APPENDIX C: OVERVIEW OF CLIMATE CHANGE, TOOLS AND RESOURCES FOR ADAPTATION

For an up-to-date overview of climate change and list of tools and resources for climate change adaptation, visit the Engineers and Geoscientists BC Climate Change Information Portal, at https://www.egbc.ca/Practice-Resources/Climate/Climate-Change-Information-Portal.

BACKGROUND: HISTORICAL CLIMATE VARIABILITY AND CLIMATE CHANGE IN BRITISH COLUMBIA

To provide context to the effects of future climate change in British Columbia, this section presents the degree of climate variability observed and projected climate trends. As with professional practice, the field of climate science continues to evolve. Thus, contents of this section is only as a primer and not be used to carry out risk assessments or inform infrastructure design.

British Columbia exhibits significant variability in climate, both spatially and over time. This variability is a result of several combined factors such as:

- highly varied topography
- geographic expanse (spanning approximately 12 degrees of latitude and 25 degrees of longitude)
- climate cycles – namely the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO)

Topography and geography are stationary factors whereas PDO and ENSO are phenomena that vary in effect over time, interact and produce short-term climate variations. Notably, the ENSO and PDO produce identifiable cycles in temperature and precipitation over the entirety of the province.

The ENSO cycle is the fluctuations in ocean and atmospheric temperatures that occur in the eastern and central Equatorial Pacific. The ENSO cycle has opposing warm phases (El Niño) and cold phases (La Niña). The resulting deviations from normal ocean surface temperatures can greatly impact ocean processes, and significantly influence global weather and climate. The warm and cold phases of ENSO are typically of 9 to 12 month, though longer phases have been recorded, and occur on a frequency of 2 to 7 years (National Ocean Service 2016). El Niño effects develop over North America during the following winter season. Those include warmer-than-average temperatures over western and central Canada and over the western and northern United States.

The PDO is similar to ENSO but occurs in the north Pacific, although over a much longer time scale, remaining in the same phase (warm or cool) for 20 to 30 years. The PDO warm and cool phases, like ENSO, greatly affect upper atmospheric winds. Shifts in the PDO phases can have significant impacts on global climate, influencing Pacific storm activity, the severity and extents of droughts and flooding around the Pacific basin, the productivity of marine ecosystems, and global land temperature patterns (Northwest Fisheries Science Center, 2019).

In addition, when the PDO and ENSO are in phase the effects are magnified; when they are out of phase the effects are dampened. The climatic variability produced by the PDO and ENSO can often be identified as short-term trends (approximately 10 to 20 years) in climate data, with periods of mild warming or cooling when compared to long-term climate norms. As such, they also tend to mask long-term historical trends in climate.

Historical Climate Trends

When long-term data are assessed, significant warming has already occurred in British Columbia. In general, increases in mean annual temperature of over 1ºC, and approaching 2ºC in northern regions of the province, were apparent over the 1901–2009 period. The increase is greater during the 1951–2009 period. Generally, the observed increases in temperature are greatest in the winter (PCIC 2019).

Trends in annual precipitation have not been as uniform across British Columbia as observed for temperature. Increases in annual precipitation vary greatly with location, but are more pronounced in regions with lower annual precipitation. There has been an increase in the occurrence of extreme wet and extreme dry conditions in the summer and a decrease in winter snowpack in the period 1951–2009 (Pike et al. 2008).

Projected Climate Change

On a provincial scale, climate change projections generally indicate warmer, shorter winters and longer summer periods. Total precipitation is projected to increase, with drier summers and a greater proportion concentrated in the shorter winter periods. However, the magnitude of these changes is not uniform over the province, and can vary significantly due to topographic or orographic effects and local influences. Table A.1 summarizes the average projected temperature change by region, and the range in the projections. Table A.2 summarizes the projected changes in key temperature/heat indices (growing and heating days, and frost-free days), while Table A.3 summarizes the projected changes in precipitation. Generally, the lower portion of the range for each parameter is associated with the milder climate change scenarios, such as B1 or RCP 2.6, while the upper portion is associated with the more severe climate change scenarios, such as A2 and RCP 8.5. (The significance of the different scenarios and their nomenclature is discussed later in this appendix.)

Table C1: Projected mean temperature changes by 2050s, from 1961 to 1990 baseline, by region

REGION	PROJECTED TEMPERATURE CHANGE (°C)				
	Mean Annual		Season of Greatest Warming		
	Average	Range	Season	Average	Range
Cariboo	1.8	1.1–2.6	Summer	1.9	1.3–2.8
Kootenay/Boundary	1.9	1.2–2.8	Summer	2.4	1.5–3.2
Northeast	1.8	1.4–2.8	Winter	2.4	0.7–3.6

Omineca	1.8	1.3–2.7	All	1.8	1.3–2.7
Skeena	1.8	1.1–2.5	All	1.8	1.1–2.5
South Coast	1.7	1.1–2.5	Summer	2.0	1.4–2.8
Thompson/Okanagan	1.8	1.1–2.7	Summer	2.1	1.5–3.0
West Coast	1.4	0.8–2.2	All	1.4	0.8–2.2

Source: PCIC 2019

Table C.2: Projected change in temperature indices by 2050s, from 1961 to 1990 baseline, by region

REGION	TEMPERATURE INDICES					
	Growing Degree Days		Heating Degree Days		Frost-Free Days	
	Mean	Range	Mean	Range	Mean	Range
Cariboo	+283	+162 to +444	–632	–930 to –398	+23	+13 to +34
Kootenay/Boundary	+295	+168 to +434	–675	–997 to –425	+24	+15 to +35
Northeast	+226	+148 to +392	–659	–997 to –483	+16	+9 to +23
Omineca	+223	+136 to +379	–642	–975 to –459	+19	+11 to +30
Skeena	+226	+142 to +353	–645	–918 to –418	+22	+12 to +34
South Coast	+336	+205 to +506	–593	–896 to –372	+24	+14 to +36
Thompson/Okanagan	+319	+183 to +482	–654	–962 to –403	+24	+14 to +35
West Coast	+327	+204 to +306	–534	–816 to –318	+22	+13 to +32

Source: PCIC 2019

"Growing degree days" is an expression of heat accumulation commonly used in agriculture to estimate plant and animal development rates. It is the sum of the average temperature in excess of a threshold temperature (generally 5◦C in Canada) for each day, over the duration of a growing season (Natural Resources Canada 1981a).

"Heating degree days" is the sum of the absolute value difference between the daily average temperatures on days where heating is required and the threshold for heating (generally 18◦C in Canada), over the duration of either a "heating season" or an entire year. It is a quasi-quantitative means of expressing the total required effort for heating over a year (Natural Resources Canada 1981b).

"Frost-free days" represents the nominal length of the growing season. It is measured between the last frost in spring and the first frost in the fall (Natural Resources Canada 1981c).

Table C.3: Projected percent change in precipitation by 2050s, from 1961 to 1990 baseline, by region

REGION	PRECIPITATION					
	Annual		Summer		Winter	
	Mean	Range	Mean	Range	Mean	Range
Cariboo	+6%	–1% to +13%	–7%	–15% to –5%	+7%	–3% to +14%
Kootenay/Boundary	+5%	–3% to +10%	-6%	–18% to 0%	+8%	–2% to +17%
Northeast	+6%	0% to +16%	+4%	–6% to +13%	+11%	–6% to +22%
Omineca	+8%	+2% to +15%	+1%	–8% to +9%	+9%	–2% to +18%
Skeena	+7%	+3% to +13%	+2%	–5% to +11%	+9%	–1% to +16%
South Coast	+6%	–2% to +11%	–14%	–23% to +3%	+6%	–4% to +14%
Thompson/ Okanagan	+6%	–1% to +11%	–9%	–19% to +1%	+7%	–4% to +15%
West Coast	+6%	+0% to 11%	–10%	–18% to +2%	+6%	–2% to +12%

Source: PCIC 2019

C.1.1 Temperature

General projects have indicated a higher average temperature throughout the province with greater likelihood of extreme warm periods than historically observed. Increased fire risk is expected, especially when combined with the effects of reduced summer precipitation and summer soil moisture (see C.1.2). Extreme high temperatures may place greater thermal stress on structures and accelerate the deterioration of asphaltic pavements.

Winter temperatures will be higher, with a corresponding reduction in the accumulation of snow precipitation. A greater proportion of winter precipitation becomes run-off with lesser volume retained in soil structures during spring (freshet). Warmer temperatures during the winter, combined with a general increase in precipitation, may increase the occurrence of fog. An increased frequency of freeze–thaw cycles will produce greater risk of “black ice” conditions on roadways, and the occurrence of ice accumulations in drainage systems. Increased freeze–thaw cycles will also accelerate degradation of paving materials on roads and deterioration of road subgrades.

Warmer winter temperatures significantly decreases the use of energy to heat structures. The increase in frost-free days will lengthens the growing seasons and the possibility of greater agricultural yields and utilization of farmland. However, this benefit to agriculture neglects changes in summer precipitation and reduced winter snowpack, as discussed below (PCIC 2019).

C.1.2 Precipitation

Average annual precipitation is projected to increase throughout British Columbia with higher frequency and magnitude of extreme events. Localized flooding and overland flow will occur where drainage systems are not upgraded to address the increased severity of extreme events.

A greater proportion of total annual precipitation will occur in the winter, which, when combined with generally higher average winter temperatures, will increase winter runoff and reduce storage of water. Increased soil moisture may increase the potential for slope instability in poor draining soils; thus increasing load on engineered soil retaining structures.

Reduced summer rainfall, as well as reduced snowpack storage, will increase the magnitude and severity of water shortages over the summer months, reducing drinking and irrigation water storage at the onset of the summer season, and increasing demands due to domestic and irrigation requirements.

Pacific Climate Impacts Consortium has also completed studies on the hydrologic impacts of climate change in several British Columbia river basins. Several key hydrologic changes in the river basins include, but are not limited to, early snowmelt and freshet, changes in the seasonal distribution of streamflow, and changes in low-flow and peak flow return periods (PCIC 2019).

C.1.3 Sea Level

Historically, sea level rise has been documented at an average rate of 1.7 mm/year over the period of the late 19th century and through most of the 20th century, as observed on a global scale. Since 1993, an accelerated rate of 3 mm/year has been recorded globally. On the British Columbia coast, recorded average sea level rise has generally been less than experienced at the global scale (i.e., less than 1 mm/year, and varies by location) (BC Ministry of Environment 2013).

Climate change–related sea level rise is driven by:

- release of water stored as ice in the polar ice caps, continental ice sheets, and glaciers
- bulk expansion of water in the oceans due to warming and reduced salinity
- water level increases due to regional-scale changes in major atmospheric currents or wind systems, and alteration of large-scale ocean currents

Geophysical processes can affect the relative rate and magnitude of sea level rise, with uplift offsetting the effect of absolute sea level rise and subsidence magnifying the effect of absolute sea level rise. Tectonic processes produce subsidence in subduction zones along the Strait of Georgia and uplift on the West Coast of Vancouver Island. Alluvial soils in the Fraser River Delta are subject to subsidence as consolidation occurs, while long-term rebound occurs in soils relieved of confining pressures due to glacial retreat. For the British Columbia coast, projected sea level rise to the year 2100 due to the more severe climate change scenarios varies between 0.8 m and 1.2 m, depending on location (Bornhold 2008).

Increased sea levels, relative to local land elevations, will exacerbate salt-water intrusion into aquifers, affecting the quality of groundwater used for agricultural, industrial and domestic purposes. Increased soil saturation will also occur, and higher average groundwater tables will place greater stress on drainage systems in low-lying coastal areas. Extreme storm conditions of wave run-up and storm-surge increases the risk of overtopping sea dikes, damage to coastal infrastructure and flooding of low-lying areas.

C.1.4 Other Climate Impacts

Secondary climatic conditions include extreme winds generated from large differences in atmospheric pressure. Increased wind intensity and frequency will result in more frequent and extensive power outages as well as increased structural damage. As warmer conditions prevail, the frost line will move northward, and permafrost will be more susceptible to melting. Reduced ground stability due to disruption of permafrost conditions will likely lead to foundation challenges, as well as slope stability issues in more northern areas of British Columbia, as well as the Yukon, Nunavut and Northwest Territories.

C.2 IMPLICATIONS FOR INFRASTRUCTURE DESIGN

Climate change will result in an increased stress on highway infrastructure. Very few benefits to highway infrastructure are apparent. In the absence of the incorporation of climate change adaptation or resilience measures, the following effects are likely:

- reduced levels of service over time, as climatic conditions change
- interruptions in service due to extreme events
- shorter service life due to increased wear and tear
- increased likelihood of significant failure under extreme conditions
- increased operating costs
- increased maintenance in response to “overloading”

Example scenarios where climate change has been addressed are provided in Appendix B.

C.3 CLIMATE PROJECTIONS

This section provides a primer in emissions projections, modelling and data extraction (downscaling). However, the professional should engage a climate specialist for complex assignments to ensure that climate projection inputs are properly understood and applied. It is also the responsibility of the design professional to obtain and use the most recent climate projection data applicable.

C.3.1 Climate Models

Two major types of climate models are used to assess future climate changes. Global climate models (GCMs) are the most common, and have been in use the longest. GCMs simulate the impacts over time of changing greenhouse gas (GHG) concentrations on the climate. GHG scenarios are an input determined externally from the GCM, and the GCM does not internally track GHGs as part of the modelling process. Alternatively, comprehensive Earth System Models (ESMs) incorporate the same functionality as GCMs, but also simulate the carbon cycle, as well as chemical and biological processes in the biosphere. As a result, they are able to account for changes in GHGs that may result as a consequence of climate change impacts, such as CO_2 released from melting permafrost.

Of the recent models considered in the Intergovernmental Panel on Climate Change's (IPCC) Coupled Model Intercomparison Project 5 (CMIP5), the Pacific Climate Impacts Consortium (PCIC) has identified 12, ordered in Table C.4, in terms of being most applicable to western North America (i.e., British Columbia). The ordering, which differs by region, is selected to provide the widest spread in projected future climate for smaller subsets of the full ensemble. It may be useful to note that all climate models in CMIP5 are ESMs.

Table C.4: Climate models applicable to British Columbia

	MODEL NAME	INSTITUTE	MODELLING CENTRE (OR GROUP)
1	CNRM-CM5-R1	CNRM-CERFACS	Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique
2	CanESM2-r1	CCCMA	Canadian Centre for Climate Modelling and Analysis
3	ACCESS1-0-r1	CSIRO-BOM	Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia
4	INM-CM4-r1	INM	Institute for Numerical Mathematics
5	CSIRO-Mk3-6-0-r1	CSIRO-QCCCE	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence
6	CCSM4	NCAR	National Center for Atmospheric Research
7	MIROC5-r3	MRI	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
8	MPI-ESM-LR-R3	MPI-M	Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)
9	HadGEM2-CC-r1	MOHC	Met Office Hadley Centre
10	MRI-CGCM3-r1	MRI	Meteorological Research Institute
11	GFDL-ESM2G-r1	NOAA-GFDL	NOAA Geophysical Fluid Dynamics Laboratory
12	HadGEM2-ES-r1	MOHC	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)

Source: PCIC, 2019

C.3.2 Downscaling

Most Highway Infrastructure projects are local or regional in scope, and carried out at spatial scales far smaller than the resolution of GCMs. GCM outputs range from sub-daily resolution to temporal resolution in the order of days. For infrastructure design or assessment purposes, a valid process for extracting finer-resolution spatial and temporal data from coarse-scale GCM results is required. The process of producing higher-resolution data suitable for analysis and design at a local scale is termed "downscaling." Two techniques used to downscale from large-scale GCM output are statistical downscaling and dynamic downscaling, using regional climate models.

Statistical downscaling makes use of statistical relationships in historical climate data at the global and local scale, and outputs data at a finer resolution for the historical and future periods.

Typically, the downscaling technique attempts to adjust for any biases in the GCM over the historical period, using either an explicit bias correction process or statistical-based methods such as quantile mapping. The primary assumption (tested by PCIC for their statistical downscaling technique) is that the relationship between coarse-scale and local-scale climate data developed based on past data will remain valid for future climate conditions.

The second approach to downscaling is a dynamic approach using regional climate models (RCMs). Similar to GCMs, RCMs are based on physical processes, but RCMs produce higher-resolution output at regional and local scales, and often include additional landscape controls, such as land use, vegetation and topography. As a result, they are more computationally intensive.

While RCMs will reproduce locally important climatic processes, such as sea breezes or lake effects, the models are driven at the boundary by GCMs. Thus, dynamic downscaling outputs may require an additional layer of statistical correction to address inherited biases propagated from GCMs. Table C.5 provides a brief overview between dynamic and statistical downscaling as described in the *Water Resources Research Report: Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate (Technical Manual v3)* from the Western University (2018).

Table C.5: Comparison of dynamic downscaling and statistical downscaling

CRITERIA	DYNAMIC DOWNSCALING	STATISTICAL DOWNSCALING
Computational time	Slower	Fast
Experiments	Limited realizations	Multiple realizations
Complexity	More complete physics	Succinct physics
Examples	Regional climate models, Nested GCMs	Linear regression, Neural network, Kernel regression

Source: (p12, Western University, 2018)

C.3.3 Greenhouse Gas Emissions Scenarios

Climate projections require that a forcing condition be incorporated into a GCM, which is generally provided by a GHG emissions scenario. Each GHG emissions scenario is an estimate of potential future releases of greenhouse gases, aerosols and other anthropogenic gases into the atmosphere. A GHG emissions scenario is developed from a particular combination of input parameters related to GHG production that includes economic activity, technological progress and potential efforts to curtail GHG production. These inputs estimate the resulting GHG emissions associated with the particular scenario. Each scenario is internally consistent (i.e., does not contain contradictory parameters) and is physically plausible.

Two different sets of GHG emissions scenarios were used to project climate change. Developed in 2000 by the IPCC for the Third Assessment Report on climate change, the Special Report on Emissions Scenarios (SRES) scenarios until 2010. The representative concentration pathway (RCP) scenarios then superseded the SRES scenarios as described below.

C.3.3.1 SRES Scenarios

The SRES scenarios were intended to represent future changes in the global environment related to emissions of greenhouse gases and aerosol precursors. There are four general scenario families, A1, A2, B1 and B2, each representing differing paths of demographic, social, economic, technological and environmental development that diverge widely as time progresses.

- The A1 scenarios represent very rapid economic growth, a global population that peaks in the mid-21st century and then begins to decline, coupled with a rapid progress to new and more efficient technologies.
- The A2 scenarios represent a future with generally slower and regionally biased economic growth, continually increasing global population and lacking consistent technological progress.
- The B1 scenarios represent a future where population peaks and then declines, similar to the A1 family, but economic activity rapidly shifts from a production economy to a service economy with the introduction of clean and efficient technologies.
- The B2 scenarios represent a future in which there is moderate economic development with continuously increasing population, at a rate lower than A2, but economic, social and environmental issues are managed at a local or regional scale.

Of these four, the A2 family produced the more severe GHG emissions, and was representative of the world proceeding on a status-quo path.

C.3.3.2 Representative Concentration Pathway Scenarios

Representative Concentration Pathway (RCP) scenarios are based on GHG concentration pathways or a number of different combinations of economic, technological, social and policy changes, rather than particular emissions scenarios. Each RCP is defined by the resulting “radiative forcing” by the year 2100. Radiative forcing is an expression of the cumulative measure of the effect of human emissions of GHGs from all sources, expressed in Watts per square meter (W/m2), and is the change in the balance between incoming and outgoing radiation. Each RCP covers the 1850–2100 period, and extensions have been formulated for the period thereafter, up to 2300 (van Vuuren et al. 2011). These new GHG scenarios specify concentrations rather than emissions. The range of equivalent emissions covered by the set of RCPs is similar to the range covered by SRES, except on the lower end, where RCP 2.6 represents aggressive GHG emissions reductions. There are four RCPs, summarized in Table C.6.

Table C.6: Representative concentration pathway scenario description

SCENARIO	DESCRIPTION
RCP 8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100
RCP 6	Stabilization without overshoot pathway to 6 W/m^2 at stabilization after 2100
RCP 4.5	Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100
RCP 2.6	Peak in radiative forcing at ~ 3 W/m^2 before 2100 and decline

Source: IPCC Data Distribution Center 2014

Generally, the most relevant scenario for infrastructure design and assessment is RCP 8.5, which is the worst of the four scenarios and is consistent with current trends in GHG emissions (status quo). The other scenarios generally produce less extreme outcomes, but may be applicable in specific situations. Notably, the current level of GHG emissions equals or exceeds the most extreme current scenarios (Olsen 2015).

C.3.4 Projected Climate Data Characteristics

Climate projection data are available in a variety of levels of detail, degree of complexity and formats. The selection of the applicable form of climate projection data greatly depends on the requirements of the project, the level of knowledge of the user and, in some cases, data availability. Projected climate data categorized based on their characteristics, detail, complexity and ease of application into (Charron, 2016):

- basic
- intermediate
- detailed

Generally, the more advanced the category of climate projection data, the greater the complexity and the effort required to make use of the data. In addition, more support from a climate specialist will likely be required with the higher categories.

The category of a required dataset further defined by three criteria:

- the purpose or application of the data
- the type of climate variable involved
- the level of detail in space and time, in terms of scale and resolution

As per Charron (2016), all three criteria are important to consider in ensuring that the data are appropriate for the assignment at hand, and to facilitate its proper use. The format in which the data obtained is also an important consideration in making the climate projection data suitable for use. Climate data can be provided in a variety of formats from digital data files for use as inputs to other analyses or models, or as summarized or consolidated data in the form of tables, maps or figures that are directly interpreted by a user. The typical characteristics of each category are briefly discussed below.

Basic category:

- Purpose – Often intended high-level assessments of potential climate change risks, such as an assessment of infrastructure sensitivity to changes in design conditions due to climate change.
- Climate variables – Generally requires simple climatic variables such as precipitation and temperature, and may involve simplified climate projection outputs, such as estimated increase of a design rainfall event at a certain time horizon.
- Spatial and temporal resolution – A coarse resolution and limited scale for the projected change is sufficient; a single general value on a regional scale, at a non-specific point in time is adequate; for example, a projected increase in mean winter temperatures in the Okanagan for the 2050s, representing a coarse envelope in both space and time.

Intermediate category:

- Purpose – Generally required for a more detailed evaluation considering a range of varying climate outcomes and potential impacts to identify risks and opportunities; used to quantify the interaction between climate and people and/or infrastructure; also used to identify critical thresholds in climate change, and when and to what degree systems become vulnerable.
- Climatic variables – Moderately complex climate indices data, and are generally a product of further analysis (such as modelling) of basic climate indices such as temperature and precipitation; often, specific future values are required, rather than a relative change in the climate indices in question.
- Spatial and temporal resolution – Generally a finer resolution and scale is required than for simpler assignments, although this may vary.

Detailed category:

- Purpose – The focus is often on a detailed assessment of climate change impacts, considering a range of impacts, identifying the most important impacts and developing detailed adaptation actions and priorities.
- Climatic variables – Required climate variables can vary greatly between assignments, but several climate variables may be involved, including ones that are themselves derived from other data; efforts to estimate climate extremes often require complex climate data, including time series data sets, incorporating several variables. Outputs are often developed indirectly from climate inputs; for instance, modelling to estimate drought occurrence, changes in stream flow characteristics or occurrence of extreme storm events usually requires complex data inputs.

- Spatial and temporal resolution – Usually requires fine spatial resolution and scales, while temporal resolution and scale may depend on the particulars of an assignment, such as the planning horizon.

C.3.5 Uncertainties and Likelihoods

There are three main sources of uncertainty in the climate projection outputs of emissions scenarios and climate modelling:

- the inherent natural variability of climate in both temporal and spatial scales
- a simplified and potentially incomplete or inaccurate representation of climatic processes, and the particular parameters employed within climate models resulting in uncertainty in any given model's response to natural and anthropogenic forcing inputs
- scenarios for forcing inputs, such as emissions, and various natural or anthropogenic factors.

Although climate model projections are really simulations from first principles, it is difficult to assign probabilities or likelihoods to any given climate projections. An ensemble of climate models, even when using the same forcing inputs, will produce a range in projected climatic conditions. Moreover, probabilistic estimates of impacts based on ensembles of model outputs are not representative of an actual range of outcomes. In particular, the probability distribution of climate model projections could underestimate the degree of uncertainty, as climate models contain biases and have limitations in their resolution at both temporal and spatial scales. The model outputs are not true random samples and their distribution does not necessarily have the true future climate as its mean. In addition, a finite number of models, with a limited set of climate scenarios, are only able to encompass an unknown proportion of all potential climate outcomes. It appears likely that the range of climate outcomes resulting from model ensembles represents a minimum representation of future climate uncertainty (Olsen 2015).

C.3.6 Climate Extremes

Recent observations, both anecdotal and quantitative, combined with climate model outputs, indicate that the range of climate extremes will increase. Individual extreme events will become greater in magnitude and occur more frequently. By extension, events of a particular magnitude that have been associated with a frequency of occurrence based on historic data will now occur more frequently. Effectively the service level of existing infrastructure, designed on the basis of events of a certain magnitude occurring at an expected frequency, will be reduced, potentially significantly. New and refit infrastructure will need to account for the increase in extreme events, with large events occurring more often over the life of a facility (Olsen 2015).

C.4 CLIMATE RESOURCES

The following organizations, resources and tools are potentially useful for engineering applications. The QP and EOR should monitor for improvement to the existing tools as well as the availability of new tools and information that may be applicable.

Note: For a more extensive list of the tools and resources available to engineers and geoscientists for climate change adaptation, please visit Engineers and Geoscientists BC's Climate Change Information Portal (www.apeg.bc.ca/climateportal). Engineers Canada's PIEVC website (www.pievc.ca/) is a resource for infrastructure vulnerability reports using the PIEVC Protocol as well as information on the protocol itself.

C.4.1 Pacific Climate Impacts Consortium

The Pacific Climate Impacts Consortium (PCIC; www.pacificclimate.org/analysis-tools/pcic-climate-explorer) is a not-for-profit corporation at the University of Victoria and is a center that undertakes applied research and quantitative assessments of climate change variability, effects and impacts for the Pacific and Yukon regions. The consortium's efforts focus on three areas: hydrologic impacts, regional climate impacts, and climate analysis and monitoring. PCIC's Climate Explorer (PCEX) tool enables users to locate, visualize and download data to project future climate conditions in regions within Pacific and Yukon in form of maps and graphs. The PCEX currently serves as a primary resource for climate change information for British Columbia and is anticipated to include other types of projections such as stream-flow, sub-daily precipitations in the near future.

C.4.2 Intensity–Duration–Frequency – Climate Change (IDF_CC) Tool

The IDF_CC tool (Version 3.5; www.idf-cc-uwo.ca/) is an analysis tool that provides estimates of intensity–duration–frequency (IDF) curves under future climate conditions. IDF curves can be generated using all the major climate models and the four standard emissions scenarios, allowing the user to assess IDF data for a variety of outcomes. The IDF_CC tool was developed at the University of Western Ontario, in the Faculty for Intelligent Decision Support. The current version of IDF-CC tool makes use of the most recent Environment Canada IDF datasets, which were revised in December 2018. There are a number of uncertainties associated with the method that the tool uses to produce sub-daily projections; therefore, it is recommended that this tool be used for exploratory rather than design purposes.

C.4.3 Environment and Climate Change Canada – Engineering Climate Datasets

Environment and Climate Change Canada provides three types of climate data that have particular application to engineering (http://climate.weather.gc.ca/prods_servs/engineering_e.html):

- the most recent short-duration IDF data for many locations across Canada, as well as historic IDF data
- the Canadian Weather Energy and Engineering Datasets (CWEEDS) – provide long-term hourly data for 21 different weather parameters that are applicable for estimating heating and cooling requirements for structures, among other uses
- the Canadian Weather year for Energy Calculation (CWEC) datasets – a subset of CWEEDS, where 12 Typical Meteorological Months are selected by statistically identifying an individual month that has mean values for several parameters that are closest to the monthly means obtained from the long term CWEEDS data set; parameters covered are daily total global radiation, mean, minimum and

maximum dry bulb temperature, mean, minimum and maximum dew point temperature, and mean and maximum wind speed

- Climate data extraction tool (https://climate-change.canada.ca/climate-data/#/) enables users to select date ranges, variables and download format of data available on the Environment and Climate Change Canada's database

C.4.4 Natural Resources Canada – Climate Adaptation Website

The Impacts and Adaptation website of Natural Resources Canada (https://www.nrcan.gc.ca/environment/impacts-adaptation10761) includes the Adaptation Platform, an initiative to promote collaboration between government, industry and professional organizations to identify adaptation priorities for a broad range of economic sectors, regions and disciplines. This site also provides access to several high-level assessments of climate change impacts and potential adaptation strategies.

C.4.5 Fraser Basin Council – BC Regional Adaptation Collaborative Program

The Fraser Basin Council (FBC) has participated in several climate change adaptation related initiatives. The key FBC climate change initiative is the BCRAC program (www.fraserbasin.bc.ca/ccaq_bcrac.html), undertaken jointly with the BC Ministry of Environment – Climate Action Secretariat, and funded by Natural Resources Canada. The BC-RAC program focuses on "Preparing for Climate Change – Securing British Columbia's Water Future," and has developed tools and resources for planning climate change adaptation, identifying risk, issues of concern, collaboration opportunities and potential options for adaptation measures.

In addition, the Fraser Basin Council website provides a portal to other climate change adaptation resources: www.fraserbasin.bc.ca/ccaq_bcrac_resources.html

C.4.6 CLIMDEX – University of New South Wales (Australia)

CLIMDEX is a project undertaken by the University of New South Wales (Australia), with support from several organizations, including PCIC and Environment Canada. The purpose of the CLIMDEX project is to develop a comprehensive dataset of indices that are used to quantify extreme climate conditions (https://www.climdex.org/). The global datasets are both climate station–based (in-situ) and gridded land–based, covering 27 key indices of extreme climate.

The datasets are useful for assessing global and regional variability in climatic extremes, and global climate model output. Detailed background information on each dataset's source, model and processing software, time series and estimates of uncertainty are also available. Generally, CLIMDEX is for expert users, and care must be taken in selecting appropriate datasets.

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