Climate Lens – Climate Resilience Assessment

Final Report

March 5, 2019

Prepared for:

Broadway SkyTrain Station Project
Ministry of Transportation and Infrastructure

Prepared by:

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Sign-off Sheet

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Prepared by Charling Li Digitally signed by Charling Li Date: 2019.03.01 10:11:32 -08'00'

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Guy Felio, PhD., P.Eng., IRP (Climate)

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Frank Bohlken, B.Sc., MRM

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Executive Summary

The Ministry of Transportation and Infrastructure (MOTI) is undertaking the development of the Broadway Subway Project (BSP) (the Project) to meet current and future ridership demands along the Broadway Corridor in Vancouver, British Columbia (BC). The Project will extend the existing Millennium Line SkyTrain (“Millennium Line”) by 5.7 km from the current terminus at the VCC-Clark SkyTrain Station to a new terminal station located at West Broadway and Arbutus Street

Stantec Consulting Ltd. (Stantec) has been retained by MOTI to assist with its federal funding agreement for the Project. This report has been completed to meet the objectives outlined in Section 3 of the Climate Lens General Guidance v1.1 (the Guidance) (Infrastructure Canada 2018).

The analysis and recommendations in this climate resilience assessment are based on information available within the timeline and scope of this assessment, and on the authors’ experience with climate risks assessments completed using Engineers Canada’s Public Infrastructure Engineering Vulnerability Committee’s climate vulnerability assessment protocol (the PIEVC Protocol). The process used for this assessment is aligned and compatible with both the PIEVC Protocol methodology and conforms to the requirements of ISO 31000:2009 Risk Management Framework, as described later in this report.

This climate risk assessment involved defining the infrastructure assets and/or components that will form the proposed Project. The timescale selected for this assessment is 30-60 years, as the Project is expected to be in service for 30+ years. This assessment is based on climate projections estimated under the RCP 8.5 scenario. RCP 8.5 is the internationally recognized global ‘business as usual’ greenhouse gas (GHG) emissions scenario.

This assessment has identified ten climate parameters that can pose hazards to Project infrastructure. Infrastructure interactions to each climate parameter were examined and an associated risk rating was assigned to each interaction. The climate parameters that presented the greatest number of risks to the Project are extreme high intensity or sustained rainfall, extreme high temperatures, and high winds. Although the majority of the Project is below grade, many climate risks are related to third-party services that are vulnerable to exposure to severe climate events.

Table 2-10 lists all risk rated at Moderate or higher. It is important to note that the Climate Change Impacts Risk Profile (Table 2-10) are a prioritization of impacts relative to each other, not against an external benchmark. Designations of ‘moderate’ or high’ risk items should be considered in the context that many risks can be further mitigated through detailed design or monitored through future operations & maintenance policies and procedures. This assessment does not include an evaluation of the effectiveness of O&M policies to reduce or mitigate climate risks. Some of the risks, involving new systems or facilities can be addressed at the detailed design stage of Project.

Recommended climate risk management measures are provided in Section 6.1.

Attestation of Completeness

I/we the undersigned attest that this Resilience Assessment was undertaken using recognized assessment tools and approaches (i.e., ISO 31000:2009 Risk Management—Principles and Guidelines) and complies with the General Guidance and any relevant sector-specific technical guidance issued by Infrastructure Canada for use under the Climate Lens.

Prepared by: Charling Li Digitally signed by Charling Li Date: 2019.03.01 10:13:14 -08'00' February 13, 2019

Charling Li, P.Eng, M.Urb.

Validated by*: February 13, 2019

Guy Felio. Ph.D., P.Eng., IRP (Climate)

* Resilience Assessments must be prepared, or at a minimum validated by, a licensed professional engineer, certified planner, or appropriately specialized biologist or hydrologist.

1 INTRODUCTION

The Ministry of Transportation and Infrastructure (MOTI) is undertaking the development of the Broadway Subway Project (BSP) (the Project) to meet current and future ridership demands along the Broadway Corridor in Vancouver, British Columbia (BC). Stantec Consulting Ltd. (Stantec) has been retained by MOTI to assist with its federal funding agreement for the Project. This report has been completed to meet the objectives outlined in Section 3 of the Climate Lens General Guidance v1.1 (the Guidance) (Infrastructure Canada 2018).

The Project will extend the existing Millennium Line SkyTrain ("Millennium Line") by 5.7 km from the current terminus at the VCC-Clark SkyTrain Station to a new terminal station located at West Broadway and Arbutus Street.
The proposed 5.7 km BSP will extend the Millennium Line's elevated guideway approximately 700 metres westward from its existing terminus at VCC-Clark Station and will continue underground to join Broadway near Main Street, where it will travel under Broadway to a new terminus at Arbutus Street. Six underground stations are proposed (listed from east to west) at the following locations:

- Great Northern Way and Thornton Street
- Main Street and Broadway
- Cambie Street and Broadway
- Laurel Street and Broadway
- Granville Street and Broadway
- Arbutus Street and Broadway

The Project will represent a significant transit expansion in the Metro Vancouver region (the Region), addressing key gaps in the existing rapid transit network and completing the first phase of a longer-term vision to extend rapid transit to the University of British Columbia (UBC).It will support economic, urban, and environmental development within the Region, provide more people with a sustainable transportation choice, connect urban centres, and increase rapid transit mode-share.

See Figure 1-1 below for Project extents.

Figure 1-1 Proposed Project

Project construction is anticipated to begin in 2020, take approximately five years to complete, with the Project becoming operational in 2025. The Project will be operated and maintained by MOTI.

At the writing of this assessment, the Project is at reference-design stage; MOTI, TransLink and the Owner's Engineer team are preparing for procurement phase. The Project will be funded by the Province of British Columbia, with contributions from the Government of Canada and the City of Vancouver.

1.1 ASSESSMENT LIMITATIONS

The analysis and recommendations in this climate resilience assessment are based on information available within the timeline and scope of this assessment, and on the authors' experience with climate risks assessments completed using Engineers Canada's Public Infrastructure Engineering Vulnerability Committee's climate vulnerability assessment protocol (the PIEVC Protocol). This information referenced for this assessment is listed in Sections 5 and 7. The process used for this assessment is aligned and compatible with the PIEVC Protocol methodology and conforms to the requirements of ISO 31000:2009 Risk Management Framework, as described later in this report.

The focus of this assessment is on the physical assets proposed for the Project (e.g. tracks, station structural and non-structural components, control systems) and does not consider other elements (such as third-party goods or services suppliers and administration, etc.) that are usually included in a PIEVC Protocol climate risk assessment. A review of this assessment, possibly leading to a more in-depth analysis, is recommended once the Project proponent has been contractually engaged to deliver the design and construction of the Project.

Climate data and trends – current and future projections – used in this assessment were obtained from published literature and data from weather stations in the Project area using the Climate Change Hazards Information Portal (CCHIP) created by Risk Sciences International (RSI). In addition to assembled climate data from weather stations, CCHIP also provided access to data sets for the entire country, on a 10km by 10km grid – known as the Canadian Gridded Temperature and Precipitation Anomalies (CANGRD) data. This CANGRD data was developed in a collaboration between Natural Resources Canada (NRCan) and Environment and Climate Change Canada (ECCC) and is based upon several sources, including interpolating weather station data. Although data from an actual local weather station is preferable, the CANGRD is well accepted and researched and has been used for this assessment.

1.2 PURPOSE

The intent of Infrastructure Canada's Climate Lens is to "incent behavioral change and consideration of climate impacts into the planning of infrastructure projects with a view to implementing Canada's mid-century goals of a clean growth low-carbon economy" (Infrastructure Canada, 2018, p5). The objective of the assessment is to identify the climate risks to the Project at a broad systems-level using a future climate scenario, and to assess the possible climate related impacts that may impact the Project over its construction and operational life. The culmination of this work is a detailed resilience analysis of individual system components during the Project's detailed design stage.

1.3 SCOPE

This assessment covers the infrastructure systems and assets identified as part of the Project. This assessment considers the climate risks during the construction of the Project, as well as the planned operation and maintenance of the Project.

1.4 GENERAL CLIMATE PROFILE

The Project is located on the Pacific Coast, in the City of Vancouver, and part of the Metro Vancouver region. The region has moderate temperatures year-round. However, its proximity to the Pacific Coast and mountainous terrain make Metro Vancouver a region of microclimates, with considerable local variations in precipitation and temperature. In 2016, Metro Vancouver, the regional governing body, commissioned detailed climate modelling and data interpretation for the region. The report “Climate Projections for Metro Vancouver” found that, in general, the region can expect the following changes in climate over the coming years:

- Warmer temperatures
- A decrease in snowpack
- Longer dry spells in the summer months
- More precipitation in the fall, winter and spring
- More intense extreme events (high winds)

Sea level rise, a climate-induced change, is a prominent concern in the Metro Vancouver region (Northwest Hydraulics, 2014). Part of the Project is a section of elevated guideway transitioning to an underground tunnel in the False Creek Flats area. The Project includes a section that is located within the False Creek Flats area that has been currently assessed as a low but present sea-level rise flood risk projected to the year 2100 (KWL, 2011 and 2012; Lyle et al., 2015).

Appendix A provides a detailed Climate Profile for geographical area covered by the Project.

2 METHODOLOGY

The Climate Lens General Guidance v1.1 (the Guidance) recognizes Engineers Canada's Public Infrastructure Engineering Vulnerability Committee's vulnerability assessment protocol (PIEVC Protocol) as a methodology for climate change resilience. Due to the timeline imposed for this assessment, a full application of the PIEVC process was not possible. However, the approach taken in this assessment is compatible with the PIEVC Protocol and consistent with ISO 31000:2009 standard Risk Management—Principles and Guidelines. The approach undertaken in this assessment is appropriate for new or upgraded assets where a detailed design has not been completed.

2.1 RISK ASSESSMENT PROCESS

This risk assessment evaluates the future climate impacts on the Project's proposed assets and identifies the potential risks associated with future changes in climate and extreme weather events. It is a high-level assessment of risks to buildings, facilities, and other infrastructure due to extreme weather and climate uncertainty based on current climate and future climate projections in the area. Extreme weather events may include, but are not limited to, heat waves and droughts, high intensity / short duration precipitation, and high winds. Refer to Section 2.4 for the full list of climate parameters applicable for this assessment, and Section 2.5 for the list of Project infrastructure assets and/or components considered in this assessment. The risk assessment focused on potential infrastructure responses associated with the exposure of infrastructure assets or components to specific climate parameters, selected based on their potential impacts on the physical or functional performance these assets or components.

The team solicited input on the climate risks to the Project through targeted phone interviews (see interviewees listed in Table 5-1). Data gaps were filled through desktop analysis of relevant Project documents or related publicly available data (see Section 5 Description of Evidence) for a detailed listing. In accordance with the Guidance, the risk assessment uses principles that are similar to those of the PIEVC Protocol and other risk assessment methodologies that conform to ISO 31000:2009 to identify relevant climate parameters and relevant infrastructure responses, set up the risk evaluation matrix, and assign risk ratings to each infrastructure response to climate considerations. This assessment will inform various design teams of potential risks that should be considered during the design stage of Project implementation. Figure 2-1 below shows the overall risk assessment process that leads to the development of the risk mitigation and adaptation strategies.

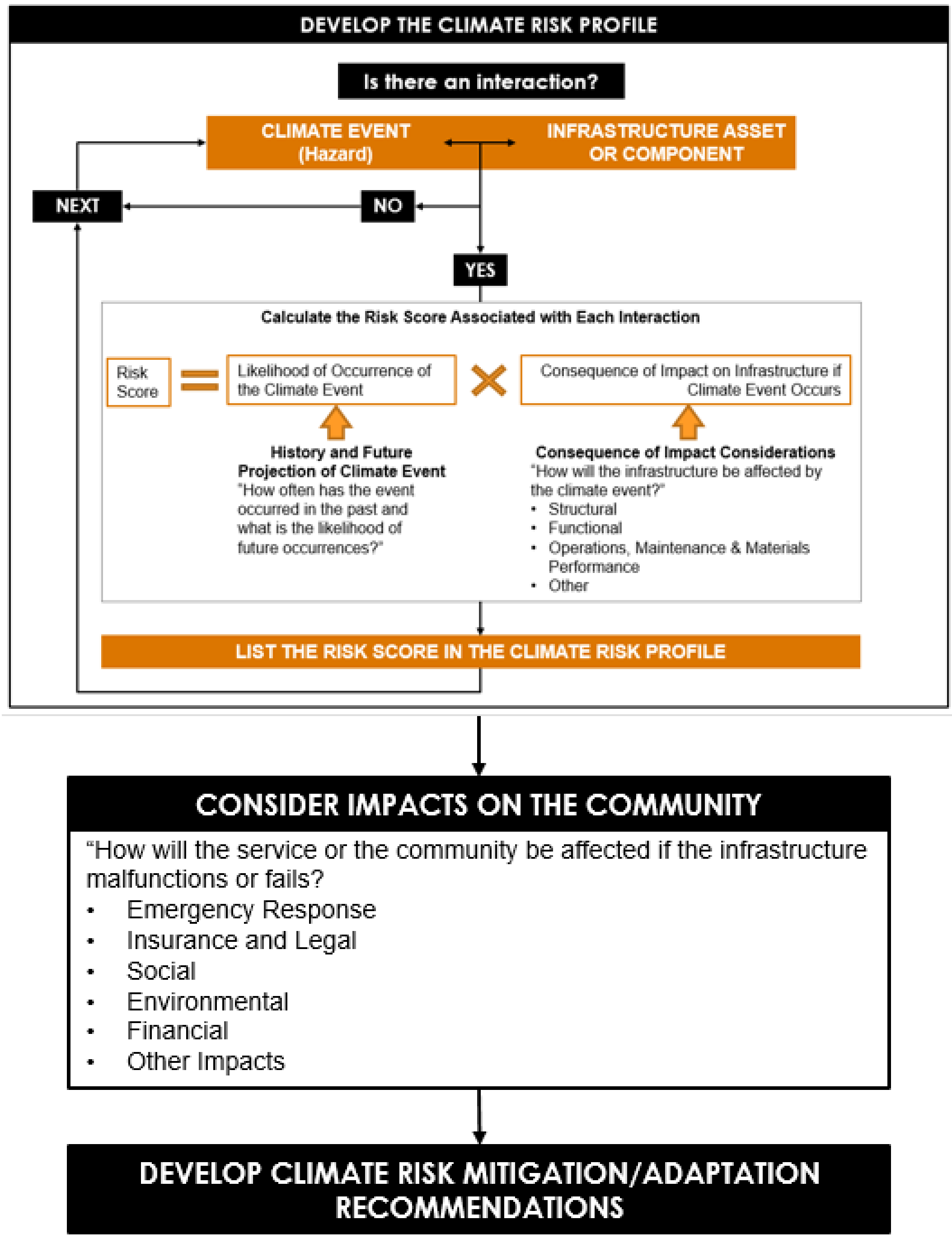

Figure 2-1 Illustration of the risk ad vulnerability assessment process

2.2 TIMESCALE OF ASSESSMENT

As the Project is expected to be in service for 30+ years, the timescale selected for this assessment is 30-60 years. There are currently no plans for Project decommissioning.

Climate projections were provided for 2020s, 2050s and to 2080s-time horizons. Short-term (up to 2020s) and longer-term (up to 2080s) climate change implications trend in the same direction for the climate parameters identified for this assessment and thus will not be separately discussed. Refer to Appendix A for the detailed climate projections up to the 2080 timeline.

2.3 PLAUSIBLE CLIMATE SCENARIOS

Climate modeling uses various greenhouse gas (GHG) emissions scenarios, known as Representative Concentration Pathways (RCPs) (see adjacent text box), to predict how future climate will behave under different concentrations and rates of release of GHGs to the atmosphere, as well as different global energy balances.

Representative Concentration Pathways (RCPs)

RCPs describe potential 21st century scenarios of GHG emissions, atmospheric GHG concentrations, air pollutant emissions, and land use. These RCPs are used for making projections and are based on the factors that drive anthropogenic GHG emissions: population size, economic activity, lifestyle, energy use, land use patterns, technology adoption, and climate policy. Each of the RCP emissions pathways is achievable, and directly relates to the choices made by global society.

(Source: Metro Vancouver, 2016)

Various future trajectories of GHG emissions are possible depending on the global mitigation efforts in the coming years. RCPs are established by the Intergovernmental Panel on Climate Change (IPCC), the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation (IPCC, 2014)

2.3.1 Using RCP 8.5 for resilience assessment

The IPCC has established four GHG emissions scenarios based on RCPs, as outlined below.

- RCP 8.5 – RCP 8.5 is considered the global ‘business as usual’ greenhouse gas emissions
- RCP 6.0 – in the RCP 6.0 scenario, GHG emissions double by 2060 and then dramatically fall but remain well above current levels
- RCP 4.5 - RCP 4.5 is considered the ‘medium stabilization’ scenario where global mitigation efforts result in about half of the emissions compared to RCP 8.5
- RCP 2.6 - the RCP 2.6 emissions scenario may be achievable with extensive adoption of biofuels/renewable energy and large-scale changes in global consumption habits, along with carbon capture and storage. RCP2.6 is representative of a scenario that aims to keep global warming likely below 2°C above pre-industrial temperatures

Current estimates of GHG emissions reflect the RCP 8.5 path; this has been re-confirmed by the recent IPCC Special Report on Global Warming of 1.5°C (IPCC, 2018). Figure 2-2 shows the various RCPs scenarios mapped out to the year 2100 reflecting different rates of GHG emissions.

This assessment is thus based on climate projections estimated under the RCP 8.5 scenario.

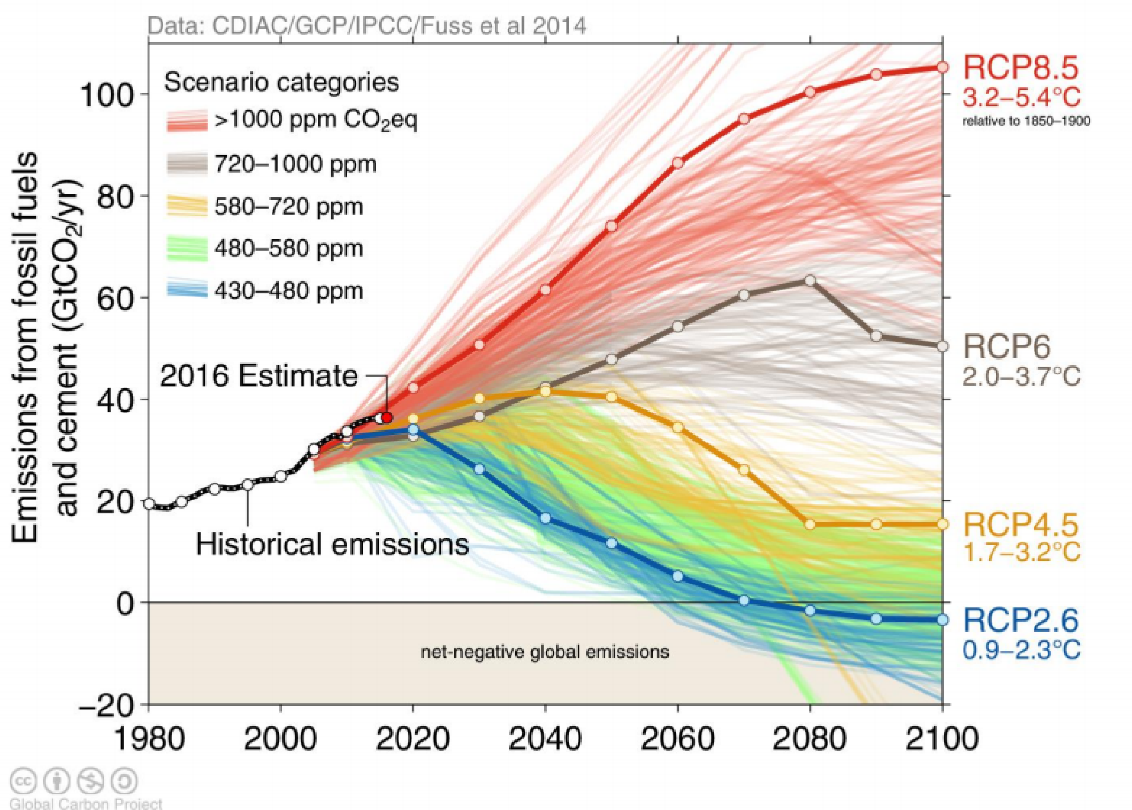

Figure 2-2 GHG Emissions estimate (Source: Global Carbon Project, 2016)

Future climate projections in this assessment were established based on data obtained through the Climate Change Hazards Information Portal (CCHIP) created by Risk Sciences International (RSI), and CANGRD data developed in a collaboration between Natural Resources Canada and Environment and Climate Change Canada. Refer to Appendix A for a detailed climate profile for the Project area.

2.4 IDENTIFICATION AND ASSESSMENT OF CLIMATE HAZARDS

For this assessment, a rating system compatible with the PIEVC Protocol was adopted for the likelihood (probability) of a climate event occurring and for the consequence (severity of the impact) on the components of the infrastructure system, should the climate event occur.

Table 2-1 shows the climate hazards identified for the Project assets under assessment. During the information gathering stage (see Section 2 Methodology), the parameters listed in Table 2-1 were identified as affecting having potential impacts on Project assets. As discussed in Section 2.2, short-term and longer-term climate change implications are similar for the climate parameters identified for this assessment and thus will not be separately discussed.

Table 2-1 also describes the confidence level associated with the data and projections for each climate parameter. For example, projections based on Global Climate Models (GCMs) and downscaling of such models are considered:

- adequate (higher confidence) for general temperature and precipitation projections
- less adequate (lower confidence) for extreme parameters
- inadequate for combined events (low confidence) such as wind/rain, freezing rain, etc.

Combined events are inferred based on other parameters, resulting in lower confidence for projections of combined event parameters. For example, fog formation is a complex process and the projected prevalence of fog events under future climate conditions is not as well understood as other parameters. Confidence may also refer to whether other studies have been done for the climate events projections in the geographical area.

Freezing rain was also considered as a potential climate parameter impacting Project assets as it is a common issue for rail infrastructure across North America. However, freezing rain in the Metro Vancouver region is not a common phenomenon. Based on the information provided by the CMBC operational staff interviewed for this climate assessment, as well as the BCRTC operational interviewed as part of the climate assessment for the Expo & Millennium Line Upgrade Program (Stantec, 2018a and 2018b), freezing rain has not been identified as a past climate issue for the Region. Future climate projections also confirms that freezing rain is not anticipated to become common in the region.

Table 2-1 Climate Parameters Selected for Resilience Assessment up to 2080s-Time Horizon

Climate Parameter	Trend	Confidence Level	Remarks
Temperature			
Mean seasonal	Increase	High	Average summer temperatures are projected to increase more than other seasonable averages.
Extremes (High Temperature)	Increase	High	Greatest maximum temperature increase is again projected in the summer season. Significant increase in number of days with temperature >= 30°C. This also has implications on fire hazards.
Precipitation			
Extremes Precipitation	Increase	Medium-High	Projected IDF information suggests increased storm intensity for all short duration rainfalls (5 min events to 24-hour events).
Sustained rainfall	Increase	Medium-High	Similar to short duration events, 3, 5, and 7-day rainfall accumulations are expected to increase. Summer was the only season to have a projected decrease in total rainfall
Snow accumulation	In Project location: Decrease	Medium	Days with snow accumulation in the Project location are already quite low but are expected to decrease even further with fewer days with temperatures capable of creating snow.
Snow storm	Frequency: Decrease Intensity: Increase	Medium	Similar to snow accumulation there are fewer days expected with temperatures capable of creating snow; however, similar to rainfall events when a storm does occur it is likely to be more intense

Table 2-1 Climate Parameters Selected for Resilience Assessment up to 2080s-Time Horizon

Climate Parameter	Trend	Confidence Level	Remarks
Other meteorological events			
Wind	Increase in extreme wind speeds	Medium-Low	Climate models have predicted a slight increase in the wind speeds of intense wind events, but this component of climate change projection is not yet as well understood as parameters such as temperature.
Ice/Frost	Decrease	High	The number of freeze-thaw events and average days of frost for the Metro Vancouver area are projected to decrease under the effects of climate change
Fog	Decrease	Low	Majority of areas globally are seeing a trend of decreasing fog events and decreasing intensity of fog. Although this trend is not as well understood as other climate parameters, there aren't obvious reasons to deviate from this trend as recent climate changes continue.

2.5 ASSETS UNDER ASSESSMENT

The Project assets and systems were grouped into the categories shown in Table 2-2.

Table 2-2 List of Project Assets under Resilience Assessment

Project Infrastructure Components	
Elevated Guideway	
• Tracks (elevated guideway sections)	• Guideway structures
Underground Civil Works	
• Tunnel(s) & tunnel excavation (tunnel boring) • Tunnel drainage systems • Station excavation • Tracks (tunnel sections)	• Tunnel lining • Station structural concrete works • Utility relocations
Stations – Non-structural Works	
• Station house building envelope • Platforms • Mechanical systems • Electrical systems • Station conveyance systems • Fire protection systems	• Station support systems (video surveillance, public address, hydro, platform intrusion, lighting) • Street access • Back-up power • Neighbourhood amenities
Integrated Systems	
• Automatic train control • Signal systems – track switching	• Communications systems (telephone, radio) • Power supply systems
Personnel	
• Operations & Maintenance Personnel	• Construction Personnel

Note that the Project scope does not include the procurement of train vehicles, additional train storage capacity, or operations and maintenance facilities (MOTI, 2018), as these are considered under the separately proposed Expo & Millennium Line Upgrade Program (EMUP). A separate climate resilience assessment has been completed for EMUP assets and is expected to be submitted to Infrastructure Canada in early 2019 (see Stantec, 2018a and 2018b).

2.6 CLIMATE CHANGE HAZARDS & CONSEQUENCES

2.6.1 Consequence of Impact

Table 2-3 shows the three consequence of impacts that were considered as part of this Climate Resilience Assessment. The list of consequence of impact provides a framework for considering the potential impacts of climate on the Project's components.

Table 2-3 Consequence of Impact

Consequence of Impact
Engineering/Structural ***For example, climate change may lead to premature failure of structures/equipment from increased thermal stresses.***
• Equipment or material safety (fracture/fatigue/deflection/deterioration/deformation, etc.) • Equipment or materials design and selection
Operations & Maintenance (O&M) ***For example, climate change may impact the ability to access worksite for maintenance or require updates to occupational health & safety procedures in maintaining access to worksites or lead to accelerated deterioration of material performance.***
• Occupational Safety, Health & Safety • Access to worksite or ability to perform maintenance • Equipment or component replacement cycles or frequencies • Materials performance (changes from design expectation)
Functionality ***For example, climate change may impact the ability of the infrastructure system to deliver at normal levels of service.***
• Operational capacity of the Broadway Subway system

Community and environmental impacts were not assessed in detail as part of this assessment. The most prominent Project-related community impacts from climate hazards are associated with the disruption of SkyTrain service. The degree of community impact is based on the extent and duration of service disruption. For example, minor disruptions of a few minutes may have no perceptible impacts while longer disruptions may lead to negative impacts to the local economy and potentially the environment. Potential impacts to the environment stemming from longer disruptions to SkyTrain service may include increased ground-level pollution and GHG emissions due to increased use of personal vehicles as displaced transit users seek alternative travel options.

2.6.2 Impact on Assets

Table 2-4 lists the potential impacts from both extreme events and incremental or slow onset climate parameters on Project assets. The table is based on input from interviews with the Project Owner's Engineer Team (see Table 5-1 for a list of the individuals providing input) and a review of the following documents (see Section 7 References for a detailed listed):

- Climate vulnerability assessment completed for TransLink assets in 2012 (AECOM, 2012)
- Climate vulnerability assessments for similar transit infrastructure (Binder et al, 2013; Chiotti et al, 2017; LACMTAC, 2013)
- Climate vulnerabilities identified as part of a Climate Resilience Assessment completed for TransLink's Expo & Millennium Lines Upgrade Program [1]
- Climate vulnerabilities identified as part of a Climate Resilience Assessment completed for TransLink's Surrey-Newton-Guildford Light Rail Transit line [2].

Table 2-4 Potential Climate Impact on Assets

Climate Parameter	System Affected	Potential Climate Impacts on Assets
Temperature		
Mean seasonal	• Station mechanical systems • Station conveyance systems (elevators)	Increase in demands on HVAC systems for stations and conveyance (e.g., more and longer cooling in summer); higher energy consumption.
Extremes (High Temperature)	• Station mechanical systems • Station conveyance systems (elevators)	Increase in demands on HVAC systems for stations and conveyance (e.g., more and longer cooling in summer); higher energy consumption.
	• Maintenance or Construction Personnel	Extreme weather working conditions may lead to delay of regularly scheduled maintenance or construction and tunnel boring procedures.
Extreme Precipitation & Sustained Rainfall	• Tracks	Potential flooding of the tracks (both elevated guideway and tunnel sections) may lead to service disruptions; impacts on underground drainage systems
	• Station building envelope	Potential increased wear on exterior membranes and envelope systems may lead to more frequent replacement.
	• Station access	Potential loss of stations access if flooding occurs due to local municipal stormwater systems failures.
	• Maintenance or Construction Personnel	Extreme weather working conditions may lead to delay of regularly scheduled maintenance or construction and tunnel boring procedures.

[1] This work was completed by Stantec in 2018 and is expected to be submitted to Infrastructure Canada shortly. These reports are titled "Expo & Millennium Line Upgrade Program (Excluding Stations) Climate Change Resilience Assessment, October 1, 2018" and "Expo & Millennium Line Upgrade Program (Stations Only) Climate Change Resilience Assessment, October 15, 2018".

[2] The report was titled "Surrey- Newton-Guildford LRT Project, Climate Lens – Climate Change Resilience Assessment. November 6, 2018".This work was completed by Stantec in 2018 and was expected to be submitted to Infrastructure Canada prior to the cancellation of the LRT Project in November 2018.

Table 2-4 Potential Climate Impact on Assets

Climate Parameter	System Affected	Potential Climate Impacts on Assets
Snow Accumulation and Snow Storms	• Tracks (elevated guideway)	Accumulated snow and ice on power rail (in elevated guideway section) may cause service delays.
	• Signal systems	Accumulated snow and ice may reduce ability of track switches (in elevated guideway section) to operate.
	• Maintenance or Construction Personnel	Extreme weather working conditions may lead to delay of regularly scheduled maintenance or construction and tunnel boring procedures below ground.
	• Third-party services: electricity	May cause loss of power to SkyTrain system or potentially loss of access to provide back-up power.
Ice/Frost	• Tracks (elevated guideway)	Accumulated ice on power rail may cause service delays.
	• Signal systems	Accumulated ice (in elevated guideway section) may reduce ability of track switches to operate.
Wind	• Tracks (elevated guideway)	High winds can cause debris such as broken tree branches to accumulate on elevated guideway section of track.
	• Third-party services	Electricity and communications' external equipment susceptible to malfunction or damage due to high winds can indirectly impact SkyTrain system functionality.
	• Maintenance or Construction Personnel	Extreme high winds may lead to delay of regularly scheduled maintenance or construction and tunnel boring procedures.
Sea Level Rise	• Tunnels • Stations	Sea level rise may impact groundwater flows which could increase seepage into underground assets such as tunnels and stations. Sea level rise may impact the tunnel opening (portal) in the False Creek Flats area when combined with wind or rain storms.

2.7 RISK ANALYSIS AND EVALUATION

In this assessment, the Risk Rating is defined as the product of two ratings.

Risk Rating = Likelihood Rating x Consequence of Impact Rating

- Likelihood Rating: a rating that represents the probability or likelihood of occurrence of a climate event above a selected threshold, ranging from 0 (not applicable) to 5 (certain to occur)
- Consequence of Impacts Rating: a rating of the impacts on the infrastructure asset or component should the climate event occur, ranging from 0 (no impact) to 5 (complete failure)

Risks are evaluated under current climate conditions to establish a baseline; future risks are assessed considering future (projected) climate changes and the projected condition of the infrastructure.

Table 2-5 Description of Likelihood Ratings

Rating	Description of Likelihood	Description of Probability
0	Negligible	Negligible
1	Very Low	Not likely to occur in assessment period; or Not likely to increase in intensity and/or duration during the assessment period
2	Low	Likely to occur once between 30-50 years; or Likely to increase in intensity and/or duration over a 30 to 60-year period
3	Moderate	Likely to occur once between 10-30 years; or Likely to increase in intensity and/or duration over a 10 to 30-year period
4	High	Likely to occur at least once a decade; or Likely to increase in intensity and/or duration over a decade
5	Very High	Likely to occur once or more annually; or Likely to increase in intensity and/or duration on an annual basis

Table 2-6 lists the future likelihood ratings for the climate parameters selected for assessment.

Table 2-6 Future Likelihood Rating for Selected Climate Parameters

Climate Parameter	Likelihood Rating
Mean seasonal - Temperature	5
Extremes (High) - Temperature	5
Extreme Precipitation	5
Sustained rainfall	5
Snow accumulation	4
Snow storm	4
Ice/Frost	4
Wind	4
Fog	4
Sea Level Rise	5

The infrastructure performance and severity of impact to each climate parameter identified are evaluated based on the professional judgement of the assessors. Table 2-7 describes the severity ratings for Project assets and systems.

Table 2-7 Consequence of Impact Rating

Consequent of impact Rating	Qualitative Descriptor	Description of Impact
0	No Effect	• No effects
1	Very Low	• Can be corrected during regular maintenance cycle • No structural or property damage • No SkyTrain service disruptions • Temporary impacts only • Access is maintained
2	Low	• Some extra costs to repair but can be covered within current O&M and capital budgets • Routine operations for minor incidents • Infrastructure is still operable and accessible although minor SkyTrain service disruption may be possible • Reduced ability to perform scheduled maintenance
3	Moderate	• Manageable infrastructure damage but repair costs may be beyond current O&M and Capital budgets • Infrastructure still operable but a few SkyTrain stations may not be accessible • Brief SkyTrain service disruption may be possible • May cause station closure
4	High	• Heavy burden on internal resources to repair infrastructure • Infrastructure still operable but several stations are not accessible • Lengthy service disruption; may require temporary bus bridge to maintain service along SkyTrain Route • Some station closure
5	Very High	• Loss of life, property, mobility, access to emergency services, or power • Complete infrastructure replacement due to inability to replace individual components • Significant SkyTrain service disruptions may be possible, requiring temporary or extensive bus bridge to maintain service along SkyTrain Route • Multiple SkyTrain Stop closure

Using the equation “Risk Rating = Likelihood Rating x Consequence of Impact Rating” provides numerical risk ratings from 0-25 which are categorized as shown in Table 2-8. In Table 2-9, risk ratings are explained with suggested risk treatments as per the Climate Lens General Guidance.

Table 2-8 Risk Evaluation Matrix (Risk Scores)

Consequence of Impact Rating (S)							
	Very High	5	5	10	15	20	25
	High	4	4	8	12	16	20
	Moderate	3	3	6	9	12	15
	Low	2	2	4	6	8	10
	Very Low	1	1	2	3	4	5
			1	2	3	4	5
			Very Low	Low	Moderate	High	Very High
			Likelihood Rating				

Table 2-9 Risk Classification

Risk Classification	Risk Rating	Description of Risk	Recommended Risk Treatment
Negligible	1	• No permanent damage. • No SkyTrain service disruption occurs	Risks do not require further consideration
Low	2-3	• Minor asset/equipment damage. • Minor SkyTrain service disruption may occur. • No permanent damage. • Minor repairs or restoration expected.	Controls likely, but not required.
Moderate	4-6	• Expected limited damage to asset or to equipment components. • Minor repairs and some equipment replacement may be required. • Brief SkyTrain service disruption may occur. • May cause SkyTrain station or Line closure.	Some controls required to reduce risks to lower levels. Risk to be monitored for changes over time.
High	8-12	• May result in significant permanent damage; or loss of asset or equipment that may require complete replacement. • Lengthy SkyTrain service disruption may occur, requiring temporary bus bridge to maintain service. • Several SkyTrain station closures may occur.	High priority control measures required.
Very High	>15	• May result in significant permanent damage; or loss of asset or equipment that may require complete replacement. • Significant SkyTrain service disruptions may be possible, requiring temporary bus bridge to maintain the service. Multiple SkyTrain station closure.	Immediate controls required.

2.8 RISK PROFILE

Using the risk evaluation process described in the above sections, a risk profile for Project assets and systems was created (Table 2-10). The confidence in future climate projections was considered in assessing the risks shown in the risk profile. Low or negligible risk events (where risk scores were less than 4) that are not recommended for further consideration have not been identified in Table 2-10.

In reviewing Table 2-10, it is important to note that the Climate Change Impacts Risk Profile is a prioritization of impacts relative to each other, not against an external benchmark. Designations of ‘moderate’ or high’ risk items should be considered in the context that many risks can be mitigated or monitored through future operations & maintenance policies and procedures.

In general, many climate risks can be mitigated through Operations & Maintenance (O&M) policies and procedures. As the Project is an extension of the Millennium Line currently operated by TransLink, it is expected to be fully integrated into existing SkyTrain systems and protocols. Furthermore, mitigation measures listed as ‘Unknown’ should not be interpreted as the fact that there are no current mitigation measures expected through the Project’s reference design and through the Project’s operational phase, but only that the Owner’s Engineer team interviewed for this assessment did not explicitly identify or confirm strategies that mitigate the specific climate risk.

It is outside the scope of this assessment to complete a detailed review of the reference design completed thus far, or to review the existing TransLink O&M policies and procedures for their effectiveness in reducing climate risks. However, this assessment may motivate internal reviews of the Project’s reference design and existing O&M policies with a focus to adapting to climate risks as they have been identified in this assessment.

Table 2-10 Climate Change Impacts Risk Profile

Climate Parameter	System Affected	Risk Rating	Asset Performance Potentially Affected	Potential Climate Impacts on Asset	Project Mitigation Measures (if known)[3]	Potential Adaptation Measure or Risk Treatment
Temperature						
Mean seasonal temperature	Stations – mechanical systems, electrical systems, conveyance systems	Moderate (5)	Engineering, O&M	Increase in demands on HVAC systems for equipment cooling (e.g. more, and longer cooling in summer) resulting in increased wear of the equipment; and increased energy consumption and costs.	• Mechanical cooling is expected to be provided for rooms housing temperature sensitive equipment.	• Consider performing detailed energy consumption and energy cost analysis during detailed design to determine degree of impact; energy analysis should account for future climate projections. • Consider mechanical systems that account for future temperature projections (i.e. incorporate cooling); or accept the risk and monitor changes. • Consider the potential unintended consequence for increased GHG emissions from increased energy consumption.
Extremes (High Temperature)	Stations – mechanical systems, electrical systems, conveyance systems	High (10)	Engineering, O&M	Increase in demand on HVAC systems (e.g. higher peak cooling in summer required); higher energy consumption and costs.	• Mechanical cooling is expected to be provided for rooms housing temperature sensitive equipment.	• Consider performing detailed energy consumption and energy cost analysis during detailed design to determine degree of impact; energy analysis should account for future climate projections. Consider mechanical systems that account for future temperature projections (i.e. incorporate cooling); or accept the risk and monitor changes. • Consider reviewing and revising existing O&M and worker safety policies around working in elevated temperatures. • Consider the potential unintended consequence for increased GHG emissions from increased energy consumption.
Extremes (High Temperature)	Tracks (elevated guideway section)	High (10)	Engineering, O&M, Functionality	Potential for track warping for areas of the track exposed to extreme heat; potential increased wear on track expansion joints leading to shorter service life.	• Track design and track laying temperature is expected to take into account high temperatures; however, it is unclear whether the future temperature projections have been referenced.	• Consider further detailed analysis to confirm potential for warping for Project location under future climate conditions. • Consider track design and track laying temperatures based on future climate projections for extreme temperatures to minimize potential for track warping. • Consider reviewing and revising existing O&M track inspection policies; or accept the risk and monitor for changes.
Extremes (High Temperature)	Third-party services (electricity)	Moderate (5)	Engineering, O&M,	Increase potential for failure of third-party services (electricity) due to increased fire risk from prolonged extreme temperatures.	• Multiple traction power substations are expected to be part of the design to allow for some redistribution of power service in case of local power outage.	• Continue to engage with BC Hydro to monitor this risk and the effectiveness of the risk mitigation strategy. • Consider the potential environmental impacts if planning for additional back-up power generation.
Extremes (High Temperature)	Maintenance or Construction Personnel	Moderate (5)	Engineering, O&M, Functionality	Extreme weather working conditions may lead to loss of productivity, delay of regularly scheduled maintenance or construction works, including station tunnel boring works.	Unknown[3]	• Consider reviewing and revising existing O&M, construction policies, and worker safety policies around working in elevated temperatures; or accept the risk and monitor for changes.
Extremes (High Temperature)	System-wide	Moderate (5)	Engineering, O&M, Functionality	Potential for increased fire risk due to prolonged extreme temperatures.	Unknown[3]	• Consider reviewing and revising existing O&M policies and procedures for monitoring fire risk during extreme temperature events.
Precipitation						
Extreme Precipitation (rainfall)	Station access	High (10)	Engineering, O&M, Functionality	Potential for loss of station access from localized street flooding (municipal stormwater system failures).	• Project has been engaging with the City of Vancouver or Metro Vancouver on stormwater system upgrades as appropriate; it is unclear whether future precipitation projections have been incorporated or which climate scenarios have been evaluated.	• Continue engaging with the City of Vancouver and/or relevant environmental agencies on options for reducing risks of localized street flooding; or accept the risk and monitor for changes.

[3] Mitigation measures listed as 'Unknown' should not be interpreted as the fact that there are no current mitigation measures expected through the Project's reference design and through the Project's operational phase, but only that the Owner's Engineer team interviewed for this assessment did not explicitly identify or confirm strategies that mitigate the specific climate risk. It is outside the scope of this assessment to complete a detailed review of the reference design completed thus far, or to review the existing TransLink O&M policies and procedures for their effectiveness in reducing climate risks. However, this assessment may motivate internal reviews of the Project's reference design and existing O&M policies with a focus to adapting to climate risks as they have been identified in this assessment.

Table 2-10 Climate Change Impacts Risk Profile

Climate Parameter	System Affected	Risk Rating	Asset Performance Potentially Affected	Potential Climate Impacts on Asset	Project Mitigation Measures (if known)[3]	Potential Adaptation Measure or Risk Treatment
Extreme Precipitation (rainfall)	Tracks (tunnels) Stations - Electrical systems Tunnel drainage systems	High (10)	Engineering, O&M, Functionality	Potential for water ingress into station from localized street flooding (municipal stormwater system failures) via ventilation shafts, station entrances, tunnel Portal, or other openings.	• Project has been engaging with the City of Vancouver or Metro Vancouver on stormwater system upgrades as appropriate; it is unclear whether future precipitation projections have been referenced. • It is unclear whether tunnel or below-grade station have considered potential impacts of street flooding.	• Continue designing for flood proofing stations and tunnels, or provide additional tunnel drainage capacity. • Consider reviewing and revising existing O&M policies around monitoring for extreme precipitation and inspection of drainage systems, or accept the risk and monitor for changes.
Extreme Precipitation (rainfall	Tracks (elevated guideway)	High (10)	Engineering, O&M, Functionality	Potential for track flooding due to plugged drainage openings.	Unknown [3]	• Consider designs for elevated guideway drainage that incorporates future precipitation projections. • Consider reviewing and revising existing O&M policies around monitoring for extreme precipitation and inspection of drainage systems, or accept the risk and monitor for changes.
Extreme Precipitation (rainfall)	Platforms	Moderate (5)	O&M	Extreme rainfall may increase occurrence of passenger slips and falls in stations.	Station finishes are expected to be selected to reduce potential for slips and falls.	• Consider reviewing and revising existing O&M policies around station cleaning during extreme weather, or accept the risk and monitor for changes.
Extreme Precipitation (rainfall)	Maintenance or Construction Personnel	Moderate (5)	Engineering, O&M, Functionality	Extreme weather working conditions may lead to loss of productivity, delay of regularly scheduled maintenance, construction works, including station tunnel boring works.	Unknown [3]	• Consider reviewing and revising existing O&M, construction policies, and worker safety policies around working in in rain conditions; or accept the risk and monitor changes.
Extreme Precipitation (rainfall)	Station building envelope	Moderate (5)	Engineering, O&M,	Potential increased wear on exterior membranes and envelope systems due to precipitation or wind-driven precipitation may lead to more frequent replacement.	Unknown [3]	• Consider selecting materials for exterior membranes and envelope systems exposed to precipitation and wind-driven precipitation for greater durability; or accept the risk and monitor for changes.
Sustained precipitation	Station access	High (10)	Engineering, O&M, Functionality	Potential for loss of station access from localized street flooding (municipal stormwater system failures).	• Project has been engaging with the City of Vancouver or Metro Vancouver on stormwater system upgrades as appropriate; it is unclear whether future precipitation projections have been referenced, or which climate scenarios have been evaluated.	• Continue engaging with the City of Vancouver and/or relevant environmental agencies on options for reducing risks of localized street flooding.
Sustained precipitation	Tracks (tunnels) Stations - Electrical systems Tunnel drainage systems	High (10)	Engineering, O&M, Functionality	Potential for water ingress into station through from localized street flooding (municipal stormwater system failures) via ventilation shafts, station entrances, tunnel Portal, or other openings.	• Project has been engaging with the City of Vancouver or Metro Vancouver on stormwater system upgrades as appropriate; it is unclear whether future precipitation projections have been referenced, or which climate scenarios have been evaluated. • It is unclear whether tunnel or below-grade station have considered potential likelihood or impacts of street flooding.	• Continue designing for flood proofing stations and tunnels, or provide additional tunnel drainage capacity. • Consider reviewing and revising existing O&M policies around monitoring for extreme precipitation and inspection of drainage systems, or accept the risk and monitor for changes.
Sustained precipitation	Tracks (elevated guideway)	High (10)	Engineering, O&M, Functionality	Potential for track flooding due to plugged drainage openings in the guideways.	Unknown [3]	• Consider designs for elevated guideway drainage that incorporates future precipitation projections. • Consider reviewing and revising existing O&M policies around monitoring for extreme precipitation and inspection of drainage systems, or accept the risk and monitor for changes.
Sustained precipitation	Platforms	Moderate (5)	O&M	Extreme rainfall may increase occurrence of passenger slips and falls in stations.	Station finishes are expected to be selected to reduce potential for slips and falls. .	• Consider reviewing and revising existing O&M policies around station cleaning from extreme precipitation or accept the risk and monitor for changes.
Sustained precipitation	Station building envelope	Moderate (5)	Engineering, O&M,	Potential increased wear on exterior membranes and envelope systems leading to more frequent replacement.	Unknown [3]	• Consider selecting materials for exterior membranes and envelope systems exposed to precipitation for greater durability; or accept the risk and monitor for changes.

Table 2-10 Climate Change Impacts Risk Profile

Climate Parameter	System Affected	Risk Rating	Asset Performance Potentially Affected	Potential Climate Impacts on Asset	Project Mitigation Measures (if known)[3]	Potential Adaptation Measure or Risk Treatment
Sustained precipitation	Maintenance or Construction Personnel	Moderate (5)	Engineering, O&M, Functionality	Extreme weather working conditions may lead to loss of productivity, delay of regularly scheduled maintenance, construction works, including station tunnel boring works.	Unknown [3]	• Consider reviewing and revising existing O&M, construction policies, and worker safety policies around working in rain conditions; or accept the risk and monitor changes.
Snow (accumulation and storms)	Signal systems – track switching	High (8)	Engineering, O&M, Functionality	Accumulated snow on elevated guideway section may reduce ability of track switches to fail and lead to service delays.	Unknown [3]	• Consider designs that can mitigate this risk (e.g. track switch heaters); consider reviewing and revising existing Winter Operations policy on snow-clearing/de-icing; or accept the risk and monitor changes.
Snow (accumulation and storms)	Third-party services: electricity	High (8)	Functionality	Loss of power or loss of access to provide back-up power may lead to service delays.	• Multiple traction power substations allow for some redistribution of power service in case of local outage.	• Continue to engage with BC Hydro to further mitigate this risk and the effectiveness of the risk mitigation strategy; or accept the risk and monitor changes. • Consider the potential environmental impacts if planning for additional back-up power generation.
Snow (accumulation and storms)	Maintenance or Construction Personnel	Moderate (4)	Engineering, O&M, Functionality	Extreme weather working conditions may lead to loss of productivity, delay of regularly scheduled maintenance, construction works or tunnel boring works.	Unknown [3]	• Consider reviewing and revising existing O&M, construction policies, and worker safety policies around working in snow conditions; or accept the risk and monitor changes.
Other Meteorological events						
Ice/Frost	Signal systems – track switching	High (8)	Engineering, O&M, Functionality	Accumulated ice may reduce ability of track switches on elevated guideway to fail and lead to service delays.	Unknown [3]	• Consider designs that can mitigate this risk (e.g. track switch heaters); consider reviewing and revising existing Winter Operations policy on snow-clearing/de-icing; or accept the risk and monitor changes.
Wind (high winds)	Tracks (elevated guideway) Signal systems – switches	High (8)	Functionality	Service may be impeded by debris blown onto tracks or switches.	Trees and landscaping are not expected to be within the vicinity of the elevated guideway.	Consider reviewing and revising the following policies around the elevated guideways: • O&M policies to monitor and remove materials during and after high wind events. • Landscaping policies around tracks or track equipment to minimize or eliminate this risk.
Wind (high winds)	Third-party services: electricity	High (8)	Functionality	Loss of power or loss of access to provide back-up power may lead to service delays.	• Multiple traction power substations allow for some redistribution of power service in case of local outage	• Continue to engage with BC Hydro to monitor this risk and the effectiveness of the risk mitigation strategy. • Consider the potential environmental impacts if planning for additional back-up power generation.
Wind (high winds)	Maintenance or Construction Personnel	Moderate (4)	Engineering, O&M, Functionality	Extreme weather working conditions may lead to loss of productivity, delay of regularly scheduled maintenance, construction works or tunnel boring works.	Unknown [3]	• Consider reviewing and revising existing O&M and worker safety policies around working in in high wind; or accept the risk and monitor changes.
Fog	Maintenance or Construction Personnel	Moderate (4)	Engineering, O&M, Functionality	Fog and reduced visibility may lead to reduced productivity and delay of regularly scheduled maintenance, construction works or tunnel boring works.	Unknown [3]	• Consider reviewing and revising existing O&M, construction policies, and worker safety policies around working in poor visibility; or accept the risk and monitor changes.
Sea Level Rise	Tunnels, tunnel lining	Moderate (6)	Engineering, O&M, Functionality	The portion of the tunnel and tunnel portal within the False Creek Flats may be vulnerable to long-term effects of sea level rise and related higher storm surges.	• Design is expected to include a barrier around the portal which may also provide protection against sea level rise and related higher storm surges; the extent of protection against sea level rise is unclear.	• Consider analyzing this risk in greater detail and incorporate floodproofing designs at the portal or throughout the tunnel (from potential for increased groundwater seepage) as deemed appropriate by the relevant design professionals.

3 ANALYSIS OF RESILIENCE OPTIONS

3.1 IDENTIFICATION OF RESILIENCE MEASURES

As seen in Table 2-10, there are many risks to infrastructure that can be efficiently and effectively addressed through operations and maintenance procedures. It is recommended O&M policies and procedures be reviewed and revised as necessary to ensure they have an emphasis on improving system resilience, and health and safety requirements of users and Project staff, under a changing climate.

3.2 COST/BENEFIT ANALYSIS

A number of resilience measures are expected to be incorporated into the Project through its reference design, these are listed in Table 2-10 under "Potential Mitigation Measures (if known)". It is outside the scope of this assessment to complete a cost/benefit analysis of resilience design options.

Furthermore, many resilience measures can be addressed through operations and maintenance procedures. The completion of a cost benefit analysis for updating O&M measures is outside the scope of this assessment.

3.3 CONSIDERATION OF RESILIENCE PRINCIPLES

As recommended by the Climate Lens – General Guidance v1.1, the following is a discussion of how the climate change resilience principles have been incorporated into this assessment.

3.3.1 Proportionate Assessment

The Broadway Subway Project will represent a significant transit expansion in the Metro Vancouver region (the Region), addressing key gaps in the existing rapid transit network and completing the first phase of a longer-term vision to extend rapid transit to the University of British Columbia (UBC). It will support economic, urban, and environmental development within the Region, provide more people with a sustainable transportation choice, connect urban centres, and increase rapid transit mode-share.

The Project will be a critical asset to the region and as such, an extensive climate risk assessment, using, for example, the PIEVC Protocol vulnerability assessment in the Project's detailed design stage to ensure that owners, designers, construction team and operators of the Project understand the full range of climate risks to the Project over its operational life. A full PIEVC Protocol assessment can take 3-6 months and involve numerous multiday and multiple stakeholder workshops but would result in higher capacity for the Project team to understand the broad spectrum of climate risks to the Project.

3.3.2 Systemic Analysis of Risk

By using an approach which aligns with Engineers Canada's PIEVC Protocol and conforms to ISO 31000 Risk Management framework, this high-level risk identification and assessment was carried out with the intention to meet the requirements set by Infrastructure Canada's Climate Lens – General Guidance v1.1.

3.3.3 Pursuit of Multiple Benefits

This assessment has identified that many climate risks to the Project can be addressed through O&M policies and procedures. As the Project is an extension to the existing Millennium Line, O&M policies and procedures will be adopted. It is outside the scope of this climate resilience assessment to complete detailed review of existing O&M policies for effectiveness in reducing climate risks. However, this climate assessment may motivate internal reviews of O&M policies with a focus to adapting to climate risks for the Project as these have been identified in this assessment.

3.3.4 Avoidance of Unintended Consequences

At the current stage of Project, it is too early to fully consider the unintended consequences of risk transference or mitigation strategies. Stantec recommends this principle to be considered in detail during the design-build of the Project. For example, some risk mitigation strategies (e.g. increased cooling to mitigate the effects of higher temperatures) may lead to increased GHG emissions as an unintended consequence. In general, O&M measures for climate adaptation are not greenhouse gas (GHG) intensive. For potentially energy- and GHG-intensive risk mitigation strategies, Stantec recommends incorporating design targets for the reduction of operational GHGs to avoid long-term unintended environmental consequences.

4 RESILIENCE MEASURES SELECTION

As the Project is in the reference design stage, resilience measures for individual system components have not been designed in detail. Reference design work has been completed in preparation for the Project's procurement process.

Stantec recommends that resilience measures be further developed and evaluated as the Project progress into procurement, detailed design, construction and operation. This may be done through referencing the climate vulnerabilities identified through this assessment as a starting point, and by conducting a full PIEVC Protocol climate vulnerability assessment involving multiple internal and external stakeholders to develop a comprehensive profile of climate risks throughout the Project's lifecycle.

5 DESCRIPTION OF EVIDENCE BASE

To anticipate the climate vulnerabilities for the Project infrastructure, Stantec relied on the review of climate vulnerability assessments or adaptation plans completed by transit agencies with similar transit infrastructure or with similar climate hazards. The following sources of information were used (refer to Section 7 for detailed citations):

- Millennium Line Broadway Extension Project Business Case (MOTI, 2018)
- TransLink's previously completed climate change vulnerability study: Regional Transportation Strategy – Asset Management Project Climate Change Vulnerability Study. May 2012. (AECOM, 2012).
- Climate vulnerability assessments and adaptation plans completed by transit agencies with similar transit infrastructure or with similar climate hazards:
  - Sound Transit Climate Risk Reduction Project, September 2013, FTA Report no. 0075 (Binder et al., 2013)
  - Planning for Resilience – Towards a Corporate Climate Adaptation Plan (Metrolinx) September 2017 (Chiotti et al., 2017)
  - Los Angeles County Metropolitan Transportation Authority Climate Change Adaptation Pilot Project Report, FTA Report no. 0073 (LACMTA, 2013).
- City of Vancouver Coastal Flood Risk Assessment – Final Report, December 2014 (Northwest Hydraulics Consultants, 2014).
- City of Vancouver Coastal Flood Risk Assessment Phase II Final Report December 15, 2015 (Lyle et al., 2015).
- Climate Lens – Climate Change Resilience Assessments completed for other TransLink major projects (but not yet submitted to Infrastructure Canada:
  - Expo & Millennium Upgrade Program (Excluding Stations) Climate Change Resilience Assessment, October 1, 2018.
  - Expo & Millennium Line Upgrade Program (Stations only) Climate Change Resilience Assessment, October 15, 2018.
- The Province of BC's Coastal Floodplain Map Section U15: Potential Impact Areas of Sea Level Rise by the year 2100 in British Columbia (KWL, 2012).
- Climate Projections for Metro Vancouver Report (Metro Vancouver, 2016).
- Environmental Assessment Certificate Application for the Richmond•Airport•Vancouver Rapid Transit Project, Section 19, Summary of the Assessment of Impacts and Mitigation and Compensation Measures for RAV Project Construction and Operation, December 2004.
- Evergreen Line Rapid Transit Project Environmental Assessment Certificate Application, Section 23: Summary of Project Impacts, Mitigation Measures and Potential Residual Effects, date unknown

Targeted phone interview with members of the Owner's Engineer Team to discuss climate risks that can be addressed through design or may impact the construction of the Project (see Table 5-1).

To address the climate risks to the operational phase of the Project, Stantec also drew on the operational experience of seven Expo & Millennium Line SkyTrain operators, the British Columbia Rapid Transit Company (BCRTC), who were interviewed through a similar climate resilience assessment for the Expo & Millennium Line Upgrade Program completed by the same Stantec resilience assessment team. These assessments, titled "Expo & Millennium Line Upgrade Program (Excluding Stations) Climate Change Resilience Assessment, October 1, 2018" and "Expo & Millennium Line Upgrade Program (Stations Only) Climate Change Resilience Assessment, October 15, 2018", were completed by Stantec in fall 2018 and have not been submitted to Infrastructure Canada at the writing of this Project's resilience assessment.

Table 5-1 Telephone Interviewees

Name	Role, Organization	Focus of interview
Alan Hartley	Technical Lead – Owner's Engineer Team, Stantec	Overall Project background
David Kong	Lead – Track & Rail, Stantec	Track design
David Tyler	Lead – Design, David Tyler Consulting	Structures design
Dena Abakumov	Lead – Utilities – Owner's Engineer Team, Stantec	Utilities upgrades
Marco Moccichino	Tunnels, McMillen Jacobs Associates	Tunnels design
Ian Graham	Operations & Maintenance Advisor, Westco Consulting	Operations & Maintenance

5.1 CLIMATE DATA

Stantec has evaluated some climate data from nearby weather stations, which was obtained through the Climate Change Hazards Information Portal (CCHIP) created by Risk Sciences International (RSI). In addition to assembled climate data from weather stations, CCHIP also publishes data sets for the entire country, on a 10km by 10km grid – known as the Canadian Gridded Temperature and Precipitation Anomalies (CANGRD) data. This gridded data was developed in a collaboration between Natural Resources Canada (NRCan) and Environment and Climate Change Canada (ECCC) – this data compiles information from several sources, including interpolating weather station data and although data from a real weather station is preferable, this CANGRD is well accepted and researched.

Future climate projections are based on published Intergovernmental Panel on Climate Change (IPCC) data; the scope of this assessment did not include additional, site-specific future climate modelling. Cross-verification between climate information sources was conducted to identify possible discrepancies between the data sources used and are described in the detailed climate analysis report (Appendix A).

5.2 INDIGENOUS HISTORICAL KNOWLEDGE OF CLIMATE

Indigenous historical knowledge of climate for the Project area was not referenced for this assessment. This type of climate knowledge is typically relied upon in project locations where relevant climate data from weather stations is unreliable, unusable or otherwise unavailable (i.e. remote or Northern locations). For the Project, historical climate data from nearby Environment Canada weather stations was readily available and reliable and thus have been used.

Refer to Table 2-1 for descriptions of climate data confidence levels and remarks. Appendix A provides the detailed climate profile for the Project area.

This resilience assessment was prepared by the following individuals from Stantec Consulting:

Table 5-2 Resilience Assessment Team

Name	Qualifications	Project Role
Charling Li	P.Eng., M.Urb.	Resilience Assessor
Jordan Stewart	P.Eng.	Climate Advisor
Guy Felio	PhD, P.Eng., IRP (Climate)	Qualified Validator - Resilience
Daniel Hegg	M.Sc., CEM, ENV SP Verifier	Independent Reviewer
Frank Bohlken	B.Sc., MRM	Project Management Review

6 SUMMARY

This climate resilience assessment conducted for the Project was generally based on the principles of Engineers Canada's PIEVC Protocol assessment and is consistent with ISO 31000 Risk Management Framework; this assessment serves to inform MOTI on the future climate related risks that should be considered at the design and construction stages of Broadway Subway Project.

This assessment has identified ten climate parameters that can pose hazards to Project infrastructure. Infrastructure interactions to each climate parameter were examined and an associated risk rating was assigned to each rating. The climate parameters that presented the greatest number of risks to the Project are extreme high intensity and sustained rainfall, extreme high temperatures, and high winds. Although the majority of the Project is below grade, many climate risks are related to third-party services (i.e. electricity, local stormwater management) that are vulnerable to exposure to extreme climate events.

Table 2-10 lists all risk rated at Moderate or higher. It is important to note that the Climate Change Impacts Risk Profile (Table 2-10) are a prioritization of impacts relative to each other, not against an external benchmark. Designations of 'moderate' or high' risk items should be considered in the context that many risks can be mitigated or monitored through operations & maintenance policies and procedures. This assessment does not include an evaluation of the effectiveness of O&M policies to reduce or mitigate climate risks, as these have not been confirmed. Some of the risks, involving new systems or facilities, may be addressed at the detailed design stage of Project.

6.1 RECOMMENDATIONS

Although moderate and high risks have been identified at this stage of the Project, many risks can be being monitored or mitigated as part of O&M policies and procedures during the life-cycle of the assets. Recommended climate risk management measures include:

- Prior to the start of the Project, consider reviewing existing Millennium Line Operations & Maintenance policies and procedures to ensure O&M policies and procedures have an emphasis on improving system resilience under a changing climate.
- Consider incorporating design criteria specific to known future climate risks into the Project's procurement to ensure the Project constructor takes future climate into account.
- Consider requiring a more detailed climate risks assessment to the Project during the detailed design stage, for example, employing the full PIEVC Protocol and involving multiple internal and external stakeholders to develop a more comprehensive assessment of risks and inform the design of components and future construction and operation of the Project.
- Consider reviewing climate risk assumptions and implement necessary measures at the time of retrofits or replacements – end-of-service life of equipment, components, or assets;
- HVAC systems – consider capacity to meet future climate conditions (higher peak loads due to higher external temperatures) when designing systems, considering the need for energy-efficiency and reduced GHG emissions
- Consider interdependencies with external infrastructure systems outside the control of TransLink or the Province of BC Ministry of Transportation and Infrastructure; for example, with BC Hydro or local municipal stormwater managers. Engage with these third-party service providers to mitigate climate risks to external infrastructure that can impact Project assets
- Consider monitoring climate risks that will be retained or transfer at the design phase and during design or operation of Project assets. Evaluate unintended consequences of risk transference or mitigation strategies.
- Consider implementing monitoring protocols to mitigate climate risks that affect functionality and O&M.

7 REFERENCES

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Unknown. (2004) Evergreen Line Rapid Transit Project Environmental Assessment Certificate Application: Section 23: Summary of Project Impacts, Mitigation Measures and Potential Residual Effects. Section 23 Summary of Impacts and Mitigation Measures

APPENDIX A

Climate Profile for BSP Project Area

APPENDIX A – BROADWAY SUBWAY PROJECT – CLIMATE PROFILE

November 9, 2018

When investigating historical climate and future climate projections for the location of a proposed project, there can be extensive research required. Fortunately, the Broadway Subway Project (BSP) project (the Project) is located in the Metro Vancouver Regional District, and *Metro Vancouver* has already invested in developing a summary of climate projections for the entire region. The *Climate Projections for Metro Vancouver* was published in June 2016 and presents information relevant to the climate of the Project.

Where further validation of climate data is required, it is typical to evaluate data from nearby weather stations. There are numerous weather stations that can contribute data to comprise a historical representation of the climate along the proposed Millennium Line Broadway Extension route as pictured in Figure 1. The nature of transit projects, however, is that they typically cover a linear corridor through a larger area so a climate profile can be difficult to characterize using a single weather station. Furthermore, not all weather stations have complete data sets and their years of operation vary significantly; many no longer in operation.

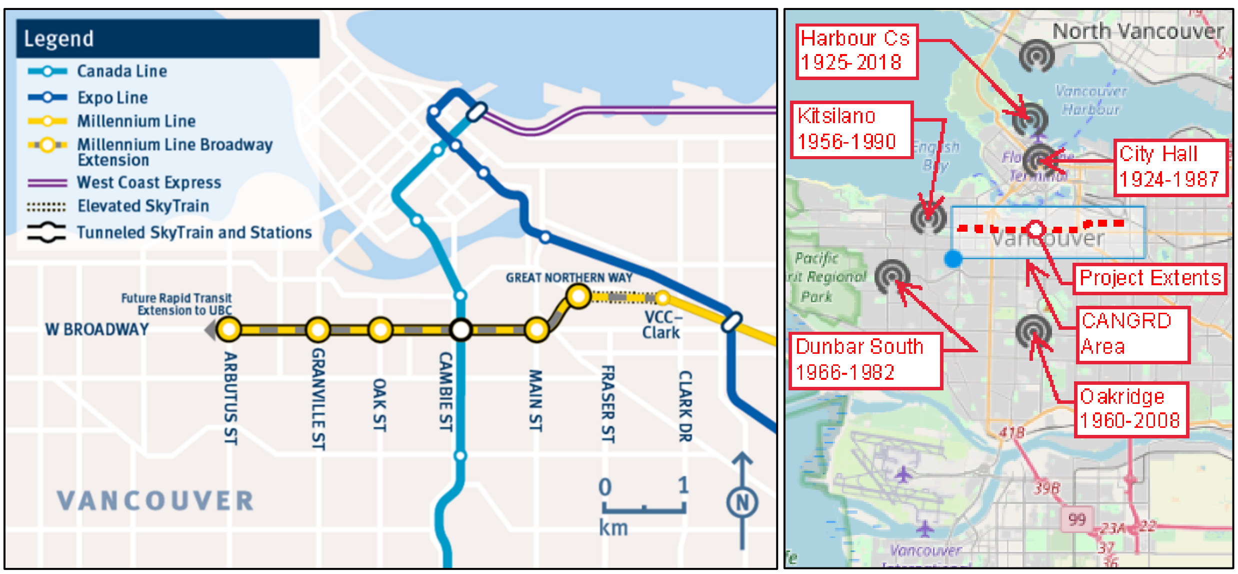


Figure 1 Project Location and proximity to closest weather stations

Stantec has evaluated some climate data from nearby weather stations, which was obtained through the Climate Change Hazards Information Portal (CCHIP) created by Risk Sciences International (RSI). In addition to assembled climate data from weather stations, CCHIP also publishes data sets for the entire country, on a 10km by 10km grid – known as the Canadian Gridded Temperature and Precipitation Anomalies (CANGRD) data. This gridded data was developed in a collaboration between Natural Resources Canada (NRCan) and Environment and Climate Change Canada (ECCC) – this data compiles information from several sources, including interpolating weather station data and although data from a real weather station is preferable, this CANGRD is well accepted and researched.

For the BSP project, obtaining weather station data from CANGRD for the area selected in Figure 1, allows for complete data sets for an area that is central to the project extents. The “historical” CANGRD Data for maximum daily temperature and average annual precipitation was compared to actual historical data from the nearby Vancouver Harbour Cs weather station to validate the use of the gridded data set. The data sets are compared in **Figure 2** and **Figure 3** respectively. Most of the Vancouver Harbour Cs and CANGRD historical data/projections are nearly equivalent. The somewhat significant difference in projected precipitation under future climate change of 8.9% can be considered when using the CANGRD data set. The average maximum daily temperature difference of 0.05°C and average total annual precipitation difference of 0.9% between the Vancouver Harbour Cs Station and the CANGRD data is very low and reinforces the validity of the CANGRD data for use in developing a climate profile.

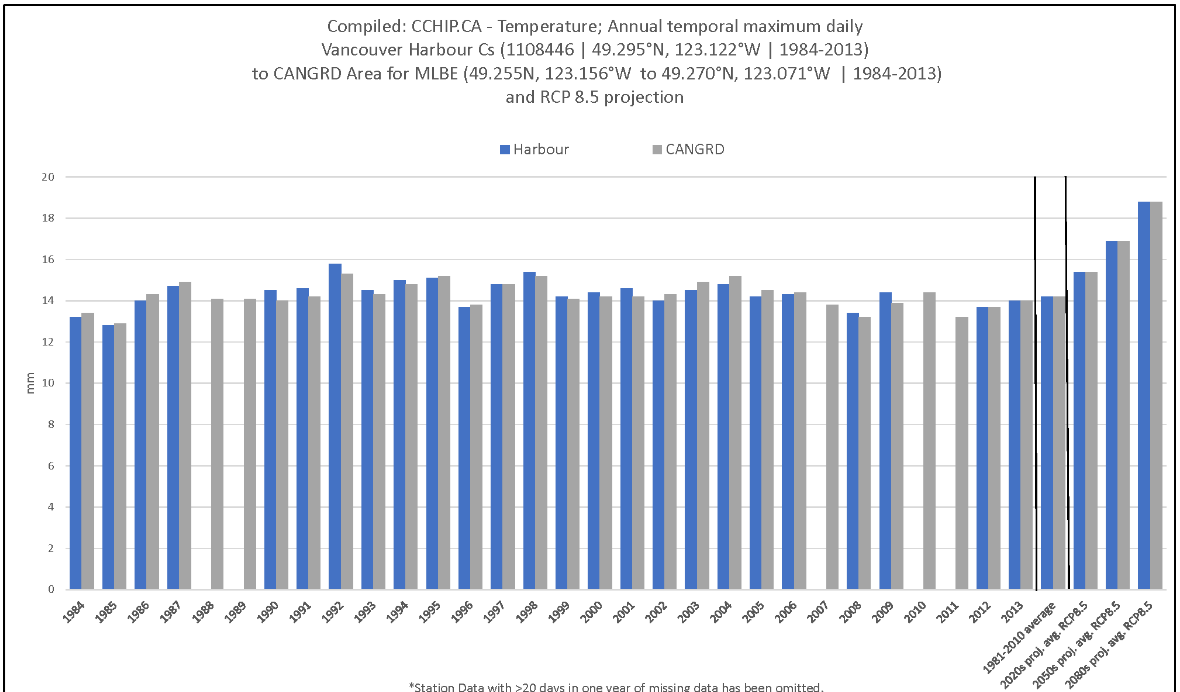
> The IPCC is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation.
>
> IPCC assessments provide a scientific basis for governments at all levels to develop climate related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC). The assessments are policy-relevant but not policy-prescriptive: they may present projections of future climate change based on different scenarios and the risks that climate change poses and discuss the implications of response options, but they do not tell policymakers what actions to take.

There are four Representative Concentration Pathways (RCP) scenarios adopted by the Intergovernmental Panel on Climate Change (IPCC) that are based on various future greenhouse gas concentration scenarios. Similar to the *Climate Projections for Metro Vancouver* Report, published by Metro Vancouver in June 2016, the future climate projections shown in this climate profile will be based on the internationally recognized “business as usual” greenhouse gas emissions scenario, known as Representative Concentration Pathway 8.5 (RCP[1] 8.5). However, global GHG emissions trends are complex to predict and thus, for comparison purposes this climate profile will also include projections based the RCP 4.5 scenario, which is characterized by GHG emissions peaking in 2040 and then declining. Currently, global GHG concentrations are closer to following the RCP 8.5 pathway, despite global agreements/targets for GHG emissions reductions. The choice of the RCP 8.5 is also supported by the results of the October 8, 2018 IPCC special report *Global Warming of 1.5ºC.*

Where the *Climate Projections for Metro Vancouver* Report uses climate projections from a selection of 12 models from the Coupled Model Intercomparison Project 5 (CMIP5), the CCHIP data gathered by Stantec uses 40 models. Additional sources of variations between the two methods’ analyses include the fact that the Metro Vancouver report is averaged for the entire Metro Vancouver area, whereas the CCHIP data is localized to the BSP area of study. The two methods also compare their projections to two different baseline periods; Metro Vancouver to 1971-2000, and CCHIP to 1981-2010. Although this causes variations for comparison purposes, it is our view that future climate projections should be compared with the most recent climate baseline. The “baseline” current climate will be based on the 1981 to 2010 Climate Normals, as this information is widely available. This baseline represents the typical climate in an area to which infrastructure designers and operators are accustomed for their designs and operations. Although climate projections will be compared to these 1981 to 2010 Climate Normals, the most recent data available will also be presented.

[1] RCP: Representative Concentration Pathways – a greenhouse gas concentration (not emissions) trajectories adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5) in 2014.

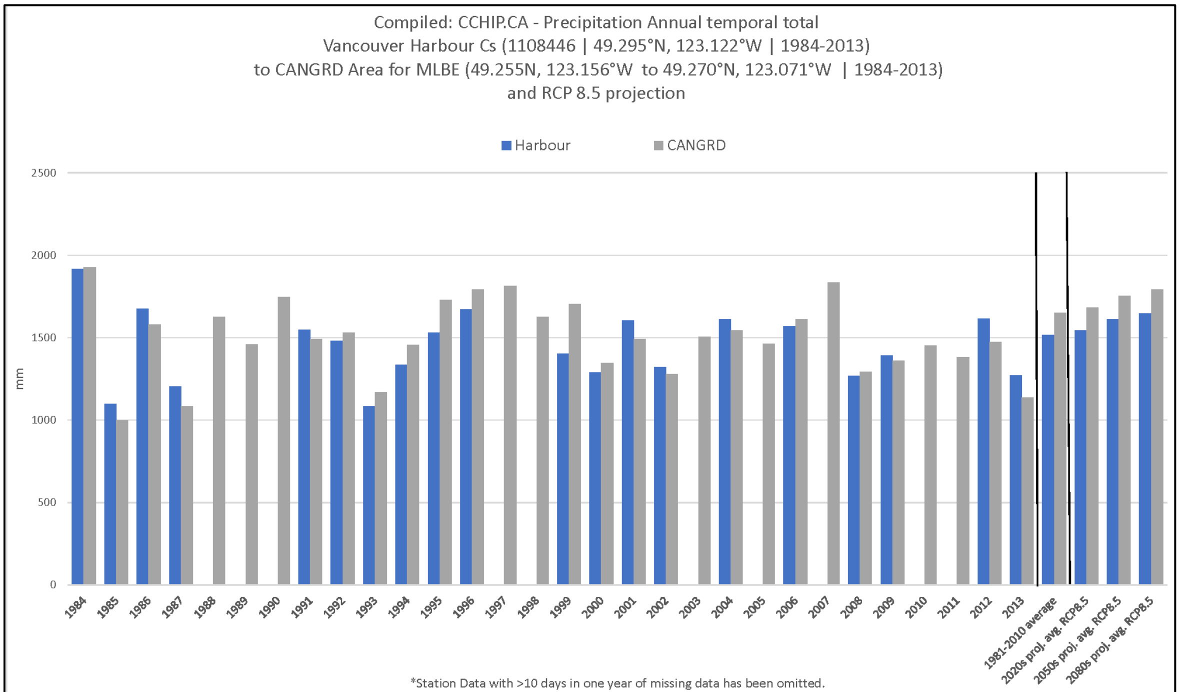
The time horizons for the study were selected as current conditions (establishing the baseline risks) and 2020s (2011 to 2040), 2050s (2041 to 2070), 2080s (2071 to 2100) for future conditions. Climate is usually defined as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of meteorological variables such as temperature, precipitation and wind over a period of time, typically 30 years.[2] The “2050s” projected climate is therefore the projected average over the 30-year period from 2041 to 2070.



The CANGRD "historical" data suggests that the project area has an average maximum daily temperature that is on average 0.05°C less than the Vancouver Harbour Cs Station. Temperature projections under future climate conditions are equivalent for the Harbour CS Station location and the CANGRD area.

Figure 2 Comparison of annual maximum daily temperature from Vancouver Harbour Cs weather station to interpolated CANGRD data

2 World Meteorological Organization, 2017: Commission for Climatology: Frequently Asked Questions. http://www.wmo.int/pages/prog/wcp/ccl/faqs.php (accessed Sept.28,2018)



The CANGRID "historical" data suggests that the project area, recieves an average 0.9% more precipitation than the Vancouver Harbour Cs Station per year.
The projections under future climate conditions suggest only an 8.9% difference from the Harbour Station Cs Station to the CANGRD area.

Figure 3 Comparison of total annual precipitation from Vancouver Harbour Cs weather station to interpolated CANGRD data

TEMPERATURE: AVERAGE

Table 1 Average Change in Daily Mean Temperature from Baseline (CCHIP)

Season	1981-2010 (°C)	Average Change in Mean Temperature from 1981-2010 Baseline (°C)					
		RCP 4.5			RCP 8.5		
		2020s	2050s	2080s	2020s	2050s	2080s
Annual	10.7	1.0	2.0	2.5	1.2	2.8	4.7
Winter	4.6	0.9	2.0	2.5	1.2	2.7	4.5
Spring	10.0	1.0	2.0	2.5	1.2	2.6	4.3
Summer	17.5	1.2	2.2	2.9	1.3	3.2	5.5
Autumn	10.9	0.9	1.8	2.3	1.0	2.7	4.4

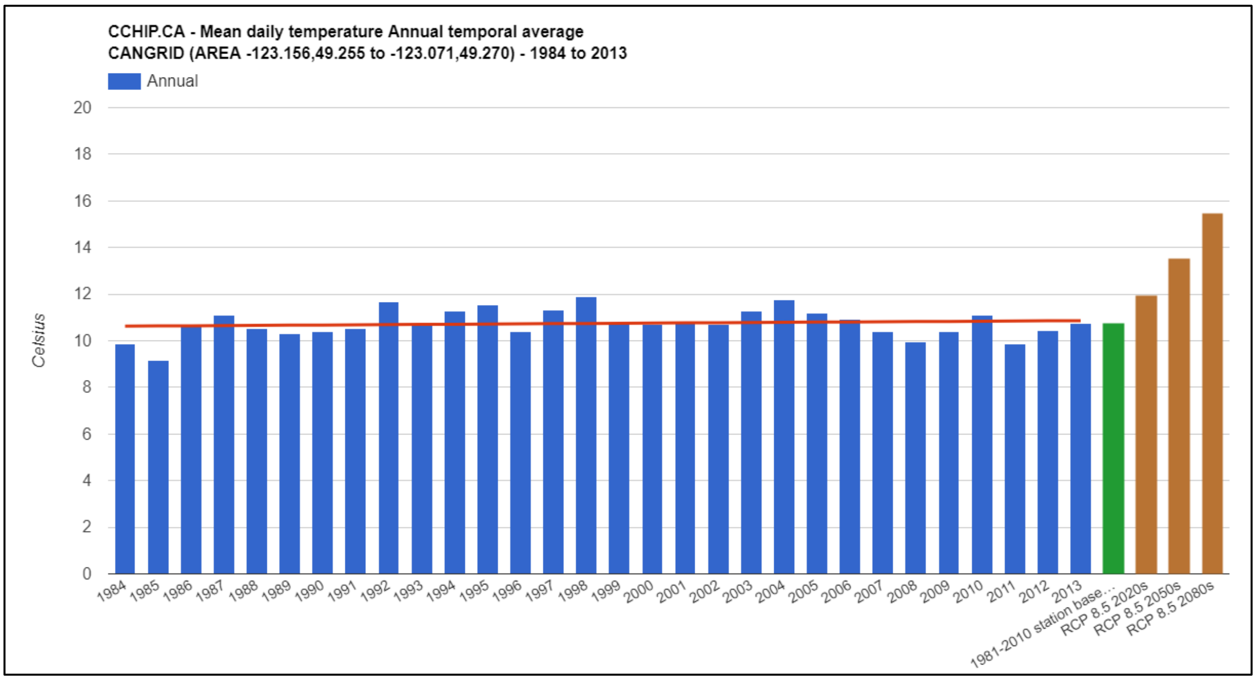


Figure 4 Annual Temporal Average – Mean Daily Temperature (RCP 8.5)

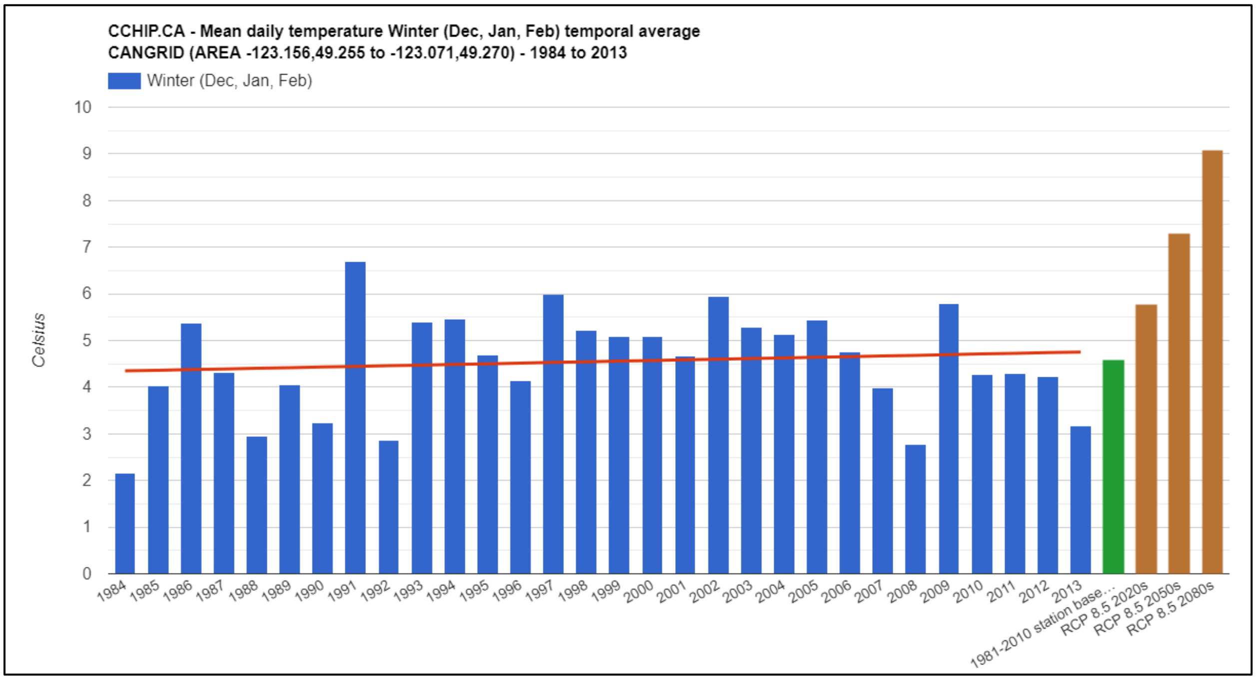


Figure 5 Winter Temporal Average – Mean Daily Temperature (RCP 8.5)

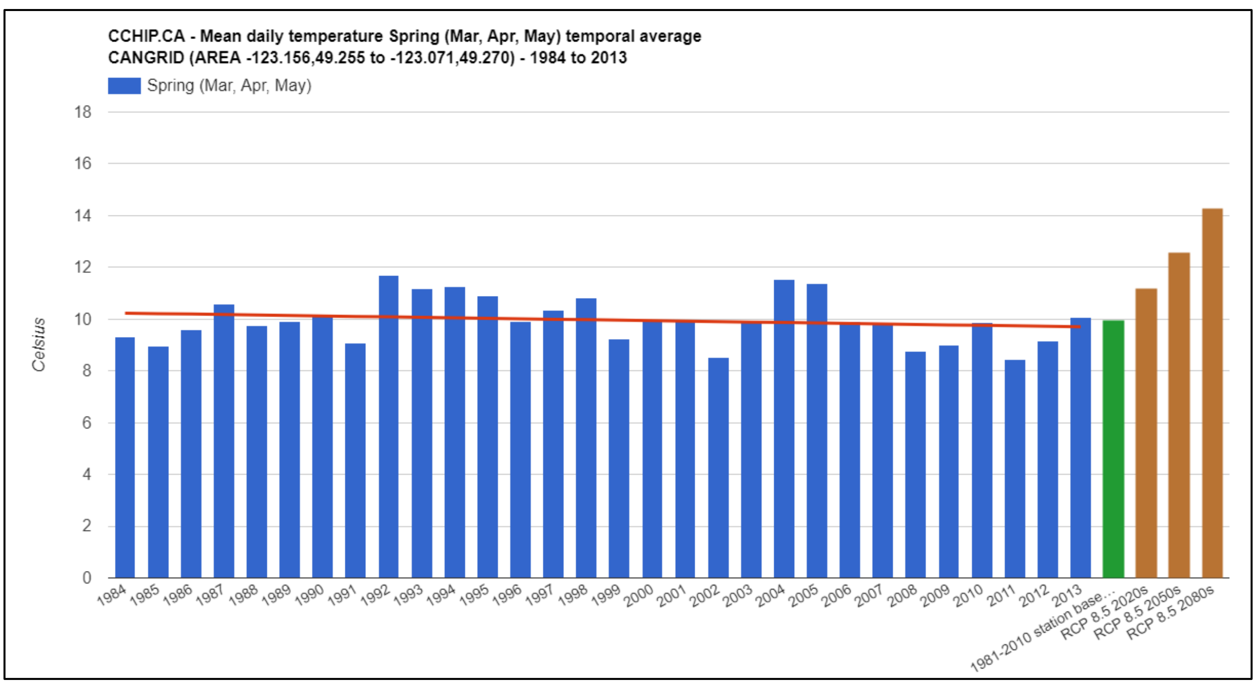


Figure 6 Spring Temporal Average – Mean Daily Temperature (RCP 8.5)

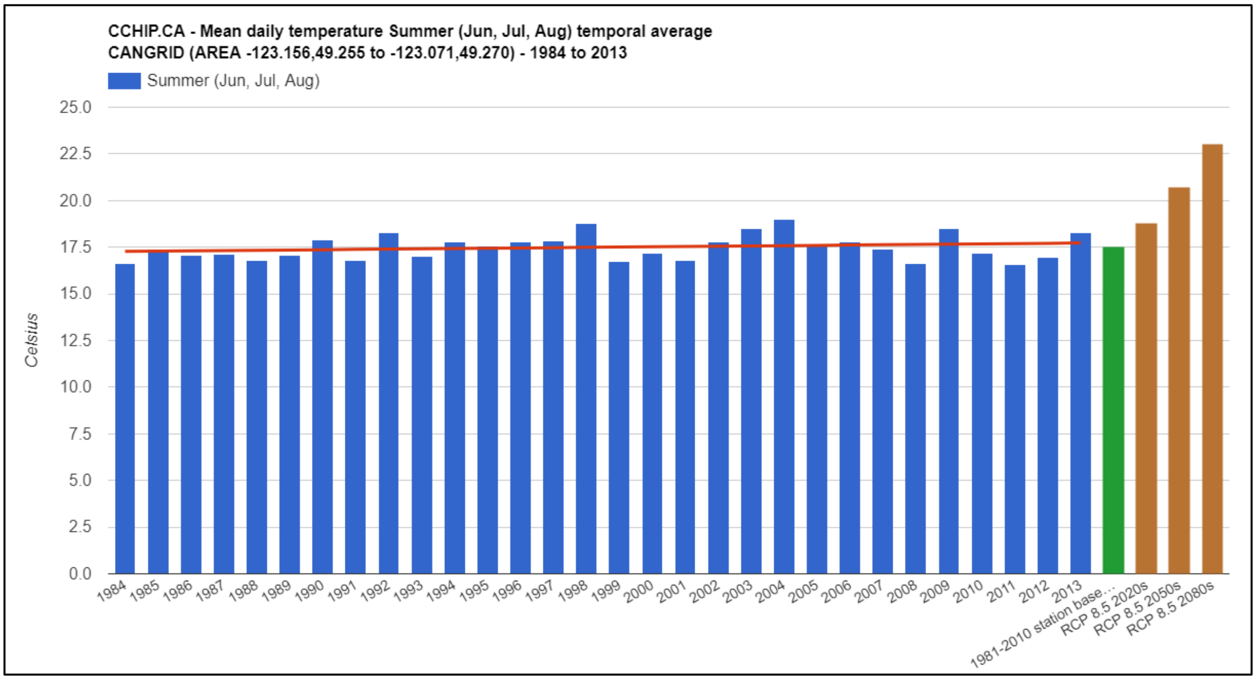


Figure 7 Summer Temporal Average – Mean Daily Temperature (RCP 8.5)

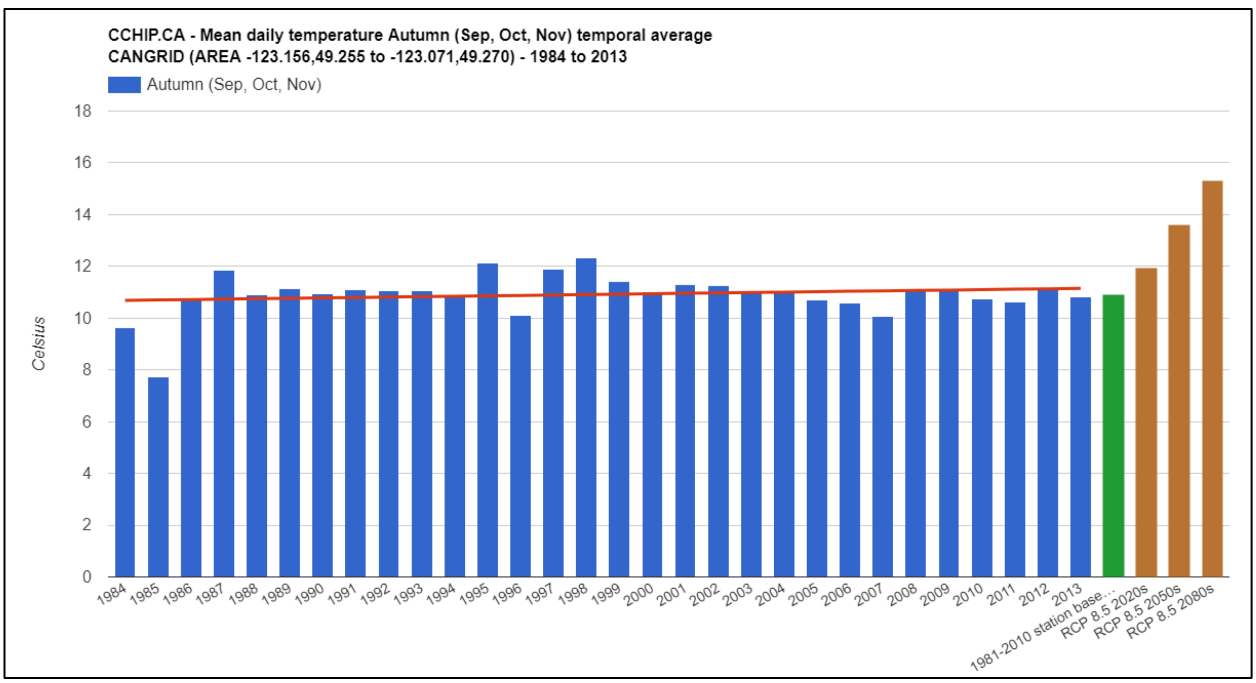


Figure 8 Autumn Temporal Average – Mean Daily Temperature (RCP 8.5)

TEMPERATURE: MAXIMUM

Table 2 Average Change in Maximum Temperature from Baseline (CCHIP)

Season	1981-2010 (°C)	Average Change in Maximum Temperature from 1981-2010 Baseline (°C)					
		RCP 4.5			RCP 8.5		
		2020s	2050s	2080s	2020s	2050s	2080s
Annual	14.3	1.0	2.0	2.5	1.2	2.7	4.6
Winter	7.1	0.8	1.7	2.2	1.0	2.3	4.0
Spring	13.8	1.1	2.1	2.6	1.2	2.7	4.4
Summer	21.9	1.3	2.4	3.1	1.4	3.3	5.8
Autumn	14.2	0.9	1.7	2.3	1.0	2.6	4.3

The CCHIP results and trends are validated by the *Climate Projections for Metro Vancouver* Report, where variations can be attributed to the differences of the two approaches as discussed in the introduction.

Table 3 Average Change in Maximum Temperature from Baseline 1971-2000; RCP 8.5 (Metro Vancouver, 2016)

	Past (°C)	2050s Change (°C)		2080s Change (°C)	
		Average	(Range)	Average	(Range)
Winter	5	2.4	(1.3 to 3.0)	4.4	(2.8 to 5.7)
Spring	12	2.9	(1.7 to 4.7)	4.7	(2.8 to 7.3)
Summer	21	3.7	(2.4 to 5.2)	6.0	(3.7 to 8.4)
Fall	13	2.8	(1.3 to 3.9)	4.5	(2.9 to 6.2)
Annual	13	2.9	(1.6 to 4.2)	4.9	(3.0 to 6.6)

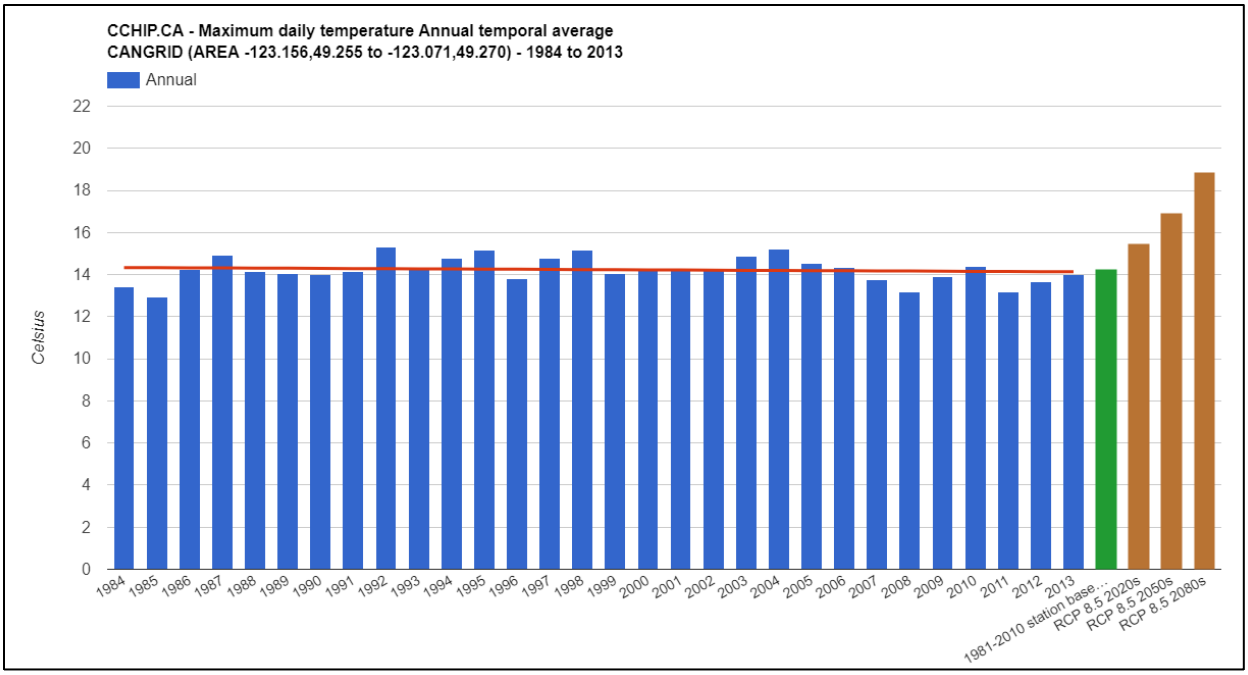


Figure 9 Annual Temporal Average – Maximum Daily Temperature (RCP 8.5)

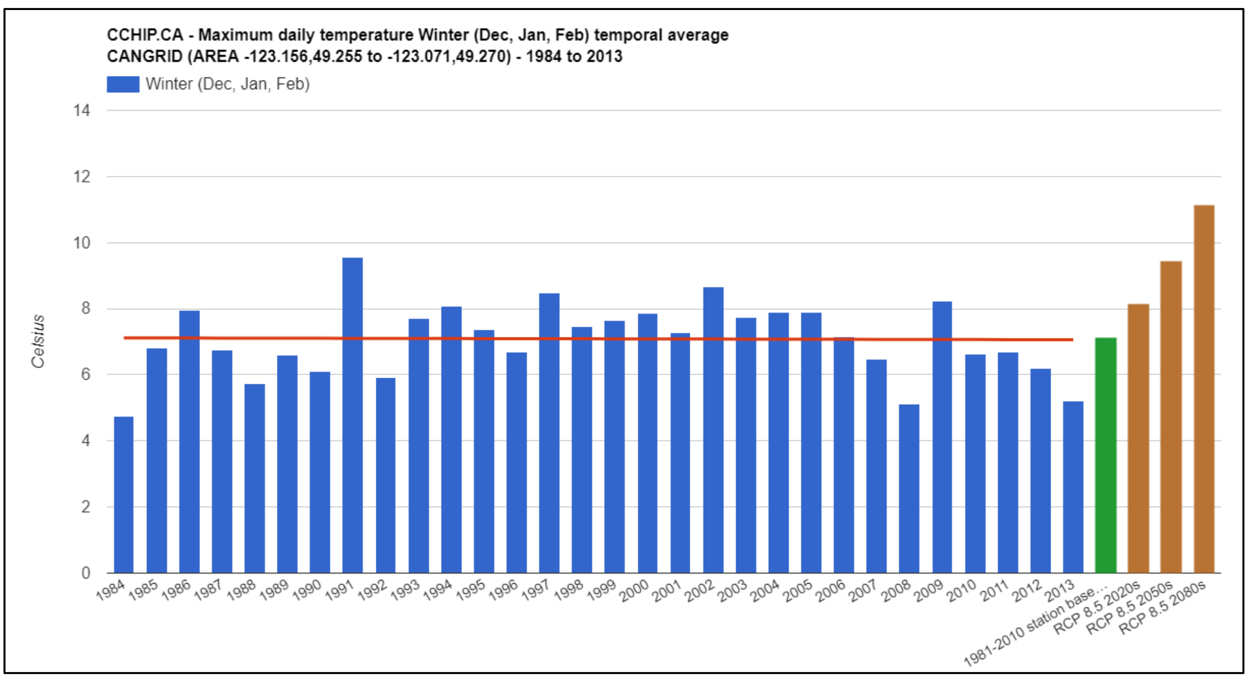


Figure 10 Winter Temporal Average – Maximum Daily Temperature (RCP 8.5)

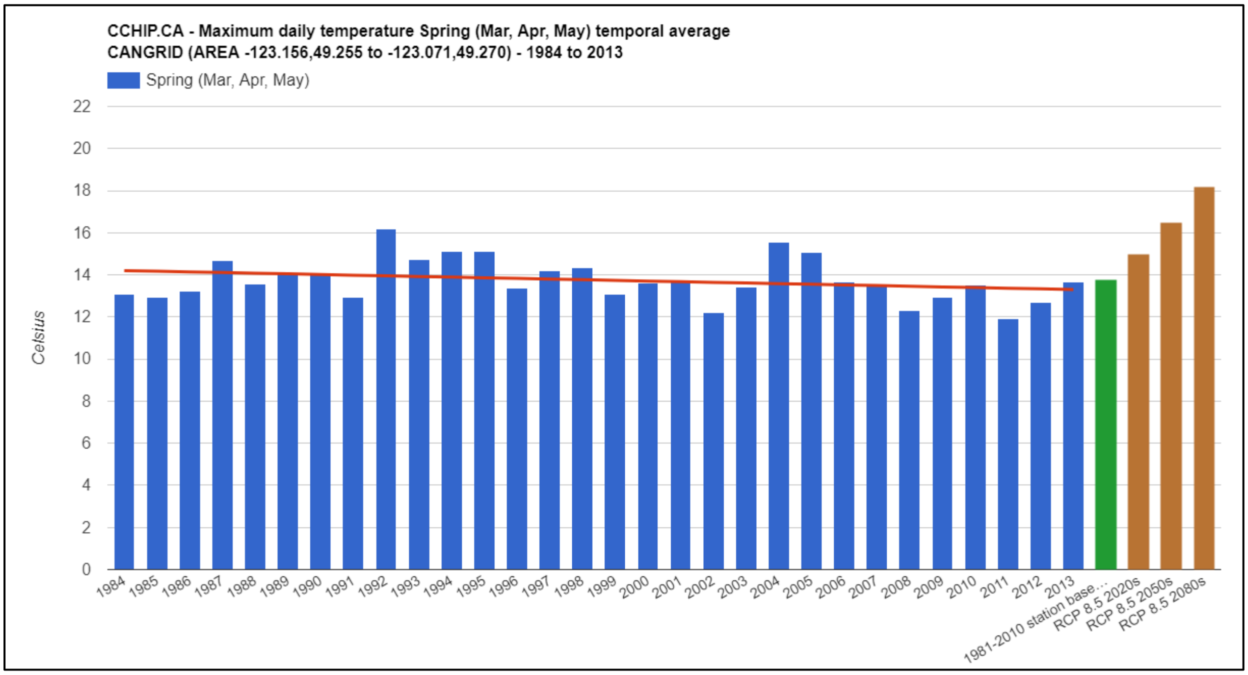


Figure 11 Spring Temporal Average – Maximum Daily Temperature (RCP 8.5)

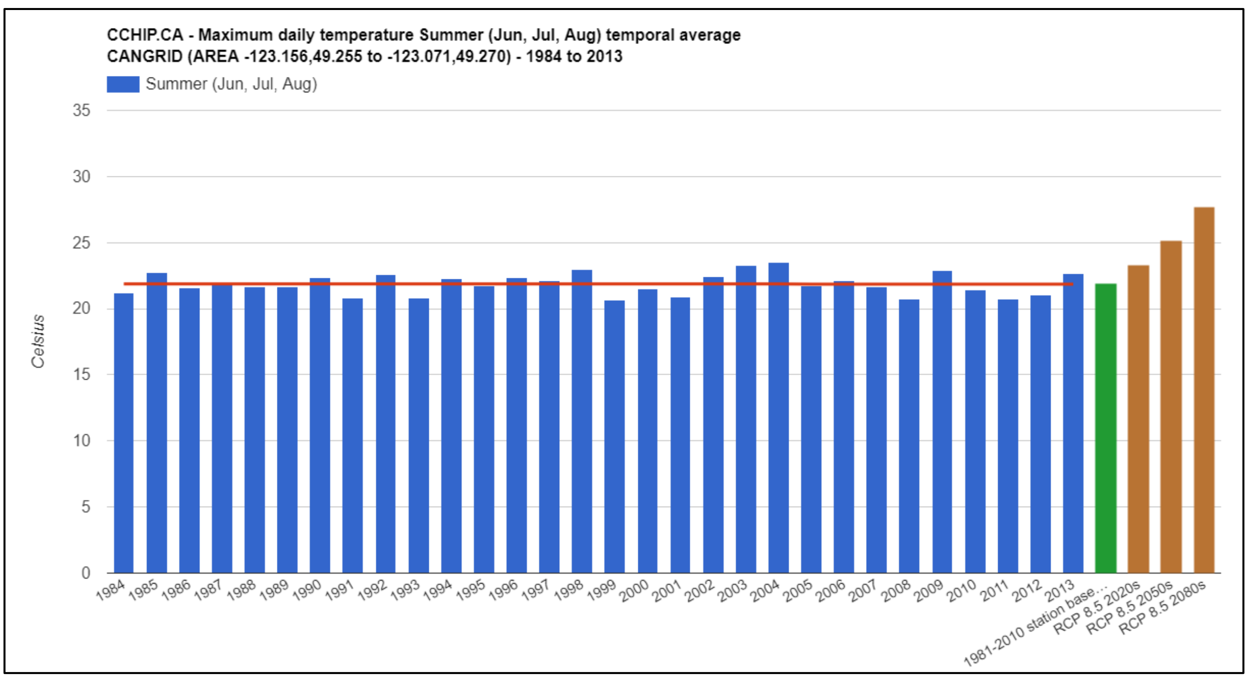


Figure 12 Summer Temporal Average – Maximum Daily Temperature (RCP 8.5)

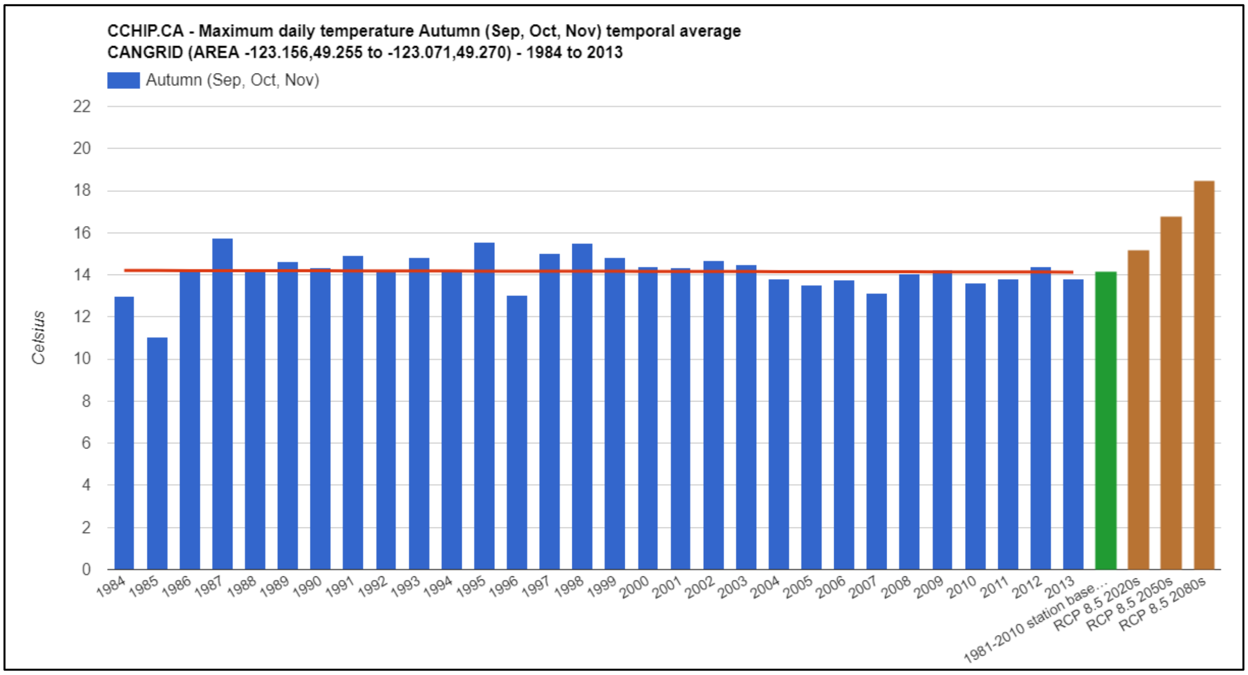


Figure 13 Autumn Temporal Average – Maximum Daily Temperature (RCP 8.5)

It can also be useful to view projected increases in temperatures as the change in the occurrence of days with a temperature higher than a certain threshold. Table 4 below presents the climate projection for the occurrence of days with temperatures greater than 30°C.

Table 4 CCHIP Custom Report: CANGRD Data set at BSP Project area coordinates

	Annual occurrence of days with Max. Temp >30°C						
	Historical 1981-2010	RCP 4.5			RCP 8.5		
		2020s	2050s	2080s	2020s	2050s	2080s
Days/year	0.7	2.1	4.2	6.2	2.4	8.2	24.5

TEMPERATURE: MINIMUM

Table 5 Average Change in Minimum Temperature from Baseline (CCHIP)

Season	1981-2010 (°C)	Average Change in Minimum Temperature from 1981-2010 Baseline (°C)					
		RCP 4.5			RCP 8.5		
		2020s	2050s	2080s	2020s	2050s	2080s
Annual	7.3	1.0	2.1	2.7	1.2	3.0	4.9
Winter	2.0	1.1	2.5	3.0	1.5	3.3	5.4
Spring	6.2	1.1	2.1	2.6	1.2	2.8	4.6
Summer	13.1	1.1	2.0	2.7	1.2	3.0	5.1
Autumn	7.7	0.9	1.8	2.4	1.1	2.8	4.6

The CCHIP results and trends are validated by the *Climate Projections for Metro Vancouver* Report, where again variations can be attributed to the differences of the two approaches as discussed in the introduction.

Table 6 Average Change in Minimum Temperature from Baseline 1971-2000; RCP 8.5 (Metro Vancouver, 2016)

	Past (°C)	2050s Change (°C)		2080s Change (°C)	
		Average	(Range)	Average	(Range)
Winter	-1	2.9	(1.8 to 3.5)	4.9	(3.6 to 5.7)
Spring	3	2.9	(2.0 to 3.8)	4.6	(3.2 to 6.0)
Summer	10	3.2	(1.9 to 4.7)	5.2	(3.5 to 7.7)
Fall	5	2.8	(1.7 to 4.0)	4.5	(3.1 to 6.0)
Annual	4	2.9	(1.9 to 4.0)	4.8	(3.3 to 6.3)

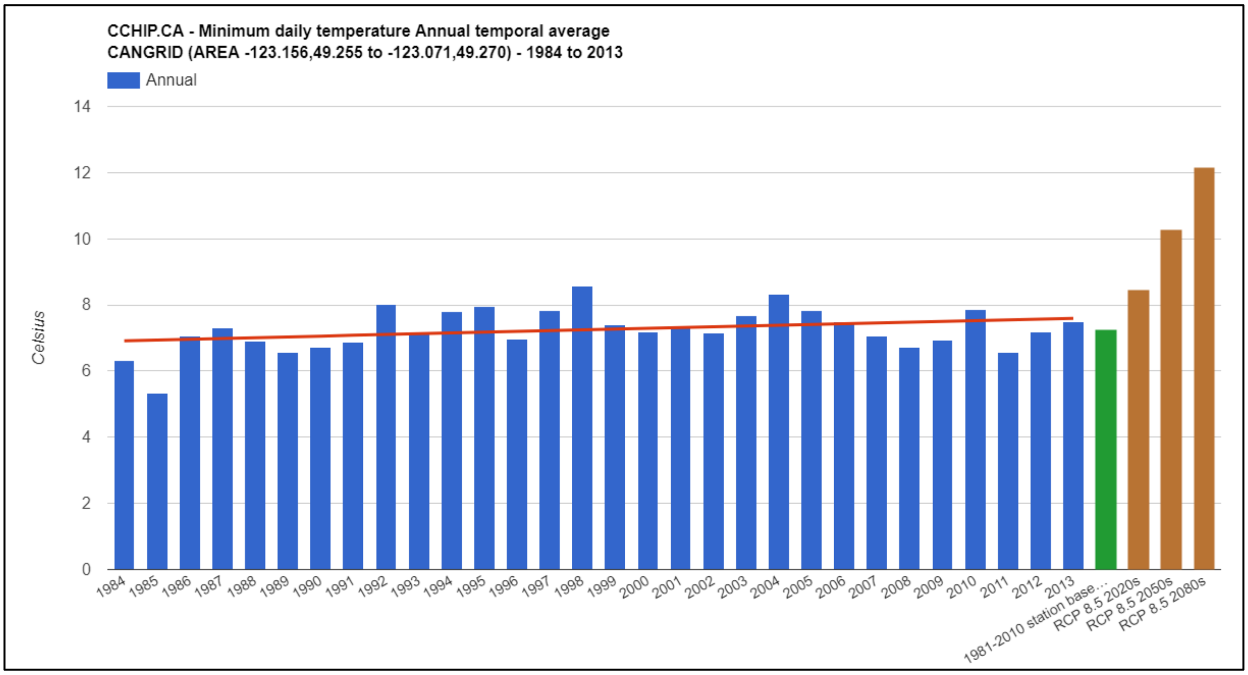


Figure 14 Annual Temporal Average – Minimum Daily Temperature (RCP 8.5)

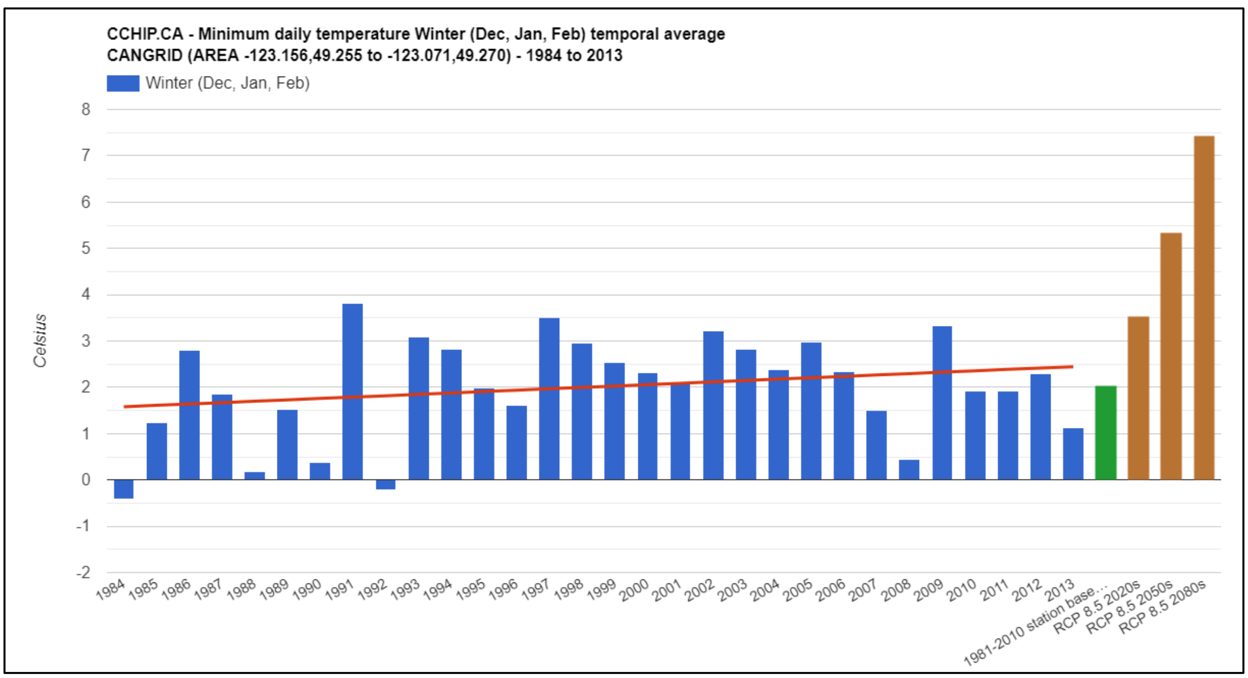


Figure 15 Winter Temporal Average – Minimum Daily Temperature (RCP 8.5)

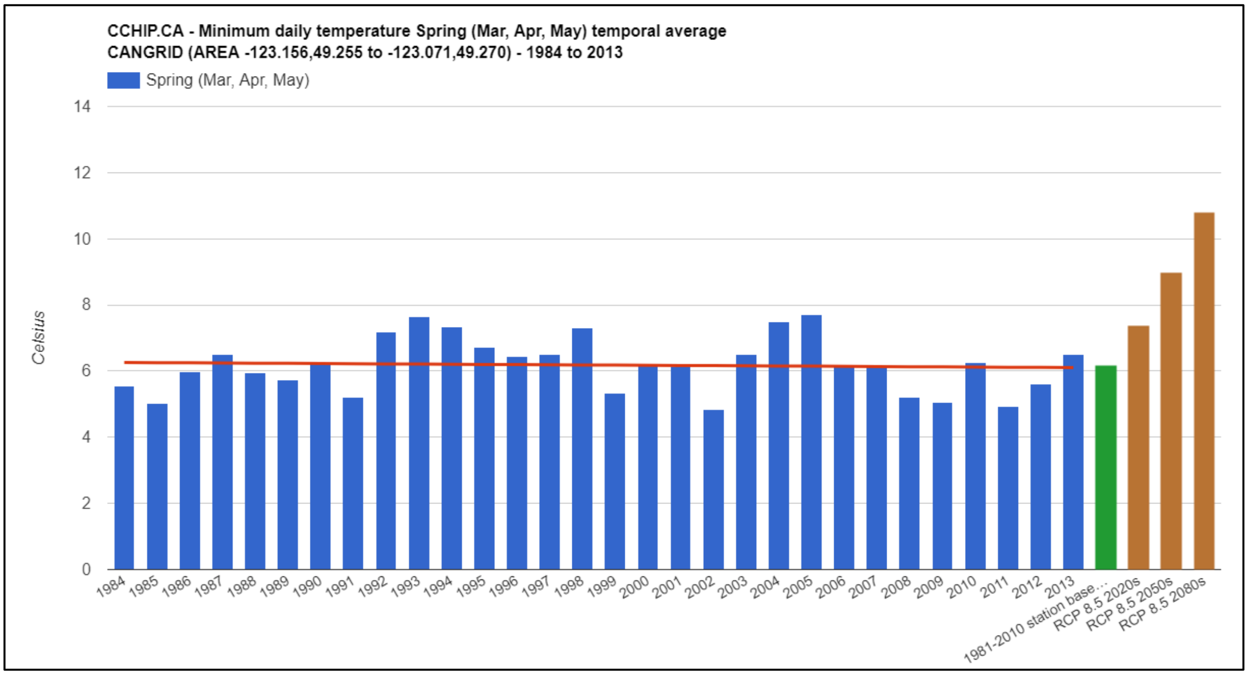


Figure 16 Spring Temporal Average – Minimum Daily Temperature (RCP 8.5)

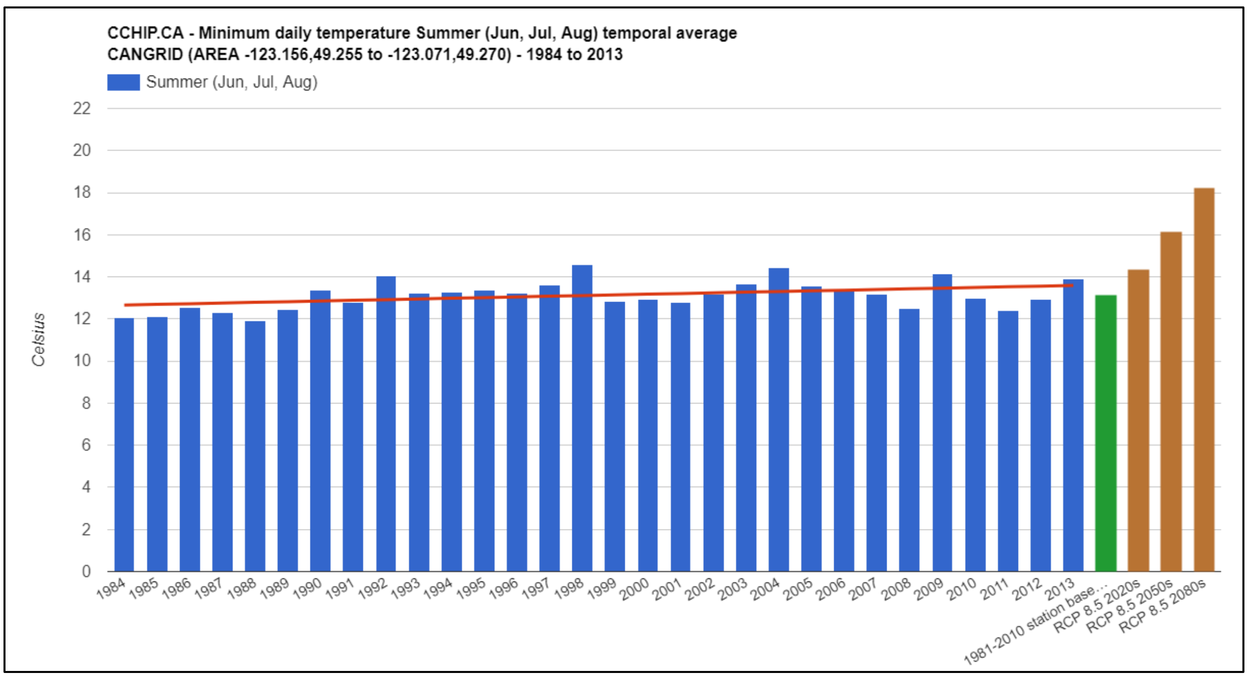


Figure 17 Summer Temporal Average – Minimum Daily Temperature (RCP 8.5)

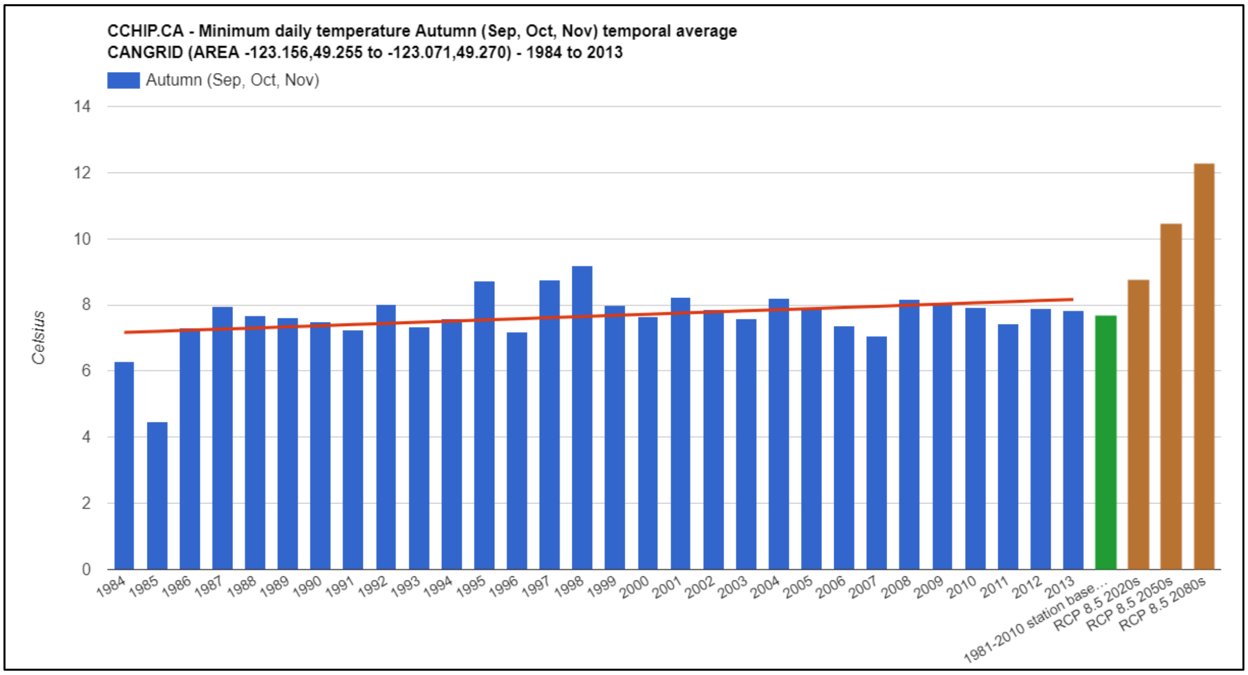


Figure 18 Autumn Temporal Average – Minimum Daily Temperature (RCP 8.5)

It can also be useful to view projected increases in minimum temperatures as the change in the occurrence of days with a temperature less than a certain threshold. Table 7 below presents the climate projection for the occurrence of days with temperatures less than 0°C.

Table 7 CCHIP Custom Report: CANGRD Data set at BSP Project area coordinates

	Annual occurrence of days with Min. Temp <0°C						
	Historical 1981-2010	RCP 4.5			RCP 8.5		
		2020s	2050s	2080s	2020s	2050s	2080s
Days/year	24.7	15.2	9.4	7.2	13.4	6.4	3.4

PRECIPITATION

Table 8 Average Percent Change in Total Seasonal and Annual Precipitation from Baseline

Season	1981-2010 (mm)	Average Percent Change in Total Precipitation from 1981-2010 Baseline (%)					
		RCP 4.5			RCP 8.5		
		2020s	2050s	2080s	2020s	2050s	2080s
Annual	1652	2.3	4.2	6.0	1.9	6.2	8.5
Winter	602	3.6	6.2	8.7	3.4	8.2	12.1
Spring	372	2.1	4.7	5.6	1.6	6.3	9.3
Summer	170	-2.7	-4.6	-6.8	-3.3	-5.8	-14.6
Autumn	512	3.0	5.2	8.3	2.4	9.0	12.9

The CCHIP general trends of "wetter winters and drier summers" are validated by the *Climate Projections for Metro Vancouver* Report, where variations can be attributed to the differences of the two approaches as discussed in the introduction.

Table 9 Average Change in Total Precipitation from Baseline 1971-2000; RCP 8.5 (Metro Vancouver, 2016)

	Past (mm)	2050s (mm)	2080s (mm)	2050s Percent Change (%)		2080s Percent Change (%)	
				Average	(Range)	Average	(Range)
Fall	580	642	693	11	(-1 to 24)	20	(10 to 38)
Winter	683	714	780	5	(-3 to 12)	14	(2 to 27)
Spring	400	430	447	8	(-4 to 15)	12	(3 to 25)
Summer	206	168	147	-19	(-41 to 1)	-29	(-53 to -6)
Annual	1869	1953	2068	5	(-1 to 9)	11	(2 to 17)

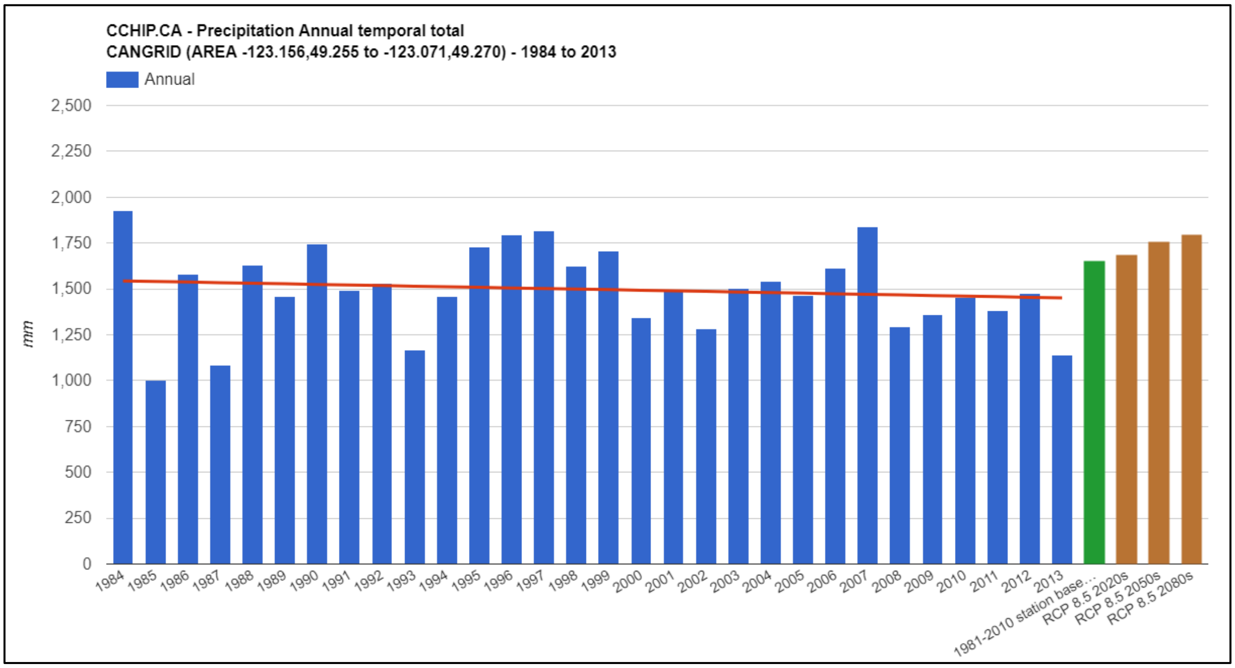


Figure 19 Annual Precipitation Temporal Total (RCP 8.5)

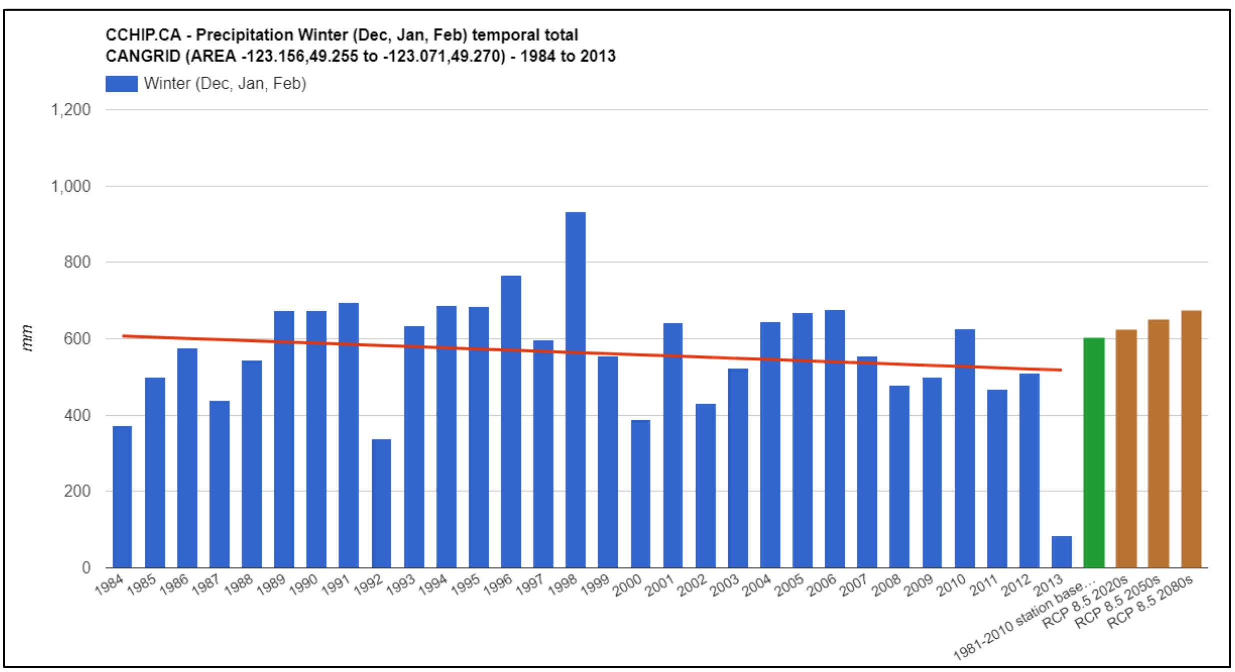


Figure 20 Winter Precipitation Temporal Total (RCP 8.5)

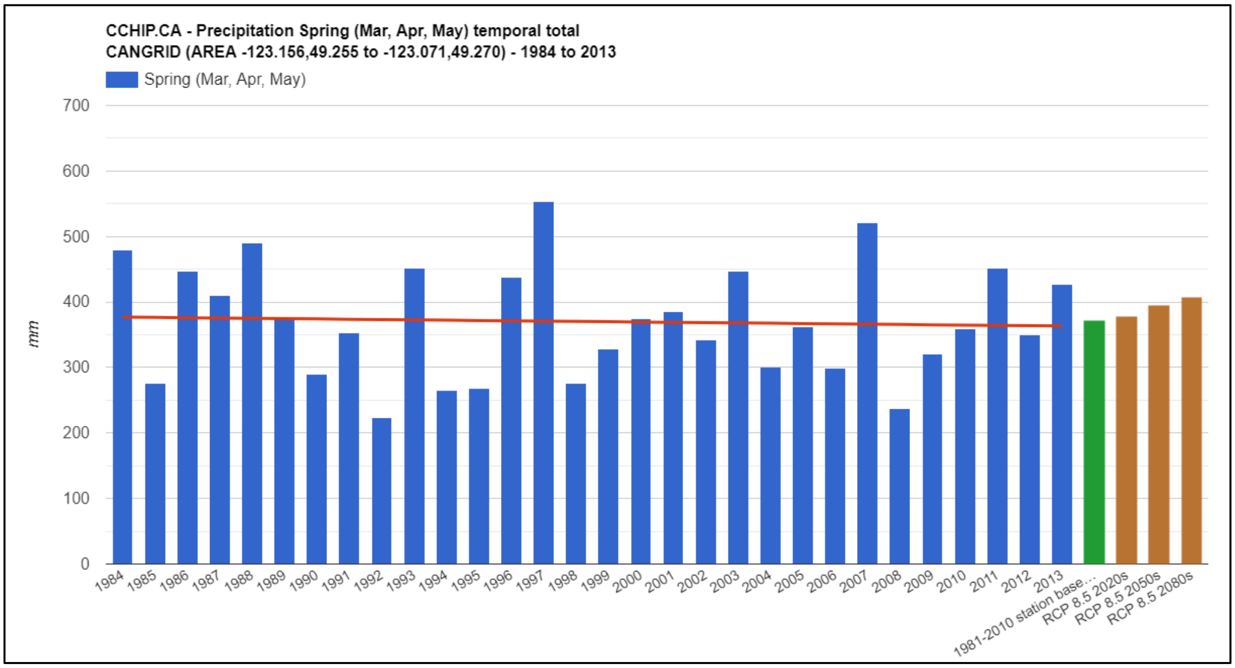


Figure 21 Spring Precipitation Temporal Total (RCP 8.5)

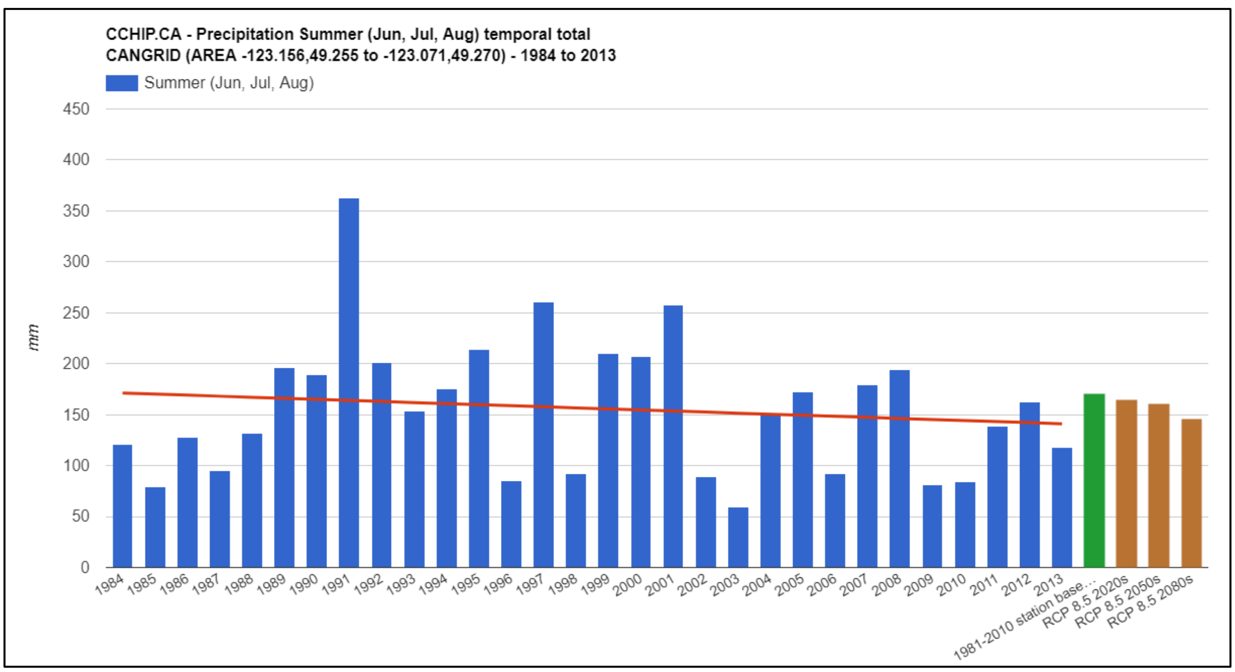


Figure 22 Summer Precipitation Temporal Total (RCP 8.5)

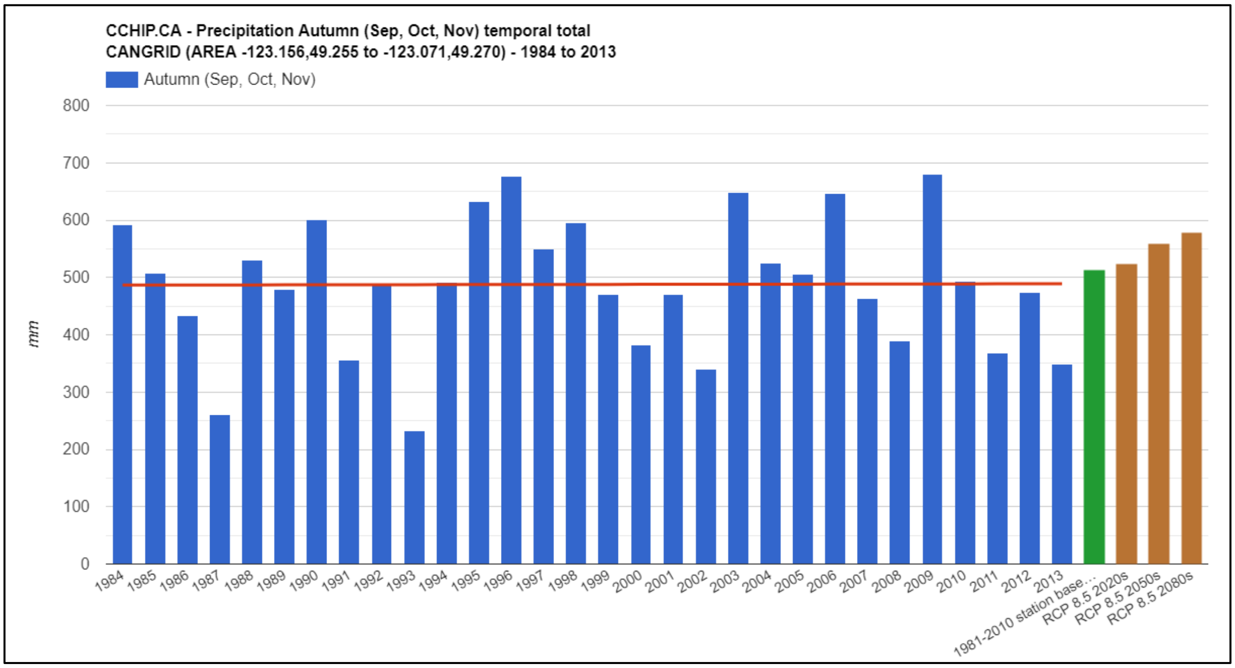


Figure 23 Autumn Precipitation Temporal Total (RCP 8.5)

PRECIPITATION: INTENSITY-DURATION-FREQUENCY (IDF)

In Stantec's experience, it is best to obtain historical IDF information from gauged weather stations as opposed to CANGRD data sets. In the introduction is was shown that there was consistency in precipitation data and future projections between the Vancouver Harbour Cs weather station and the selected CANGRD area for the Project extents. The projections below apply results from 24 Global Circulation Models that simulate future climate conditions, and were obtained from information published by the Institute for Catastrophic Loss Reduction (ICLR), at Western University. The projected IDF information is based on biased corrected results from 9 climate models from the Pacific Climate Impacts Consortium.

TOTAL PRECIPITATION - FOR: VANCOUVER HARBOUR CS STATION ID:1108446

Total precipitation amount (mm) in specific time interval (5 minutes to 24 hours) for various return periods (2 years to 100 years)

Historical (Data 1970 – 1994)

T (years)	2	5	10	25	50	100
5 min	3.57	4.75	5.54	6.55	7.3	8.04
10 min	5.19	7.47	9.32	12.13	14.63	17.52
15 min	6.27	9.07	11.31	14.69	17.66	21.06
30 min	8.16	11.53	14.17	18.05	21.39	24.86
1 h	10.45	13.86	16.29	19.57	22.15	24.86
2 h	15.84	19.8	22.58	26.26	29.14	32.11
6 h	31.54	38.03	42.76	49.28	54.53	60.13
12 h	46.82	57.5	64.49	73.23	79.65	85.96
24 h	66.34	84.27	95.78	109.94	120.16	130.09

2025 – 2075 (RCP 4.5)

T (years)	2	5	10	25	50	100
5 min	4.18	5.91	6.96	8.76	10.91	12.32
10 min	6.07	9.31	11.58	15.72	20.86	25.56
15 min	7.34	11.29	14.05	19.09	25.28	30.84
30 min	9.55	14.36	17.65	23.56	30.86	37.05
1 h	12.23	17.26	20.42	25.88	32.72	37.45
2 h	18.54	24.69	28.37	34.54	43.02	48.29
6 h	36.91	47.55	53.82	63.91	79.56	89.29
12 h	54.85	71.44	81.08	97.02	118.77	131.07
24 h	77.69	104.46	120.38	146.88	180.16	200.11

2025 – 2075 (RCP 8.5)

T (years)	2	5	10	25	50	100
5 min	4.09	5.6	6.7	8.29	9.58	10.69
10 min	5.95	8.74	11.14	15.01	18.56	22.86
15 min	7.19	10.61	13.54	18.2	22.47	27.6
30 min	9.35	13.51	16.99	22.42	27.37	33.08
1 h	11.98	16.3	19.62	24.6	28.54	33.08
2 h	18.16	23.25	27.15	33.05	37.75	42.84
6 h	36.18	44.54	51.25	61.76	70.22	80.4
12 h	53.69	67.61	77.71	92.74	105.06	114.61
24 h	76	99.12	115.58	139.81	159.45	173.73

The above results indicate an increase in precipitation accumulation that can be expected for all rainfall events. The projected percentage increase from the 1970 – 1994 IDF data to the period of 2025 - 2075 for precipitation events under RCP 4.5 & 8.5 range from 14.6% to 53.8% as shown below in Table 10. Due to statistical limitations when developing IDF models, the ICLR only provides data for a 50-year climate window; which is longer than the 30 year window for the projections obtained through CCHIP. The window chosen (2025-2075) for this climate profile is centered around 2050 to correlate with one of the project's selected time horizons. When considering annual precipitation, it should be noted that snowfall depth equates to a liquid depth of precipitation by a factor of about 10mm snow to 1mm precipitation

Table 10 Projected percentage precipitation accumulation increase for Vancouver Harbour Cs weather station under RCP 4.5 and 8.5, 2025-2075. (ICLR, 2018)

T (years)	2		5		10		25		50		100	
RCP	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5
5 min	17.1%	14.6%	24.4%	17.9%	25.6%	20.9%	33.7%	26.6%	49.5%	31.2%	53.2%	33.0%
10 min	17.0%	14.6%	24.6%	17.0%	24.2%	19.5%	29.6%	23.7%	42.6%	26.9%	45.9%	30.5%
15 min	17.1%	14.7%	24.5%	17.0%	24.2%	19.7%	30.0%	23.9%	43.1%	27.2%	46.4%	31.1%
30 min	17.0%	14.6%	24.5%	17.2%	24.6%	19.9%	30.5%	24.2%	44.3%	28.0%	49.0%	33.1%
1 h	17.0%	14.6%	24.5%	17.6%	25.4%	20.4%	32.2%	25.7%	47.7%	28.8%	50.6%	33.1%
2 h	17.0%	14.6%	24.7%	17.4%	25.6%	20.2%	31.5%	25.9%	47.6%	29.5%	50.4%	33.4%
6 h	17.0%	14.7%	25.0%	17.1%	25.9%	19.9%	29.7%	25.3%	45.9%	28.8%	48.5%	33.7%
12 h	17.2%	14.7%	24.2%	17.6%	25.7%	20.5%	32.5%	26.6%	49.1%	31.9%	52.5%	33.3%
24 h	17.1%	14.6%	24.0%	17.6%	25.7%	20.7%	33.6%	27.2%	49.9%	32.7%	53.8%	33.5%

PRECIPITATION INTENSITY - FOR: VANCOUVER HARBOUR CS STATION ID:1108446

The increase in precipitation for accumulation shown above correlates to increased precipitation event intensity (mm/hr) as shown below:

Historical (Data 1970-1994)

T (years)	2	5	10	25	50	100
5 min	42.83	57.05	66.53	78.57	87.55	96.5
10 min	31.13	44.81	55.91	72.8	87.78	105.11
15 min	25.08	36.26	45.24	58.75	70.62	84.24
30 min	16.32	23.06	28.34	36.1	42.78	49.73
1 h	10.45	13.86	16.29	19.57	22.15	24.86
2 h	7.92	9.9	11.29	13.13	14.57	16.06
6 h	5.26	6.34	7.13	8.21	9.09	10.02
12 h	3.9	4.79	5.37	6.1	6.64	7.16
24 h	2.76	3.51	3.99	4.58	5.01	5.42

2025 – 2075 (RCP 4.5)

T (years)	2	5	10	25	50	100
5 min	50.16	70.87	83.47	105.1	130.93	147.83
10 min	36.41	55.84	69.47	94.34	125.19	153.35
15 min	29.34	45.16	56.21	76.37	101.1	123.36
30 min	19.1	28.73	35.3	47.12	61.72	74.1
1 h	12.23	17.26	20.42	25.88	32.72	37.45
2 h	9.27	12.35	14.19	17.27	21.51	24.15
6 h	6.15	7.93	8.97	10.65	13.26	14.88
12 h	4.57	5.95	6.76	8.08	9.9	10.92
24 h	3.24	4.35	5.02	6.12	7.51	8.34

2025 – 2075 (RCP 8.5)

T (years)	2	5	10	25	50	100
5 min	49.1	67.23	80.38	99.47	114.96	128.27
10 min	35.69	52.42	66.85	90.08	111.38	137.17
15 min	28.75	42.46	54.15	72.79	89.88	110.42
30 min	18.71	27.03	33.98	44.84	54.73	66.16
1 h	11.98	16.3	19.62	24.6	28.54	33.08
2 h	9.08	11.62	13.58	16.52	18.87	21.42
6 h	6.03	7.42	8.54	10.29	11.7	13.4
12 h	4.47	5.63	6.48	7.73	8.76	9.55
24 h	3.17	4.13	4.82	5.83	6.64	7.24

Correlating with the projected increases accumulation; the above results indicate an increase in the intensity of the rainfall events for each return period. The projected percentage increase from the 1970 - 1994 data to the period of 2025 - 2075 for precipitation events under RCP 8.5 range from 14.6% to 53.9% as shown below in Table 11.

Table 11 Projected percentage storm intensity increase for Vancouver Harbour Cs weather station under RCP 4.5 and RCP 8.5, 2025-2075. (ICLR, 2018)

T (years)	2		5		10		25		50		100	
RCP	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5	4.5	8.5
5 min	17.1%	14.6%	24.2%	17.8%	25.5%	20.8%	33.8%	26.6%	49.5%	31.3%	53.2%	32.9%
10 min	17.0%	14.6%	24.6%	17.0%	24.3%	19.6%	29.6%	23.7%	42.6%	26.9%	45.9%	30.5%
15 min	17.0%	14.6%	24.5%	17.1%	24.2%	19.7%	30.0%	23.9%	43.2%	27.3%	46.4%	31.1%
30 min	17.0%	14.6%	24.6%	17.2%	24.6%	19.9%	30.5%	24.2%	44.3%	27.9%	49.0%	33.0%
1 h	17.0%	14.6%	24.5%	17.6%	25.4%	20.4%	32.2%	25.7%	47.7%	28.8%	50.6%	33.1%
2 h	17.0%	14.6%	24.7%	17.4%	25.7%	20.3%	31.5%	25.8%	47.6%	29.5%	50.4%	33.4%
6 h	16.9%	14.6%	25.1%	17.0%	25.8%	19.8%	29.7%	25.3%	45.9%	28.7%	48.5%	33.7%
12 h	17.2%	14.6%	24.2%	17.5%	25.9%	20.7%	32.5%	26.7%	49.1%	31.9%	52.5%	33.4%
24 h	17.4%	14.9%	23.9%	17.7%	25.8%	20.8%	33.6%	27.3%	49.9%	32.5%	53.9%	33.6%

PRECIPITATION: ACCUMULATION

Table 12 Record Maximum 3/5/7 days precipitation accumulation, CANGRD Data set

	Record Maximum precipitation accumulation					
	Recent Climate (1984-2013)			**Historic (1950-2013)**		
	3 day	**5 day**	**7 day**	**3 day**	**5 day**	**7 day**
Precip.(mm)	205.38	226.95	272.94	205.38	226.95	272.94
Ended	17-Oct-03	19-Oct-03	22-Jan-05	17-Oct-03	19-Oct-03	22-Jan-05

Data from projected climate models for 3, 5, and 7 day accumulation was not available through CCHIP, however the Metro Vancouver report suggests there will be a **12% increase in the wettest 5-day period by the 2050s** and a **25% increase by the 2080s**. (Metro Vancouver, 2016) These results seem appropriate given the projected increase of intensity of all shorter duration events as well.

PRECIPITATION: DRY SPELLS

Dry Spells is a measure of the number of consecutive days where daily precipitation is less than 1 mm. The value denotes the longest stretch of dry days in a year, typically in summer. (Metro Vancouver, 2016)

Table 13 Average annual dry spell duration. Past=1971-2000. Projections=RCP 8.5 (Metro Vancouver, 2016)

CLIMDEX index: CDD	Past (days)	2050s (days)	2080s (days)	2050s Percent Change (%)		2080s Percent Change (%)	
				Average	(Range)	Average	(Range)
Dry Spell duration	21	26	29	22	(3 to 40)	37	(16 to 65)

PRECIPITATION: SNOW

DAYS WITH SNOWFALL

Neither the CANGRD data nor the Vancouver Harbour Cs weather station distinguish precipitation data between rain and snowfall, thus using the more complete snowfall information from the nearby Vancouver International Airport weather station presents a more reliable approximation of the snowfall in the Project area. The Airport Station is less than 10 km from the Project area. At the Vancouver International Airport the historical prevalence of snow is as follows:

Table 14 Days with snowfall – Vancouver International Airport, 1981-2010 Canadian Climate Normals (Environment Canada)

Snowfall	Days/year
≥ 0.2 cm	8.7
≥ 5 cm	2.5
≥ 10 cm	1
≥ 25 cm	0.13

Although total winter precipitation is projected to increase, the average daily minimum temperature is also projected to increase from -1°C to almost 4°C by 2080. (Metro Vancouver, 2016) The data obtained through CCHIP, shown in the "Temperature: Minimum" section of this climate profile, suggests the "past" minimum temperature average in Winter is around 2°C. This difference can again be contributed to the Metro Vancouver report defining the "past" as the 1971-2000 Climate Normals; whereas CCHIP presents 1981-2010. The future climate projections obtained through CCHIP for winter temperature changes are consistent with the projections in the Metro Vancouver report. The result of warming winter temperatures is more infrequent temperatures capable of producing snow. Days capable of producing snow are summarized using "Ice days" data. "Ice days" is an annual count of days when the daily maximum temperature is less than 0°C. This indicator is useful when predicting snow formation and retention, and the projections indicate there will be far fewer days capable of forming and retaining snow.

Table 15 Ice days. Past = 1971-2000. Project=RCP8.5 (Metro Vancouver, 2016)

CLIMDEX index: ID	Past (days)	2050s (days)	2080s (days)	2050s Change (days)		2080s Change (degree days)	
				Average	(Range)	Average	(Range)
Region	12	4	2	-8	(-10 to -5)	-11	(-12 to -8)
Low elev.	4	2	1	-3	(-3 to -1)	-3	(-4 to -3)

DAILY FROST

There is a great degree of consistency between the Metro Vancouver Report and CCHIP data for the projected future average days of frost.

Table 16 Average Frost Days – low elevation (Metro Vancouver, 2016)

Period	RCP 8.5
Baseline (Historical 1971-2000)	39
2050s	11
2080s	4

Table 17 Average Frost Days – CANGRD data set, BSP Project Area (CCHIP)

Period	RCP 4.5	RCP 8.5
Baseline (Historical 1981-2010)	25	
2020s	16	14
2050s	10	7
2080s	8	4

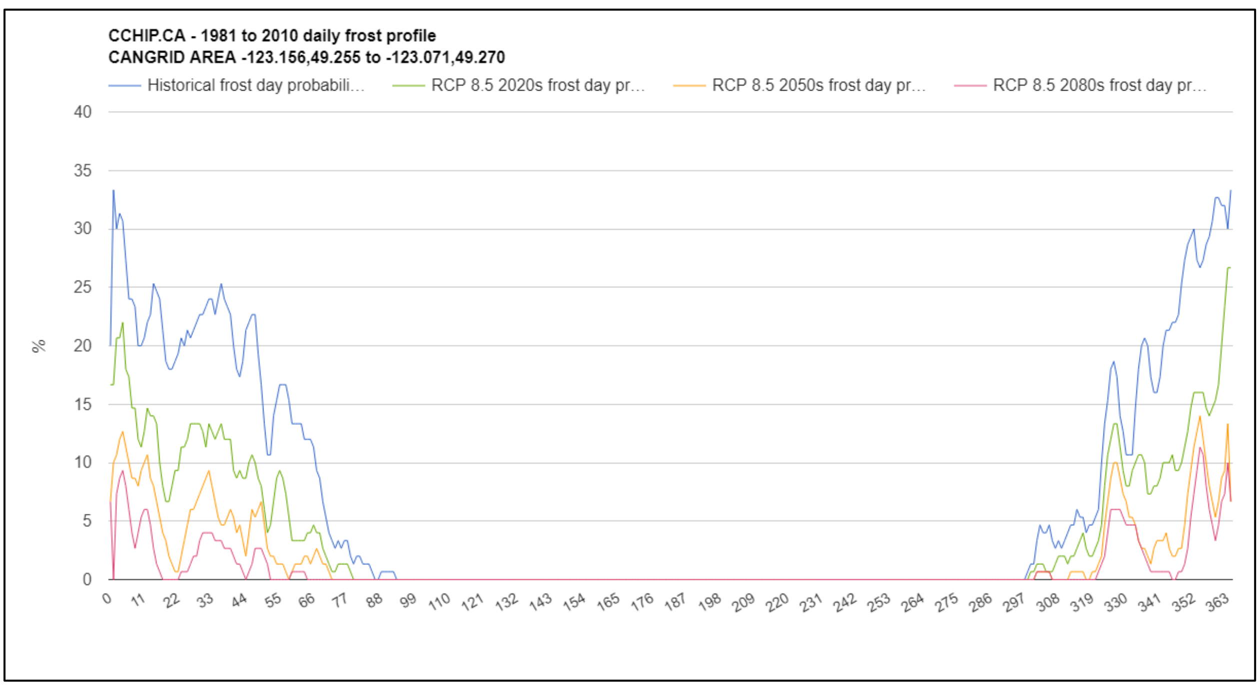


Figure 24 Daily Frost Profile (RCP 8.5) – lines represent the % probability of frost occurring on a particular day of the year. Days of year are numbered 0 – 365 starting January 1st

FREEZE-THAWS

With fewer freezing temperatures projected for the coming decades, the number of freeze thaw events for the Metro Vancouver area is projected to decrease under the effects of climate change.

Table 18 Average Freeze-thaw (day with max. temp >0°C & min. temp <0°C) – CANGRD data set, BSP Project Area (CCHIP)

Period	RCP 4.5	RCP 8.5
Baseline (Historical 1981-2010)	22.1	
2020s	13.4	11.3
2050s	7.7	5.2
2080s	5.8	2.8

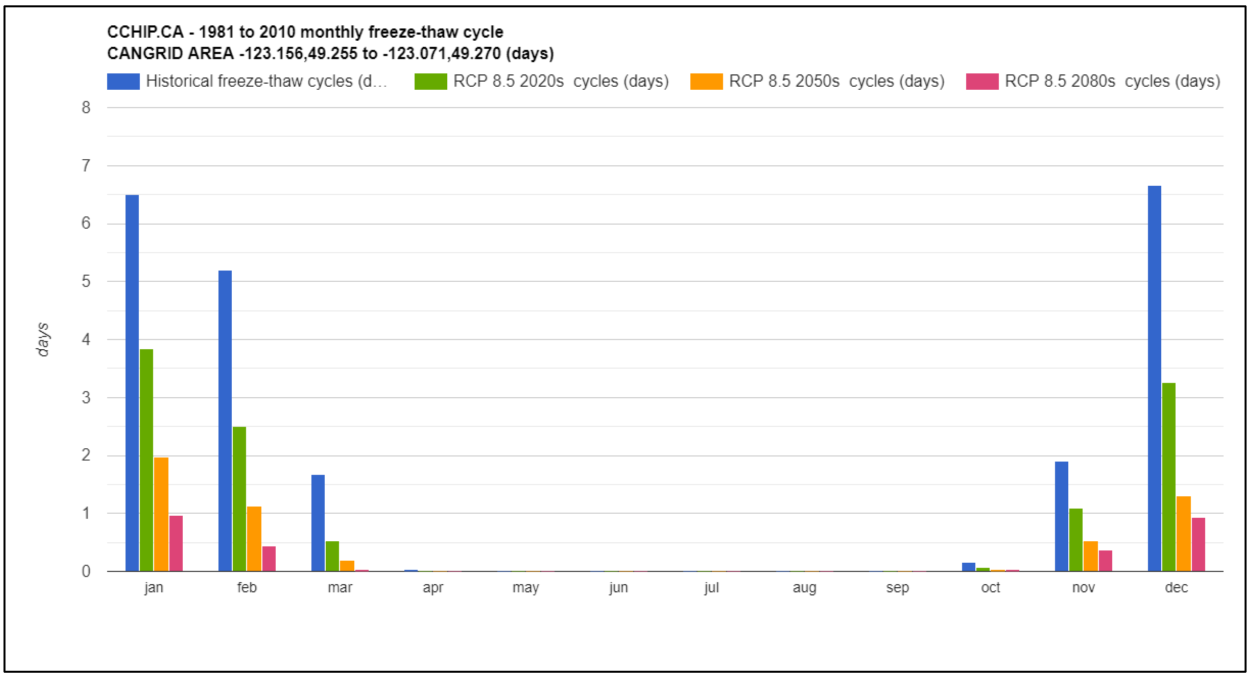


Figure 25 Freeze Thaw Cycles CANGRD data set, BSP Project Area (CCHIP)

WIND

In Stantec's experience, it is best to collect historical wind data from airport weather stations if available since the data is much more complete. Fortunately, the Vancouver International Airport is not far from the BSP project area and Environment Canada publishes wind data from that station.

Table 19 1981 to 2010 Canadian Climate Normals – Wind Station: Vancouver International Airport weather station Source: Government of Canada – Environment and Natural Resource

	Speed (km/h)	Most Frequent Direction	Max Hourly Speed (km/h)	Date (yyy/dd)	Dir. of Max Hourly Speed	Maximum Gust Speed (km/h)	Date (yyy/dd)	Direction of Maximum Gust	Days with Winds >= 52 km/h	Days with Winds >= 63 km/h
Jan	11.9	E	78	2007/09	W	113	2007/06	W	1	0.2
Feb	11.7	E	89	1960/20	W	119	1961/21	W	0.5	0.1
Mar	13.2	E	77	1975/30	W	108	1975/30	W	1	0.3
Apr	13	E	78	2010/08	W	100	1961/03	W	0.5	0.2
May	12.5	E	61	1982/25	W	90	1955/07	W	0.4	0.1
Jun	12.4	E	52	1979/06	W	70	1992/02	W	0.1	0
Jul	12.3	E	54	2004/07	W	71	1960/07	W	0	0
Aug	11.6	E	50	2002/14	W	85	1980/17	NW	0	0
Sep	11.2	E	65	2005/09	W	91	1999/25	NW	0.2	0.1
Oct	11.7	E	82	2003/28	W	126	1962/13	SE	0.6	0.1
Nov	12.9	E	89	1961/01	W	129	1957/25	W	1.4	0.3
Dec	12.2	E	82	2001/14	NW	100	1957/23	SE	1	0.3
Year	12.2	E	89	1960/20	W	129	1957/25	W	6.6	1.8

The projected climate changes with respect to wind are not as well understood as variables such as temperature, however there has been significant research in this field. However, borrowing from sources cited in a 2013 publication by the Government of BC, titled Climate Change in BC, the following are projected changes in wind expected under future climate conditions: (as cited in Daust, 2013)

- *"In general, climate warming is expected to increase the intensity of atmospheric convection processes, leading to an increased frequency of intense windstorms" (Pojar 2011, Haughian et al 2012; Lambert and Fyfe 2006).*
- *"The average speed of intense wind events (i.e., top 10% of wind events) is expected to increase by up to 14% in coastal BC and the Northern Boreal mountains" (Haughian et al 2012).*

FOG

Fog formation is a complex process and the projected prevalence of fog events under future climate conditions is not as well understood as other climate parameters. However, in studies completed on the subject there are some conclusions regarding the overall historic trend of fog events. "*There is vast evidence in the scientific literature that the frequency of fog events and the intensity of fog exhibit significant changes over time. The literature analysis . . . shows that the majority of stations worldwide show a decrease of fog."* (Klemm et al., 2016)

REFERENCES

Daust Dave, (2013) Climate Change in BC, Adapting to Climate Change (retreived Sept 2018) https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/applied-science/2a_va_bc-climate-change-final-aug30.pdf

Klemm, O., Lin, N.-H., 2016. What causes observed fog trends: air quality or climate change? Aerosol Air Quality Reaserch, 16: 1131-1142