they carry increased uncertainty. According to Cheng et al. (2014), the mean annual frequency of gust and sustained wind events are projected to increase in both scenarios over the short and long terms. The frequency of lower velocity gusts and mid velocity gusts are projected to increase no more than 12 and 62%, respectively, while the frequency of high velocity gusts is projected to increase no more than 290%. The frequency of sustained wind events is also projected to increase due to climate change (Table 3-3). This suggests that changes in gusts in the region are characterized mostly by substantial increases in the frequency of high velocity winds.

Table 3-3 Wind projections.

CLIMATE INDICATOR	VELOCITY (km/h)	MAXIMUM PROJECTED PERCENT (%) INCREASE IN EVENT FREQUENCY
Low velocity gust events	≥28 and >40	12
Mid velocity gust events	≥70	62
High velocity gust events	≥90	290
Low velocity sustained wind events	≥28 and >40	17
Mid velocity sustained wind events	≥70	22
High velocity sustained wind events	≥90	65

Maximum projected percent (%) increase in mean annual frequency of low, mid, and high velocity hourly (gust) and daily (sustained) wind events. The maximum increase presented is the highest of the values projected over either the short (2046-2065) or long (2081-2100) terms; in all instances, the increase in the time frame not presented is not markedly different.

3.5 WILDFIRES

The median numbers of annual wildfire spread days in La Grande Alliance study area, including the Eastern Subarctic and Eastern James Bay fire zones, are projected to increase over the short and long terms in both climate change scenarios (Table 3-4; Wang, et al., 2017).

Table 3-4 Fire spread day projections

		RCP 4.5		RCP 8.5	
CLIMATE INDICATOR	HISTORICAL	SHORT	LONG	SHORT	LONG
Median number of annual fire spread days (Eastern Subarctic zone)	2	2.4	2.5	2.3	3.2
Median number of annual fire spread days (Eastern James Bay zone)	1	1.2	1.5	1.3	1.6

Historical baselines and short- and long-term projections for fire spread days in two regions encompassing La Grande Alliance Study area. Projections for scenarios 4.5 and 8.5 are included. Red text denotes an increase in fire spread days relative to the previous time period. Uncertainty ranges not indicated but would be considered in detailed climate change adaptation risk assessment.

3.6 COASTAL AND RIVERINE FLOODING

Although riverine flood mapping across the region is not readily available, maximum 5-day precipitation (presented in Table 3-2 above), which is a proxy for the conditions that may drive riverine flooding, is projected to increase in both scenarios over the short and long-terms (Prairie Climate Centre, 2019).

Coastal flooding in La Grande Alliance study area is projected to decrease over time in both scenarios with relative decreases in sea level. However, the potential frequency of extreme-water-level events may increase over the short term (Ford et al., 2016). Relative to a 1986-2005 baseline, median sea levels are projected to decrease 50 and 78 cm over the short and long terms, respectively, under the RCP 4.5 scenario. Under the RCP 8.5 scenario, sea level is projected to decrease 47 and 67 cm over the short and long terms, respectively (ClimateData.ca, 2021).

4 CLIMATE HAZARDS & POTENTIAL IMPACTS

Given the historical and projected conditions, there are eight ongoing and future climate hazards in La Grande Alliance study area (Table 4-1).

Table 4-1 Climate hazards

CLIMATE HAZARD	EXPLANATION
1. Extreme Cold	Although (winter) temperatures are projected to continue increasing, La Grande Alliance study area will continue to experience very cold conditions, which can threaten human safety and infrastructure.
2. Extreme Precipitation	IDF curves project increases in total precipitation during extreme sub-daily and daily events. Maximum 5-day precipitation projections also show increases over both time periods in both scenarios. These represent pluvial (overland) flood risks and preconditions for riverine flooding.
3. Freezing Rain	Freezing rain, especially in winter, is projected to increase markedly in the region. The conditions during freezing rainfall and the ice and associated damage are hazards.
4. Land Instability	Although the recent landslide in La Grande Alliance study area is not attributable to climate change and freeze-thaw cycles are projected to decrease, land instability due to permafrost degradation remains an increasing hazard.
5. High Winds	The frequencies of high-velocity gusts and sustained wind events are projected to increase markedly in an area with recorded maximums already exceeding 90 km/hr. These winds pose hazards to human safety, infrastructure, and structures.
6. Wildfires	Fire spread days are projected to increase, presenting ongoing burn and smoke hazards.
7. Riverine Flooding	Despite a lack of riverine flood mapping for the region, projected increases in maximum 5-day precipitation suggest riverine flooding in waterway-adjacent areas may be an ongoing hazard.
8. Coastal Flooding	Although land uplift is causing lower sea levels, there is remaining short-term potential for coastal flooding and damage given reductions in sea-ice extent and duration and storm intensity.

Identification and explanation of ongoing and future climate hazards in La Grande Alliance study area given the conditions and projections included above.

These climate hazards have the potential to interact with the La Grande Alliance proposed infrastructures (Table 4-2).

Table 4-2 Potential interactions between climate hazards and infrastructure components

	EXTREME COLD	EXTREME PRECIP.	FREEZING RAIN	LAND INSTABILITY	HIGH WINDS	WILDFIRES	RIVERINE FLOODING	COASTAL FLOODING
Ports	N	Y	Y	Y	Y	N	N	Y
Roads	Y	Y	Y	Y	N	Y	Y	N
Rails and Signals	Y	Y	Y	Y	Y	Y	Y	N
Drainage	Y	Y	Y	Y	N	N	Y	N

When an interaction is marked as N (no), it does not indicate that there is no interaction or impact; rather, it indicates that the impact is negligible.

5 DATA GAPS & NEXT STEPS

Robust data at meaningful scales are critical. In this assessment, a few data gaps were identified.

- **Riverine data.** La Grande Alliance study area is not included in Quebec's Hydroclimatic Atlas of Southern Quebec. Riverine flood mapping at a useful scale is not readily available and it is recommended that this mapping be located or pursued.
- **Geotechnical and permafrost data.** Permafrost degradation is occurring and will continue in the study area and may be impactful to infrastructure. Improved characterization of the extent and condition of the region's sporadic permafrost would be useful to understand ongoing and future hazards and risks.
- **Wind data.** Historical wind data (velocities and days exceeding velocities) do not match available projections (percent change in occurrence of events with specific velocities). Further, there are no known or readily available projections for future wind direction.

In addition to remedying important data gaps through flood mapping, geotechnical studies, and wind forecasting, proposed next steps include a more detailed climate resilience assessment following the *Guide aux initiateurs de projet du ministère de l'Environnement et de la Lutte contre les Changements Climatiques (MELCC)* and the second part of the *Directive pour la réalisation d'une étude d'impact sur l'environnement via l'Annexe II de la Loi sur la qualité de l'environnement (LQE)*, while complying with the requirements of the ISO 31000 and ISO 14091 standards for risk management and climate change adaptation. This will enable to better quantify the level of risk for each climate-infrastructure interaction identified given the risk tolerance of the promoter.

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