DEVELOPING CLIMATE CHANGE–RESILIENT DESIGNS FOR HIGHWAY INFRASTRUCTURE IN BRITISH COLUMBIA (INTERIM)

APEGBC PROFESSIONAL PRACTICE GUIDELINES

V1.0

Professional Engineers and Geoscientists of BC

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PREFACE

These interim guidelines apply only to highway infrastructure owned by the BC Ministry of Transportation and Infrastructure (BCMoTI). After a period of one year, it is expected these guidelines will be reviewed based on the experience gained in their application, and revised as appropriate.

These APEGBC Professional Practice Guidelines address the consideration of climate change and extreme weather event factors in the designs for BCMoTI highway infrastructure in British Columbia in order to promote climate resilience. The guidelines have been developed with support and partial funding from BCMoTI. Subject to Section 1.5 on the applicability of these guidelines, they identify the standard of practice to be followed when carrying out climate change–*resilient design* of highway infrastructure under the authority of BCMoTI, to promote functionality and reliability of provincial highway assets in BC.

In addition to offering guidance on the standard of practice to be followed, the guidelines also provide examples from practising professionals in BC (see Appendix C). These are intended to demonstrate the use of climate projections along with engineering judgment in decision-making, and to demonstrate ways in which climate change resilience is considered and incorporated in the design of highway infrastructure projects.

These APEGBC professional practice guidelines were developed in response to BCMoTI's Technical Circular (T-06/15), *Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design* (June 22, 2015; www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/technical-circulars/2015/t06-15.pdf) (see Appendix B). As these guidelines were developed specifically in response to BCMoTI's Technical Circular, they only apply to BCMoTI projects, and therefore the standard of practice set out in the guidelines is not intended to apply to any other projects.

These guidelines will complement the existing *APEGBC Professional Practice Guidelines – Legislated Flood Assessment Guidelines in a Changing Climate in BC* (2012).

These sets of guidelines were informed by a national-level guidance document prepared by Engineers Canada (2015). *Principles of Climate Change Adaptation for Engineers* includes nine principles and establishes the scope of professional engineering practice in carrying out climate change adaptation work.

Guidance offered by the APEGBC practice guidelines is consistent with one of the primary objectives of APEGBC, which is to establish, maintain and enforce standards for the professional practice of engineers and geoscientists in BC. The guidelines are not, in and of themselves, prescriptive design requirements, nor do they supersede provisions specified by local governments or other approving agencies.

These guidelines establish a common level of expectation for clients, statutory decision makers, and APEGBC professionals regarding the standard of practice to be followed by APEGBC professionals when addressing climate change and extreme weather events for BC MoTI's highway designs. Where relevant, APEGBC professionals are reminded to confirm the adequacy of their liability insurance coverage when carrying out such work.

PROCESS AND OUTCOMES

The processes and outcomes described in these guidelines provide detailed guidance supporting the directive set out in the BCMoTI technical circular, which requires design adaptation to climate change, including documentation, for BCMoTI projects.

The BCMoTI technical circular requires the following work to be completed to demonstrate that infrastructure designed for the Ministry includes the reasonable consideration of climate change and extreme weather events appropriate to the scale of the project:

1. Infrastructure and climate vulnerability assessment for the design life of components
2. *BCMoTI Design Criteria Sheet for Climate Change Resilience*, summarizing parameter changes due to climate change

Correspondingly, the APEGBC guidelines refer to the following documents:

1. Climate change vulnerability risk assessment (risk assessment)
   a) Screening-level risk assessment
   b) Risk assessment
   c) Engineering analysis (if required)
2. Highway Infrastructure Climate Change–Resilient Design Report
3. Climate Change Vulnerability Risk Assessment Assurance Statement

The relationships between the output documents referenced in the APEGBC guidelines and the BCMoTI technical circular are as follows:

- The infrastructure and climate vulnerability assessment in the BCMoTI technical circular is the same as the APEGBC climate change vulnerability risk assessment (risk assessment) in these guidelines.

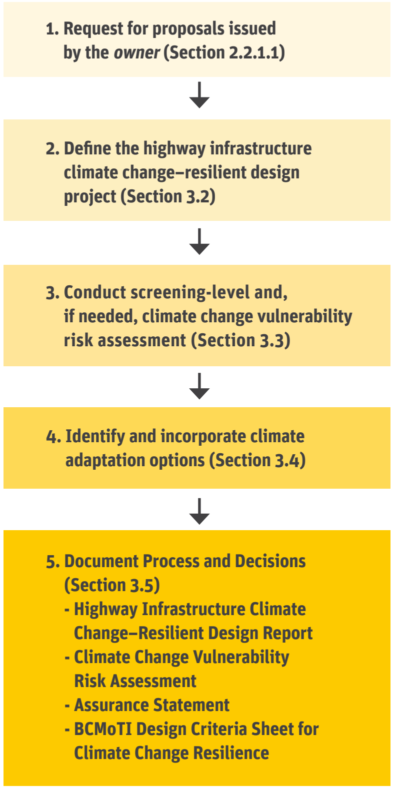
- The Highway Infrastructure Climate Change–Resilient Design Report to be prepared for each climate change vulnerability risk assessment must contain:
    - details of the screening-level risk assessment conducted and the results from the assessment
    - if a climate change vulnerability risk assessment was conducted, the results from the assessment
    - details of the infrastructure component and climate parameter interactions considered, and identified risks; as well as sources of climate data used in the assessment
    - how changes to design criteria were developed as will also be summarized in the BCMoTI Design Criteria Sheet for Climate Change Resilience
    - discussion of adaptation to climate change considering changes to design criteria, if any, and recommendations for operations and maintenance of the infrastructure, if any

The deliverables for every BCMoTI highway infrastructure design project include, at minimum:

1. a Highway Infrastructure Climate Change–Resilient Design Report
2. a *Climate Change Vulnerability Risk Assessment Assurance Statement* (to provide assurance that the appropriate standard of practice has been followed in completing the climate change vulnerability risk assessment)
3. a BCMoTI Design Criteria Sheet for Climate Change Resilience

The following flowchart (Figure 1) summarizes the major steps outlined in the APEGBC guidelines for developing climate change–resilient designs for highway infrastructure. Further details about conducting climate change vulnerability risk assessments and preparing the Highway Infrastructure Climate Change–Resilient Design Report and the Climate Change Vulnerability Risk Assessment Assurance Statement are provided in the guidelines.

Figure 1: Flow chart process for climate change–resilient design of highway infrastructure in BC



The appendices in this document provide further information to support practice manual guidance:

Appendix A: Assurance Statement

Appendix B: BCMoTI Climate Change Design Process and Project Design Criteria Sheet

Appendix C: Adaptation Examples from Practising Professionals

Appendix D: Overview of Climate Change

Appendix E: Tools and Resources for Climate Change Adaptation

Appendix F: Authors and Reviewers

DEFINITIONS

The following definitions are provided within the context of highway infrastructure design and climate change. All of these terms are italicized the first time they appear in the text.

ACEC
The Association of Consulting Engineering Companies of Canada.

Adaptation measures
Actions that reduce the vulnerability of highway infrastructure to the impacts of climate change by reducing the likelihood and/or consequences of failure. These may also include other infrastructure designed to reduce or deflect loads on the primary infrastructure, policies or infrastructure designed to reduce the consequences of failure, increased monitoring, and increased or different maintenance procedures.

Agreement
A formal written or verbal contract or terms of engagement between the client and the engineer of record, or his or her company, for carrying out climate change–resilient design of highway infrastructure. This may also refer to a formal written or verbal contract or terms of engagement between the qualified professional or their company and the engineer of record or the client, for conducting a climate change vulnerability risk assessment of new or existing highway infrastructure.

APEGBC
The Association of Professional Engineers and Geoscientists of British Columbia.

APEGBC Climate Change Information Portal
The Climate Change Information Portal is an APEGBC online resource (available at www.apeg.bc.ca/climateportal) with links to a range of tools and resources to support professional engineers and professional geoscientists in incorporating climate change adaptation into their practice.

BCMoTI
British Columbia Ministry of Transportation and Infrastructure.

BCMoTI Design Criteria Sheet for Climate Change Resilience (BCMoTI Design Criteria Sheet)
A form that engineers working on highway infrastructure design projects under the ownership of BCMoTI are required to complete. The BCMoTI Design Criteria Sheet for Climate Change Resilience documents how the engineer has used their engineering judgment to incorporate consideration of climate change into the appropriate design components of the highway infrastructure. The form is usually completed by the professional overseeing the design of the highway infrastructure, who in these guidelines is referred to as the engineer of record or, for large projects with multiple engineers of record, the coordinating engineer of record.

Client
An individual or company working on a BCMoTI project that engages an engineer of record to carry out resilient design of new or existing highway infrastructure. In some cases, the client may also engage a qualified professional to conduct a climate change vulnerability risk assessment. The client is typically BCMoTI or a third party that has been contracted to maintain or design the highway infrastructure on behalf of BCMoTI.

Climate change-resilience
Facilitating modification, renewal or renovation of infrastructure such that its ability to recover from a climate impact is achieved through resistance to failure, swiftness with which functionality is re-established, and reliability of service. Climate resilience often includes flexible design strategies, which do not unreasonably limit options available in the future for addressing changing conditions by committing to a specific course of action, or fully building for future conditions

in the present. Examples are securing sufficient right-of-way to allow for future dyke rising when necessary, or increasing the size of a culvert to allow extreme precipitation events to pass through the infrastructure without damaging it. As some infrastructure may require periodic renewal or replacement of components in any case, climate resilience can be relatively easily included as a measure to address climate change for these projects.

Climate specialist
A specialist who studies long-term weather patterns and the processes that cause them. Climate specialists use long-term meteorological data to study trends in weather patterns, understand their causes, and make predictions. In the context of these guidelines, a climate specialist is a professional who, through their expertise and qualifications, assists the qualified professional in conducting the climate change vulnerability risk assessment by providing projections of future climate for the region under consideration. Climate specialists may also assist the qualified professional in understanding what climate parameters need to be considered and some of the likely impacts of future climate conditions on the highway infrastructure under consideration.

Climate change vulnerability risk assessment (risk assessment)
An assessment that involves investigations to determine the risk to the infrastructure under consideration due to climate change, supported with an appropriate level of analysis and professional engineering/geoscience interpretation. The risk assessment is conducted by a qualified professional; however, it may also be conducted by an engineer of record if the individual has the appropriate expertise. Engineers Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol (www.pievc.ca) is a risk assessment method that has been successfully applied to a wide range of public infrastructure projects in Canada and internationally. Alternatively, a risk assessment may be carried out in accordance with the generally accepted practices characterized by the technical resources referenced in the Climate Change Information Portal.

Climate Change Vulnerability Risk Assessment Assurance Statement (assurance statement)
A statement sealed by a qualified professional or the engineer of record that provides assurance that they have applied these guidelines in completing the climate change vulnerability risk assessment (Appendix A). A qualified professional or the engineer of record prepares the assurance statement and provides this to the owner.

Climate risk
The level of a negative impact due to a change in climate. In these guidelines, risk is a function of the likelihood of the climate event and the severity of its consequence. In *the climate change vulnerability risk assessment*, risk is a measure of the level of vulnerability of the infrastructure to the effects of climate change.

Climate risk tolerance
The level of climate change-related risk that the owner is willing to accept in consideration of a given infrastructure. It is typically dependent on the functions and design life of the infrastructure.

Coordinating engineer of record (CEOR)
A professional engineer who is responsible for the overall design of a large project, overseeing multiple engineers of record responsible for different aspects of the project.

Engineers and Geoscientists Act
Engineers and Geoscientists Act, RSBC 1996, Chapter 116, as amended.

Engineer of record (EOR)
A professional engineer within a design firm who oversees a project and establishes the overall concept, sizing, risk analysis, design, costing, project management and documentation, and assumes professional responsibility for the project. If the EOR has the appropriate expertise, he or she may also act in the capacity of the qualified professional and take responsibility for the climate change vulnerability risk assessment.

Flexible design
Highway infrastructure with flexible design has the capacity for components of the design to be changed in the future. Flexible design may include redundant systems or the ability for the size or functions of design components to be changed in the future. (The term "adaptive design" is synonymous with "flexible design.")

Highway infrastructure
For the purpose of these guidelines, "highway infrastructure" refers to infrastructure under the ownership of BCMoTI. Examples of highway infrastructure include, but are not limited to bridges, interchanges, junctions, tunnels and structures that cross streams, pavements, embankments, ditches, engineering stabilization works, retaining walls, pavements, drainage appliances, and roads.

Highway Infrastructure Climate Change–Resilient Design Report (report)
A document that includes the details of the screening-level risk assessment, the climate change vulnerability risk assessment, the engineering analysis, details of the development of climate change–resilient design criteria, and conclusions and recommendations provided by the qualified professional with regard to designing for climate change adaptation. The report must be provided to the owner in conjunction with the assurance statement contained in Appendix A.

Member(s)
Professional engineer or professional geoscientist who is a member of APEGBC.

Mitigation
Measures that reduce the emissions of greenhouse gases (GHGs) that drive climate change. This area involves improved energy efficiency, reduced energy use or reductions in embedded energy in materials or products.

Owner
The BC Ministry of Transportation and Infrastructure (BCMoTI). For most highway infrastructure projects, the owner is the client (see definition of "client").

Professional engineer
An engineer who is a member or licensee in good standing with APEGBC and, in relation to highway infrastructure design, is a professional typically registered in the disciplines of civil (geotechnical, structural, hydro-technical), mechanical or electrical engineering, or other disciplines with scopes of practice that contribute to infrastructure design.

Professional geoscientist
A geoscientist who is member or licensee in good standing with APEGBC and, in relation to highway infrastructure design, is a professional typically registered in the disciplines of geology or environmental geoscience, or other disciplines with scopes of practice that contribute to infrastructure design.

Qualified professional (QP)
A professional engineer or professional geoscientist in good standing with APEGBC who has the appropriate knowledge and experience to allow them to carry out a climate change vulnerability risk assessment. The qualified professional should have knowledge of climate science as it relates to the practice of professional engineering/geoscience to allow them to

carry out appropriately comprehensive climate change vulnerability risk assessments. This knowledge should include familiarity with climate models, tools, and resources that are appropriate for the project, and the ability to carry out design changes in consideration of the risk assessment they have completed. The qualified professional is not expected to have competencies similar to those of a climate specialist; however, they should understand what information they need to obtain from a climate specialist to carry out a climate change vulnerability risk assessment when required. If the EOR has the necessary experience, they may fulfill the role of the qualified professional by conducting the climate change vulnerability risk assessment.

Representative Concentration Pathway (RCP)
Defines a specific emissions trajectory and subsequent radiative forcing (a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the earth-atmosphere system, measured in watts per square metre). As defined in the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (2014), there are four RCPs (RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5).

Resilient design
For the purposes of these guidelines, "resilient design" refers to the process of incorporating measures into the design of highway infrastructure components that address potential negative impacts of climate change and measures to recover from those impacts over the full lifespan of the infrastructure components.

Robust design
An approach that affords highway infrastructure the ability to reasonably withstand future climate and weather extremes across a range of future scenarios. The decision to develop and implement a robust design will be communicated by BCMoTI and may be due to one or more factors: low incremental cost to increase climate resilience compared to a high cost of incremental upgrades, low owner risk-tolerance, political or societal influence, and/or limited post-construction opportunities to implement additional adaptation measures.

Screening-level risk assessment
A screening-level risk assessment is the first step in a climate change vulnerability risk assessment conducted to help the qualified professional determine if a more comprehensive climate change vulnerability risk assessment is required. One possible result of the screening-level risk assessment is the determination that no further work is required at the time—if no vulnerabilities were found that require more detailed assessment. It follows the same procedure as a comprehensive risk assessment; the only difference between the two is the level of effort expended.

Status-quo design
Recognizes that implementing no explicit adaptation measures is a valid response, provided that the qualified professional documents the reason or reasons that this is done. Examples of situations where status quo may be a valid design method are when the risk assessment shows that the infrastructure is at no or low risk due to climate change or when the service life of the infrastructure is very short and plans are made to reconsider adaptation measures when the infrastructure is replaced.

Uncertainty
Within the scope of these guidelines, "uncertainty" generally refers to all of the factors that affect how well climate data and related information, selected for assessment and design, will ultimately reflect reality. Climate specialists also use the term "uncertainty," but with a different and more specific definition (see Section D.3.5). The guidelines will use the terms "range of values" or "range of potential values" when referring to uncertainty associated with climate projections. An antonym of "uncertainty" is "confidence," and within the context of these guidelines, the qualified professional or the engineer of record is looking for confidence that the values used adequately reflect real-world conditions that the infrastructure will be exposed to, and under which it is designed to function. The less confidence (more uncertainty) that the qualified professional or the engineer of record has in the available information, the greater the perceived risk. Greater risk demands more resilient designs.

Vulnerability
The inability of highway infrastructure to withstand negative effects and benefit from any positive effects of changes in climate. In these guidelines, vulnerability is a function of the magnitude of the changes in the climate, the sensitivity of the infrastructure to those changes, and the adaptive capacity of the infrastructure.

INTRODUCTION

1.1 INTRODUCTION TO THE GUIDELINES

With these guidelines *APEGBC* develops professional practice processes in response to potential impacts of climate change regarding BCMoTI infrastructure designs, and provides a framework in which APEGBC professionals can provide services while meeting an established standard of practice in addressing climate change.

In light of strong evidence of climate changes, APEGBC released a position paper titled *A Changing Climate in British Columbia* (APEGBC 2014a) that includes the following statements:

A. APEGBC recognizes that the climate is changing and commits to raising awareness about the potential impacts of the changing climate as they relate to professional engineering and geoscience practice, and to provide information and assistance to APEGBC registrants in managing implications for their own professional practice.

B. APEGBC registrants (*professional engineers, professional geoscientists*, provisional *members*, licensees, limited licensees, engineers-in-training and geoscientists-in-training) are expected to keep themselves informed about the changing climate, and consider potential impacts on their professional activities.

Historically, infrastructure has been designed in accordance with the relevant codes and standards based on assumptions of constancy in climate—that is, past climate being a good predictor of future climate. But various indications and recent experiences with changes in extreme weather conditions indicate that historical climate cannot be relied upon for designing infrastructure expected to withstand the forces of a climate that is changing significantly (BC Ministry of Environment 2015). Climate modelling has become more proficient in providing future climate scenarios; however, there is *uncertainty* in the projected form and magnitude of estimated future climate conditions. The three main sources of uncertainty are natural variability of the climate, a simplified representation of climatic processes, and uncertainty in future emissions of greenhouse gases. Thus, in using climate modelling output for engineering design, substantial engineering judgment on the part of the APEGBC members will be required.

Tools and resources to enable practitioners to incorporate climate change and extreme weather resilience in *highway infrastructure* design are evolving and improving. These guidelines aim to introduce concepts relating to climate change resilience and to provide a structured approach to decision-making and record-keeping. It does not list all the tools and resources available to practising professionals. To help members and registrants stay current with the science of climate change and to provide tools and resources for incorporation of climate adaptation in design, APEGBC has developed the *Climate Change Information Portal*, which can be accessed at www.apeg.bc.ca/climateportal. More information on climate science as it relates to professional practice is provided in Appendix D.

The fields of civil engineering and geoscience and other allied fields are evolving in response to a changing climate. While adaptation to a changing climate is imperative, more guidance is required on what constitutes good professional practice in order to incorporate a changing climate in the designs and services provided in *BCMoTI* highway infrastructure projects.

Many have indicated that the tools and resources for climate adaptation require more refinement to enable mass uptake. It has been suggested by various sources (Engineers Canada 2011, 2015; ICF International and Parsons Brinckerhoff 2014) that a multi-stakeholder approach that includes building on existing efforts and knowledge from across different sectors and professions is required to make adaptation efforts successful.

In addition, it is recognized that the uniform implementation of a standard of practice along with an established quality management process providing climate change resilience services would enable *clients*, stakeholders and various levels of government to work together for the protection of public safety and the environment. APEGBC recognizes that development of this initial version of practice guidelines is the first of many iterations. As more information becomes available and experience with climate change and adaptation is gained, these guidelines will be revised and updated.

The *APEGBC Professional Practice Guidelines – Sustainability* (APEGBC 2013) outlined many ways in which APEGBC professionals could contribute to the development of a sustainable society through their professional practice. Designing highway infrastructure to increase its resilience to the impacts of future climate conditions is one of the ways in which professionals can contribute to making highway infrastructure more sustainable.

These guidelines have been prepared in consultation with a steering committee consisting of members from the Association of Consulting Engineers of Canada's Subcommittee for Engineering Adaptation for Climate Change (BC Chapter), members of the APEGBC's Climate Change Advisory Group, Engineers Canada, practising consulting engineers, a climate scientist from the Pacific Climate Impacts Consortium (PCIC), and staff from BCMoTI.

1.2 PURPOSE OF THE GUIDELINES

This document provides professional practice guidelines for an engineer of record *(EOR)* or *coordinating engineer of record (CEOR)* carrying out highway infrastructure climate change–resilient design and for a *qualified professional (QP)* completing a *climate change vulnerability risk assessment* (risk assessment). These interim guidelines apply only to highway infrastructure owned by BCMoTI.

The specific objectives of these guidelines are to:

1. outline the professional services of an EOR carrying out climate change–resilient design of highway infrastructure in BC.
2. outline the professional services to be provided by a QP (or EOR if they are sufficiently trained) conducting risk assessments on highway infrastructure in BC.
3. describe the standard of practice to be followed when a QP is providing professional services related to conducting risk assessments of highway infrastructure in BC.
4. specify the tasks that should be performed by the QP and/or EOR to demonstrate that climate change has been considered in the design of the highway infrastructure and demonstrate that their obligations under the *Engineers and Geoscientists Act* (the *Act*) have been met. These obligations include the duty to protect the safety, health and welfare of the public and the environment.
5. describe the roles and responsibilities of the various participants/stakeholders involved in carrying out climate change–resilient design of highway infrastructure and risk assessments.
6. describe the record-keeping and other quality management processes to be followed when conducting risk assessments of highway infrastructure.

7. provide consistency in the approach to risk assessments, including the relevant reports and other documents prepared when providing professional services in this field of practice.
8. describe the typical knowledge required and the responsibilities that professionals take on when providing services related to conducting risk assessments.

By outlining the process of developing *resilient design* for highway infrastructure, these guidelines aim to promote adaptability and resilience of highway infrastructure to future climate conditions.

Appendix A to these guidelines provides a *Climate Change Vulnerability Risk Assessment Assurance Statement* (assurance statement) to be provided to the *owner*, along with the *Highway Infrastructure Climate Change–Resilient Design Report* (report) and *BCMoTI Design Criteria Sheet for Climate Change Resilience*. **It is important to note that the assurance statement provides assurance that the professional has followed the suggested standard of practice as defined in these guidelines. It does not guarantee that a specific design will perform without issue under future climate conditions**.

The preparation of the Highway Infrastructure Climate Change–Resilient Design Report, the assurance statement and the BCMoTI Design Criteria Sheet for Climate Change Resilience is informed by the risk assessment conducted by the QP.

1.3 ROLE OF APEGBC

Members and licensees are professionally accountable for their work under the *Act*, which is enforced by APEGBC. These interim guidelines have been adopted by the Council of APEGBC, and form part of APEGBC's ongoing commitment to maintaining the quality of services that members and licensees provide to their clients and the general public.

These guidelines may be used to assist professional activity in agreement with the client in establishing the objectives, type of risk assessment, level of service, terms of reference and associated fees. Insufficient fees are not a justification for services that do not meet the intent of these guidelines.

Following these guidelines demonstrates to the client or the owner how professional obligations are fulfilled, especially with regard to APEGBC Code of Ethics Principle 1 (Hold paramount the safety, health and welfare of the public, protection of the environment and promote health and safety in the workplace) Failure to meet the intent of these guidelines could be evidence of unprofessional conduct and lead to disciplinary proceedings by APEGBC.

1.4 SCOPE OF THE GUIDELINES

These guidelines establish the standard of practice for conducting climate change vulnerability risk assessments and for incorporating *climate change resilience* into the design of new or retrofit highway infrastructure that is under the ownership of BCMoTI (see Appendix B: BCMoTI Climate Change Design Process and Project Design Criteria Sheet). These guidelines facilitate the application of a consistent and comprehensive level of professional practice for BCMoTI projects in BC.

Furthermore, these guidelines are provided so that climate adaptation planning can be adequately performed by the owner. They do not address greenhouse gas *mitigation* in relation to the construction activities to be carried out.

Similar in format to the *APEGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC* (APEGBC 2012), these guidelines are organized as follows:

- Section 2 outlines the roles and responsibilities of the professionals involved
- Section 3 provides guidelines for professional practice
- Section 4 provides information on quality assurance and control
- Section 5 explains the registration, education, training and experience requirements for professionals
- Section 6 and the appendices provide information on climate science, the assurance statement, references, case studies on how these guidelines would apply on large and small projects, and design examples.

APEGBC supports the development of common standards of care in professional practice in engineering and geoscience across Canada. This includes carrying out *climate risk* assessments and preparing reports. Therefore, APEGBC encourages other engineering and geoscience regulators in Canada to make use of these guidelines in their jurisdictions, with revisions where considered appropriate.

1.5 APPLICABILITY OF THE GUIDELINES

These guidelines are influenced by the BCMoTI Technical Circular T-06/15, *Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design*, advances in knowledge, and evolution of general professional practices in British Columbia. As such, the current version of the guidelines is the first of what may be many iterations.

Notwithstanding the purpose and scope of these guidelines, a decision not to follow one or more elements of these guidelines does not necessarily mean a failure to meet professional obligations or the standard of practice established by these guidelines. Such judgments and decisions depend upon weighing the facts and circumstances to determine whether reasonable and prudent conduct was followed, in a similar situation and during the same time frame.

Specific climate change–related resources may be referenced (e.g., those referenced in these guidelines and the Climate Change Information Portal); however, professional discretion should be exercised in determining which resources are necessary on a particular project. This reflects the constant introduction of new, or revisions to existing, resources that are associated with this emerging field.

1.6 ACKNOWLEDGMENTS

These guidelines were prepared by a steering committee of APEGBC professionals and reviewed by several external parties, stakeholders and members. The authors and reviewers are listed in Appendix F. The authors thank the reviewers for their constructive suggestions. A review of this document does not necessarily indicate that the reviewer and/or his employer endorses everything in the document.

APEGBC thanks the BCMoTI for funding and technical support provided in the preparation of these guidelines.

PROJECT ORGANIZATION AND RESPONSIBILITIES

2.1 COMMON FORMS OF PROJECT ORGANIZATION

Typically the highway infrastructure owner is the client, who establishes an *agreement* for professional services with the EOR. Within the agreement, the EOR should ensure that their role in relation to the client is clearly defined. The EOR oversees the project and is responsible for incorporating climate change resilience into the design of the highway infrastructure. For large projects where there may be multiple EORs overseen by a CEOR, the CEOR will oversee the overall project, ensure that climate change resilience is incorporated appropriately into the design of the highway infrastructure, and fulfill the responsibilities of the EOR as outlined in this section.

If the EOR is unable to act in the capacity of a *qualified professional* (QP), the EOR establishes an agreement for professional services with a QP who will be responsible for the climate change vulnerability risk assessment. The report detailing the results of the climate change vulnerability risk assessment should be prepared in consultation with the EOR, who will then incorporate the QP's recommendations into the highway infrastructure design.

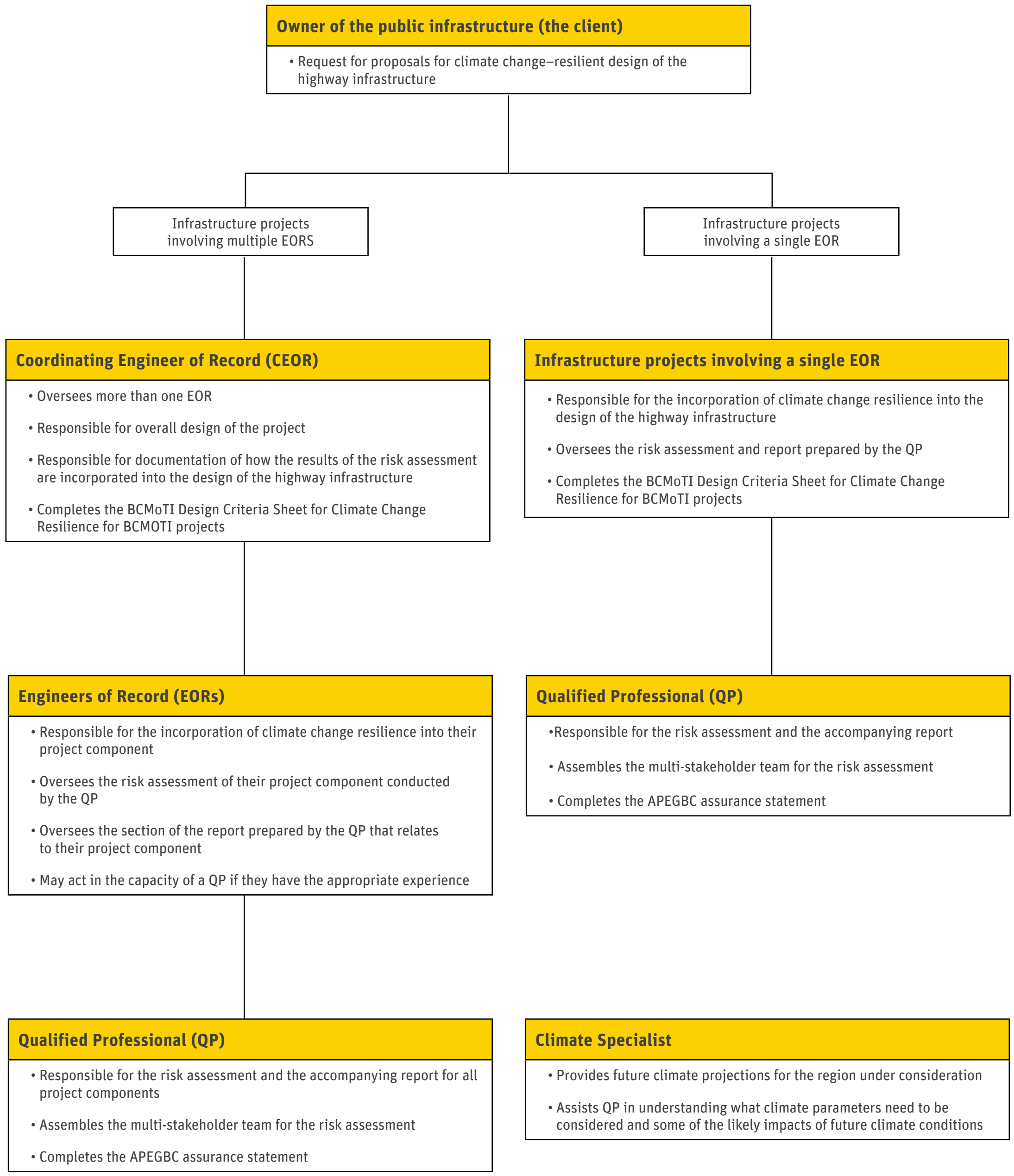
In some cases, the client may not fully understand or appreciate the level of effort required by the EOR to carry out climate change–*resilient design* of the highway infrastructure. These data and previous assessments that are available to the QP for conducting the risk assessment may significantly affect the level of engineering analysis carried out by the EOR.

The EOR should review the typical responsibilities listed below, to assist in establishing an appropriate agreement for professional services with the client and inform them of the expectation of appropriate and adequate compensation (*APEGBC* Code of Ethics Principle 5).

2.2 STAKEHOLDER RESPONSIBILITIES

Sections 2.2.1, 2.2.2 and 2.2.3 describe some of the typical responsibilities of the client, the EOR and the QP. Section 2.2.4 describes how another suitably qualified professional may be engaged to carry out an independent external review of the Climate Change–Resilient Design Report at the owner's expense. The responsibilities of the EOR, the QP and the CEOR are illustrated by the project organization chart in Figure 2.

Figure 2: Roles and responsibilities of professionals in highway infrastructure projects



2.2.1 The Client/Highway Infrastructure Owner

The highway infrastructure owner may recommend climate projection resources to the QP/EOR for use in the risk assessment. These may include climate data providers, such as the Pacific Climate Impacts Consortium, that can produce appropriate climate projections; depending on the project, it may be advisable to engage a *climate specialist* from these organizations.

2.2.1.1 Preparing Requests for Proposals

The scope of the risk assessment portion of the highway infrastructure climate change–resilient design project should normally be described in the request for proposals. It should be based on the *climate risk tolerance* identified by the *owner* (if available) and reflect the state of knowledge of the design, construction, operation and maintenance of the *highway infrastructure* as well as to reflect the availability of climate projections, the level of service and the service life.

2.2.1.2 Procurement of Engineer of Record

It is recommended that the client select the EOR and the firm they work for based on their qualifications, availability, experience and local knowledge, using a qualifications-based selection process. The recommended best practices for selecting an engineering consultant to act in the capacity of an EOR can be found in *Selecting a Professional Consultant* (Federation of Canadian Municipalities and National Research Council 2006). Through this process the need for a QP to be engaged in a project can also be identified.

The Association of Consulting Engineering Companies - BC (ACEC-BC) has developed an online resource to help municipalities and other owners implement effective procurement practices. Supported in part by ACEC-Canada, the website www.yes2qbs.com/ brings together qualifications-based selection (QBS) related information in one convenient location and includes guides, templates and studies that offer a detailed explanation of QBS.

2.2.2 The Engineer of Record

The EOR oversees the project and is responsible for the overall concept, sizing, risk analysis, design, costing, project management and documentation. The EOR normally receives and approves the *climate change vulnerability risk assessment* report from the QP and is responsible for documenting how the recommendations made in the report are incorporated into the design of the highway infrastructure. For projects under the ownership of BCMoTI, the EOR should complete the *BCMoTI Design Criteria Sheet for Climate Change Resilience* to document how climate change was considered for each design component.

On large projects, it is the responsibility of the EOR assembling a multi-stakeholder team of individuals with the appropriate qualifications and experience to carry out highway infrastructure climate change–resilient design. It is appropriate for the client to approve the multi-stakeholder team prepared by the EOR.

For large projects, there may be a CEOR who oversees multiple EORs. In this case, the CEOR may fulfill the role of the EOR identified throughout these guidelines.

2.2.2.1 Selection of Qualified Professional

It is recommended that the EOR select the QP (who should be an APEGBC member) that will be part of the design team, based on their qualifications, availability and local knowledge, using a QBS process. Although the EOR is likely to engage the QP to conduct the risk assessment, this decision may need to be approved by the client. The client would normally delegate this to the EOR, who would submit the person's name as part of the multidisciplinary team that would undertake the work. Approval of this person would be implied by their selection in the RFP evaluation process and not after the fact.

Once the EOR has selected a QP to conduct the risk assessment, the EOR, with assistance from the QP, should complete a written agreement with the QP. This agreement should confirm the scope of work, schedule and cost estimate for the risk assessment, as well as the need and scope of specialty services and the need for external peer review. It is recommended that such an agreement include a clause that deals with potential disclosure issues due to the QP's obligation under APEGBC Code of Ethics Principle 1.

The QP's scope of work and cost estimate may have to be amended during the risk assessment, depending on their findings and analysis. The estimated cost, based on an understanding of the information provided by the client, should be discussed and agreed to prior to initiation of the risk assessment.

During the risk assessment, it will be necessary for the client to provide the relevant background information for the QP through the EOR. The QP will discuss this with the client and the EOR to ensure that an understanding is established. In addition, the client may be required to provide access to the highway infrastructure to enable to the QP to conduct field work.

It is important that the EOR and the client review the report and understand its conclusions and recommendations. The report should be written using clear language and should unambiguously convey the potential risks and consequences associated with not implementing the recommended climate change *adaptation measures*. This addresses the QP's obligation under APEGBC Code of Ethics Principle 8 (Present clearly to employers and clients the possible consequences if professional decisions or judgments are overruled or disregarded).

It is recommended that a clause be included within the agreement to address the EOR's obligations regarding potential disclosure issues under APEGBC Code of Ethics Principle 1. The EOR may have to convey adverse risk assessment findings to parties who may not be directly involved, but who have a compelling need to know. Following is suggested wording for such a clause:

> Subject to the following, the qualified professional will keep confidential all information, including documents, correspondence, reports and opinions, unless disclosure is authorized in writing by the client. However, in keeping with APEGBC's Code of Ethics, if the qualified professional discovers or determines that there is a material risk to the environment or the safety, health and welfare of the public or worker safety, they shall notify the client as soon as practical of this information and the need that it be disclosed to the appropriate parties. If the client does not take the necessary steps to notify the appropriate parties in a reasonable amount of time, the EOR shall have the right to disclose that information in order to fulfill their ethical duties and the client hereby agrees to that disclosure.

2.2.3 The Qualified Professional

The risk assessment must be carried out by a suitable qualified professional. It is the responsibility of the EOR and as applicable, the QP to assemble a multi-stakeholder team of individuals with the appropriate qualifications and experience in relevant disciplines to carry out a risk assessment. The QP is responsible for ensuring that proper coordination occurs between the various members of the multi-stakeholder team. The multi-stakeholder team may require approval by the client.

On projects where past climate data and regional climate projections are readily available and are endorsed by the owner, the QP may act individually to conduct a risk assessment under the following circumstances:

- The QP must have developed proficiency in these kinds of assessments, which can include working on projects in the same geographic area,
- The QP has worked with multi-stakeholder teams on risk assessments, while ensuring that the assessment is compatible with other relevant work being completed by the owner, which can include related infrastructure, and
- The QP must have access to appropriate regional climate projections.

The risk assessment allows the QP to communicate the climate change implications and risk to the owner and the EOR. After the QP communicates the implications and risk, the EOR will carry out climate change–resilient design under the advisement of the highway infrastructure owner.

Although risk assessment is to be completed by a multi-stakeholder team, the QP is responsible for preparing the report, which will include recommended adaptive measures and the assurance statement and providing these documents to the EOR and the client.

If certain professional activities, such as aspects of field work, are delegated by the QP to subordinates including non-professionals, this must occur under the QP's direct supervision. The QP assumes full responsibility for all work delegated in accordance with the *Act*.

2.2.4 Internal and External Review of a Highway Infrastructure Climate Change–Resilient Design Report

If additional external review of a Highway Infrastructure Climate Change–Resilient Design Report is deemed necessary by the owner, another suitably qualified professional may be engaged to carry out an independent external review at the owner's expense.

Engineers Canada has launched an Infrastructure Resilience Professional certification program that may be useful for identifying professionals who are able to provide a review of a Highway Infrastructure Climate Change–Resilient Design Report. (Visit www.engineerscanada.ca/news/engineers-canada-certifies-qualified-engineers-as-first-infrastructure-resilience-professionals to register.)

GUIDELINES FOR PROFESSIONAL PRACTICE FOR HIGHWAY INFRASTRUCTURE CLIMATE CHANGE–RESILIENT DESIGN

Professionals who design highway infrastructure already consider climatic factors—either explicitly or implicitly. Examples of explicit application are wind loads and snow loads for bridges, and rainfall intensities for drainage systems. An example of implicit application is the use of codes and standards: minimum dimensions, maximum spans, or maximum drainage areas.

Currently, most climate design values are determined from statistical analysis of historical climate records. The key assumption of this process is that climate in the future will be essentially the same as that in the past. This assumption is no longer valid, since there is evidence that the climate is changing (see Appendix D). While the general design process for each type of highway infrastructure will remain relatively unchanged, it is essential that the proposed infrastructure's functionality under both existing and future climate conditions are considered. This is especially true for highway infrastructure with longer service lives (50 to 100 years, for example).

It is important to acknowledge that historical climate records will continue to play a vital role in the development of climate design values. These data provide context for understanding the range of probable values as well as the basis for developing future climate projections. It is also important to recognize that many historical climate records carry significant, and usually unacknowledged, *uncertainty* due to recording and archiving errors, short or incomplete records, or the use of statistical analysis.

Design professionals currently account for uncertainty by establishing design event or threshold criteria, then applying safety factors. Historical climate records are considered to be a reflection of "reality," and there is a sense that applying statistical analysis to these data to develop design values addresses uncertainty, and that the design values can be used with some confidence.

From an engineering perspective, future climate projections are considered to carry greater uncertainty than do historical climate records. This is primarily due to the large range of values generated by the full ensemble of global climate models (GCMs) contrasted with the need to select values for design. The fact that climate science is still being refined, especially with respect to projecting extreme values at a sub-daily level, reduces confidence in the projected values. All of this combines to create a perceived increase in risk, which must be acknowledged and managed.

These factors make it imperative to conduct a risk assessment as part of the highway infrastructure design process. It is also essential to determine appropriate measures to facilitate a resilient design, keeping identified risks at a level acceptable to the stakeholders. This will require new approaches to design, since each climate value within the range of projected values has the same likelihood of actually occurring in the future as all of the other values in the range. This means that rather than selecting a single climate value from a single model for design purposes, design risk must be addressed by determining the impact of the full range of climate values and developing appropriate adaptive measures to ensure resilience over that range.

Note that there is potential for secondary impacts from climate change, such as changes to land cover, resource availability and demographics. These impacts should also be considered, but are not the focus of these guidelines since they may affect the viability of a project rather than the actual design.

This section of the guidelines establishes the standard of practice that is expected of each professional involved in the design of highway infrastructure with respect to incorporating climate change resilience, subject to the reasonable exercise of professional judgement. Section 3.1 outlines the general process for incorporating climate change into a resilient design. The remaining subsections provide approaches for developing climate change–resilient designs for highway infrastructure. Professionals are encouraged to exercise their judgment in the use of any approaches outlined in the following subsections.

3.1 GENERAL PROCESS

Each highway infrastructure design project is unique, given the combination of location, service objectives, stakeholders and design team. Consequently, the design process for each project will also be unique. There are, however, common aspects of the design process, which are addressed in this section of the guidelines. These aspects are each influenced by, or exert an influence on, the climate design values used for the design.

For the purposes of these guidelines, it is assumed that the EOR or CEOR (if there are multiple EORs on a project) is responsible for the overall project design and for ensuring that climate change impacts are considered and that adaptation measures are incorporated where appropriate. It is also assumed that the QP is responsible for conducting the climate change risk assessment and for facilitating development of adaptation measures.

3.1.1 Level of Effort and Detail

Given that the scope, scale and objectives of design projects can vary significantly from one project to another, the level of effort expended to meet the standard of practice with respect to preparing a climate resilient design will also vary.

Projects that are complex and large in scale and/or scope will usually require a greater level of effort and detail. This may include specialized team members, rigorous risk assessment, detailed engineering analysis and detailed reporting. The roles of EOR, QP and other team members are likely to be performed by separate individuals.

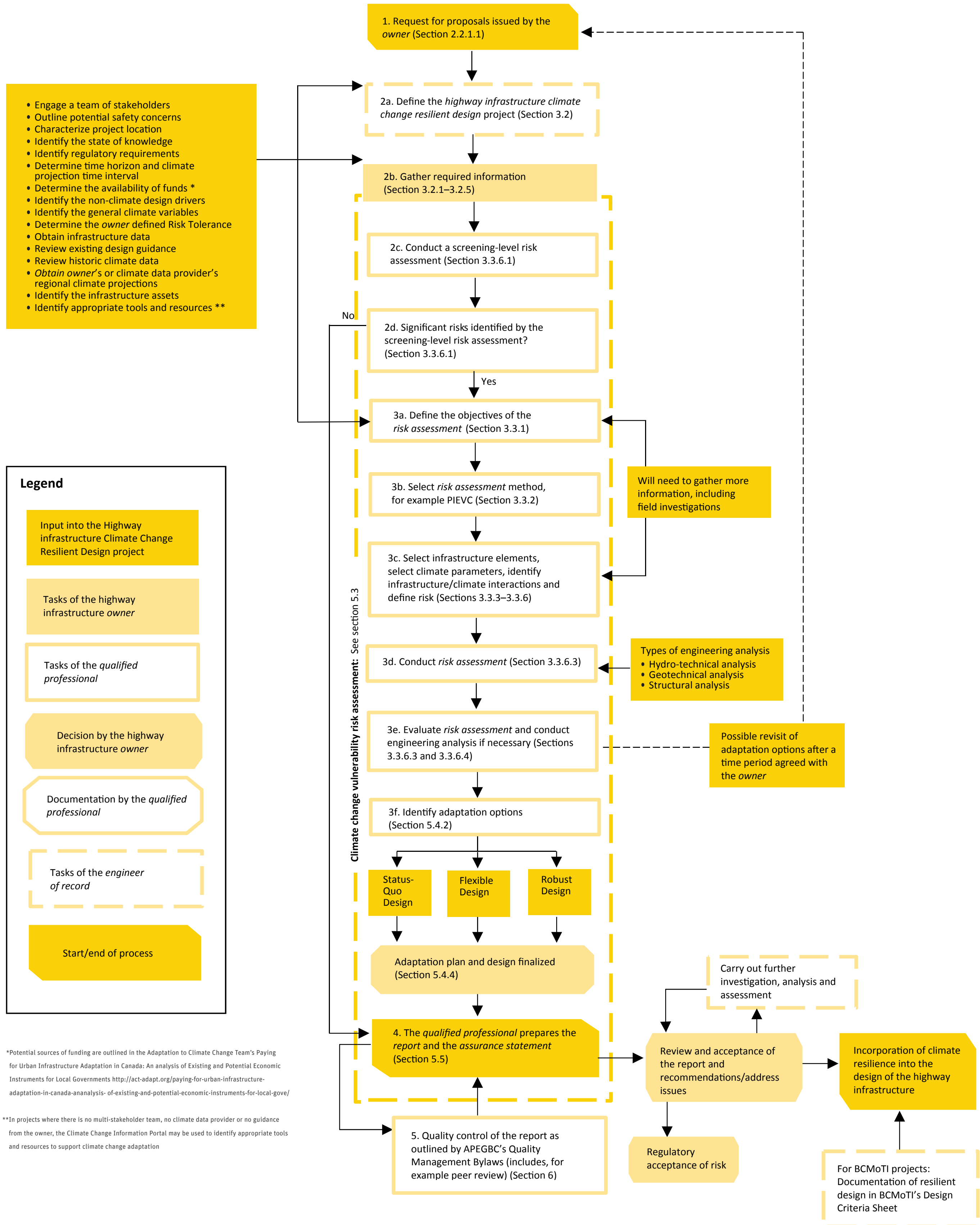
For some projects, however, significantly less effort may be required to prepare a climate change–resilient design. The project may have negligible consequences should it fail, or be governed by climate design criteria prescribed by the owner or approving authority.

The level of effort does not always depend on the scope and scale of the project. It can also depend on the climate data available for the analysis. For instance, consider the hydrotechnical design of two bridges with similar scope but in different geographic locations: one of the bridges may be in one of the four watersheds where PCIC already provides projected flows, whereas only projected temperatures and precipitation data may be available for the other location. Developing a hydrologic model to estimate flows from projected temperature and precipitation requires significant effort. That is, the amount of effort required for the two projects will be significantly different.

Whatever level of effort is ultimately applied, it is essential that the roles of EOR and QP with respect to incorporating climate resilience in the design are fulfilled and that documentation showing that future climate was appropriately considered is provided. For BCMoTI projects, this is a requirement.

Figure 3 presents a flow chart outlining the process of carrying out highway infrastructure climate change–resilient design and the roles and responsibilities of the QP, the EOR, and the owner. The flow chart has been adapted to work with the BCMoTI technical circular (see Appendix B) and Engineers Canada's PIEVC Engineering Protocol.

Figure 3: Process for carrying out climate change resilient design of highway infrastructure



*Potential sources of funding are outlined in the Adaptation to Climate Change Team's Paying for Urban Infrastructure Adaptation in Canada: An analysis of Existing and Potential Economic Instruments for Local Governments http://act-adapt.org/paying-for-urban-infrastructure-adaptation-in-canada-ananalysis- of-existing-and-potential-economic-instruments-for-local-gove/

**In projects where there is no multi-stakeholder team, no climate data provider or no guidance from the owner, the Climate Change Information Portal may be used to identify appropriate tools and resources to support climate change adaptation

3.2 DEFINE THE PROJECT

It is critical to establish the context within which *climate risks* can be evaluated and adaptation measures can be developed and integrated into the design. This context is established by:

- characterizing the project location
- listing the key infrastructure components
- identifying non-climate design drivers
- identifying general climate parameters that should be considered
- selecting the key team members
- identifying key stakeholders
- defining the project time horizons

Each of these tasks is described in more detail in the following subsections.

3.2.1 Characterize Project Location and Identify Infrastructure

For the purposes of these guidelines, "project location" encompasses more than just the coordinates of the project extents. It provides the context for determining what infrastructure is to be constructed and what climate-based events are likely to occur. For example, a road located along the coast may be affected by tides and storm surges, while a road located in a mountain pass is more likely to be affected by deep snow. Both could be subject to high stream flows, avalanches or intense rainfall.

Different location characteristics also contribute to different potential risks. Flood plains are subject to potential flooding, alluvial fans to both flooding and potential debris flows, and steep mountain passes to avalanches and/or unstable slopes. It is essential, therefore, to fully characterize the project location in a way that identifies and communicates climate-related issues that must be addressed through design. This could include, but not be limited to:

- Project limits
- Water bodies, streams, drainage catchments
- Topographic characteristics – elevation range, slopes, high and low points
- Geographic characteristics – flood plain, alluvial fan, mountain side, narrow valley
- Geologic characteristics – soil types, groundwater
- Populated or developed areas
- Environmental resources – wetlands, habitat, riparian areas
- Other critical infrastructure – power lines, dams, gas or oil facilities
- Local or provincial standards, applicable bylaws and land use zoning

It is also useful to list the key infrastructure components to be designed and constructed. Great detail is not required at this stage of the project, but it should be sufficient for team members to fully understand project elements. For example, it would be sufficient to identify the following infrastructure components for a highway project, including estimated quantity and location:

- Roadway – number of lanes, lane separation
- Bridges
- Grade-separated intersections
- Culverts – by relative size (small, medium, large)
- Stormwater detention/treatment facilities
- Snowsheds
- Breakwaters
- Retaining walls

All of this information may not be known at the start of the project. However, any infrastructure component that has some likelihood of being constructed should be included in the project definition. This will provide a broader context for identifying climate parameters later in the process.

Minimum level of effort

In this case, the level of effort would be proportional to the scope and scale of the project. If, for example, the project consists of lane widening for a couple of kilometres and includes one stream crossing, the list of components would be relatively short, with simple descriptions. Only key items would be shown on the location map—the extents of the project, the stream and any other items that might impact the infrastructure because of climate.

3.2.2 Identify Non-Climate Design Drivers

There are many reasons for constructing highway infrastructure. These could include responding to population growth, fostering economic development, delivering goods and services to communities, improving safety, or any combination thereof. The purpose of identifying these non-climate design drivers is to establish a base design scenario. For example, if the project is to provide increased capacity in response to population growth, then design criteria will be established accordingly. This base scenario provides the means to evaluate the significance of any potential climate change impacts on the project.

Depending on the specific project, and especially on its design service life, some non-climate drivers likely have the potential to be impacted by climate change. Should this be the case, it would be useful to consider the broader potential impacts to the project. For example, increasing capacity to service population growth in an area that might ultimately be abandoned because of sea level rise could influence not only the design of the infrastructure, but the very viability of the project itself. Identifying these issues as part of the project definition could be useful when determining what, if any, design changes will be incorporated into the project in order to address risks posed by climate change. However, they will not be assessed as part of the climate risk assessment.

Minimum level of effort

A simple list or short description of these drivers should be sufficient. The key is to be aware that they exist and have an impact on the design.

3.2.3 Identify General Climate Parameters

Identifying the general climate parameters that are typically used during design of the subject infrastructure may include, but are not to be limited to:

- Rainfall – intensity, duration, depth
- Temperature – maximum, minimum, average degree-days
- Snow – daily snowfall, total accumulated depth
- Wind – average speeds, maximum gusts, direction
- Sea level – average level, high tides, storm surges

It is important to recognize that one or more of these general climate parameters usually directly affect other design values. Rainfall, temperature and snowmelt, for example, all impact streamflow, which is used to size hydraulic components such as culverts and bridges. Certain combinations of humidity and temperature can form fog and ice, which could impact safety. Therefore, endeavour to identify all pertinent climate parameters, even those that indirectly impact the design. Specific parameter values will be defined later in these guidelines.

3.2.4 Define the Team and Identify Stakeholders

Each highway infrastructure design project will require its own set of specialized skills and knowledge in order to be completed successfully. Regardless of project scale and scope, and whether there are many or few team members and stakeholders, it is essential that all involved are aware of potential impacts of climate change and corresponding potential implications for design. Initially, team members may be limited in number until the *screening-level risk assessment* is completed.

Early in the project, the EOR or CEOR should list the key team members and stakeholders, as well as their roles. The following list is an example only; details will vary by project.

- Owner – project scope definition, financial decisions, risk acceptance
- EOR – overall concept, sizing, risk analysis, design, costing, project management, documentation, overall design responsibility
- Specialty engineers and practitioners (e.g., functional, geotechnical, structural, hydrotechnical, drainage, environmental, coastal, electrical, communications) – performance, safety, operations and maintenance, sizing, risk analysis, detailed design (e.g., costing, longevity, documentation)
- Approvals officers – review and approvals, standards enforcement

For addressing climate change, the team should be expanded to include qualified professionals and specialists with respect to the following:

- Climate projections – typically climatologists or climate specialists
- Risk assessment – a group of experienced individuals who can provide sound judgment with respect to potential interactions between specific climate parameters and components of the subject infrastructure under design; in many cases, the specialty engineers and practitioners can provide this function; however, depending on the design project, additional team members might include individuals with knowledge and experience in:
  - hydrology, geology, forestry, biology, environment
  - hands-on operation and maintenance personnel for the infrastructure being assessed
  - hands-on management
  - local knowledge and history of previous climatic events
- Climate adaptation – a qualified professional or group of qualified professionals that are able to develop and recommend design adaptation measures to improve the climate change resilience of the proposed infrastructure
- Risk-based design – a design professional who can communicate the various risks associated with projected climate change to the owner and, at times, to the approvals officers, and who can complete the design to meet an acceptable level of risk

In special cases, the team members should have individuals with knowledge and experience in one or more of the following fields:

- Social impacts
- Economic impacts
- Politics
- Insurance
- Community issues
- Emergency preparedness and response

These additional team members can be critical to the success of the highway infrastructure design project. It is the QP's responsibility to know when the expertise of each of the specialty team members is required, and to engage them accordingly.

Minimum level of effort

The team selected should include, at a minimum, the owner, the EOR, and a person reasonably knowledgeable about general climate projections. The team members must have sufficient knowledge and experience to identify and characterize key climate events that could impact the infrastructure, determine what types of interactions might occur between the climate events and the infrastructure, estimate the likelihood of the interactions occurring, and estimate the corresponding consequences should the interaction occur.

3.2.5 Define Assessment Time Horizons

Highway infrastructure projects can have relatively long service lives, typically 50, 75, and even 100 years. Rights-of-way for these infrastructure projects can remain in place even longer. Some infrastructure or infrastructure components, however, have relatively short service lives, ranging between 10 and 20 years. Considering that many climate parameters exhibit a trend of increasing or decreasing average annual values, it is important to select projected climate data that correspond to each infrastructure project's service life.

In many cases, depending on the climate parameter under consideration, the range of values projected using different GCMs may also increase as the time horizon is extended. For example, the difference between the highest and lowest average annual temperature generated by the full ensemble of GCMs for the year 2100 is greater than that for the year 2030. In situations where the projected trend for a climate parameter increases the *vulnerability* of selected infrastructure over time, from an engineering perspective an increasing range of these climate values as the time horizon extends will further increase infrastructure vulnerability.

Therefore, the combination of infrastructure longevity and corresponding potential increase in the range of plausible future climate parameter values makes it important to identify the service life of the components and systems that comprise the proposed highway infrastructure. This provides context for developing climate projections, conducting risk assessments, and identifying appropriate adaptation measures.

Infrastructure with a short service life is usually subject to periodic refurbishment or replacement. This provides an opportunity to re-evaluate corresponding climate risks and adaptation measures. Risks associated with climate change for such infrastructure may be low because the climate trend has had little time to develop. However, for infrastructure components that are not eligible for replacement or refurbishment prior to the end of their service life, the consequences of decisions made during the design process can be significant.

Note that the above discussion is based on the relationship between infrastructure service life and long-term climate trends of average values. Within this context, it is important to recognize that extreme annual climate values may exhibit greater increases over a short time horizon than average climate values. This should be identified and considered when selecting climate parameter values for the vulnerability risk assessment.

It is also important to recognize that the QP is not expected to make perfect decisions, but is expected, "based on professional judgment, to make appropriate decisions within the context of current scientific, economic, and social constraints" (Engineers Canada 2015).

Minimum level of effort

At a minimum, the team could assign a single assessment time horizon for the whole project, based on the infrastructure component with the longest service life. To further reduce total effort, identify infrastructure elements that have a relatively short service life and, if appropriate, eliminate them from the assessment.

3.3 CONDUCT CLIMATE CHANGE VULNERABILITY RISK ASSESSMENT

Risk management is not a new concept for engineers and geoscientists. It consists of identifying risks, evaluating them and then making decisions to ensure that effective risk controls are developed and implemented. The risk assessment addresses the first part of risk management: identifying and evaluating the risks. The QP should have a reasonable level of competence in risk assessment—particularly with respect to the impacts of climate change.

Table 1 outlines the standard of practice that a QP should apply when carrying out risk assessments. The elements of this table are further explored throughout Sections 3.4 to 3.6.

Table 1: Table outlining suggested standard of practice defined in guidelines for a qualified professional conducting a risk assessment

Project Details	Professional Considerations
Project scope	• Identify whether an owner-defined *climate risk tolerance* is available; if not, engage with the owner to establish their *climate risk tolerance.* • Establish owner-defined time horizon for the infrastructure.
Project team	• Assemble qualified team in collaboration with the owner.
Regional climate projections	• Could be developed by a climate specialist. • A range of *representative concentration pathways (RCPs)* or equivalent Special Report on Emissions Scenarios (SRES) scenarios should be used to generate regional climate projections • An ensemble of models should be used to generate regional climate projections. For example, the top three climate models for Western North America as indicated by PCIC are CNRM-CM5-r1, CanESM2-r1 and ACCESS1-0-r1 (PCIC 2013). • Design should be based on existing codes and standards, but future climate projections for the time horizon identified should be used in place of climate data referred to in the codes and standards.
Background information	• Sufficient fieldwork should be conducted by the QP and their team. • The QP should review available background information and collect additional information (see step 2b in Figure 3).
Climate adaptation method	• Explore the following adaptation methods: · *robust design* that makes the infrastructure resilient to a wide range of future climate projections (this approach is preferable) · *flexible design* that includes redundant systems or has the capacity for design components to be changed in the future · *status-quo design* that recognizes that implementing no explicit adaptation measures is a valid response • If appropriate, revisit adaptation options after a time period agreed to with the owner.
Highway Infrastructure Climate Change–Resilient Design Report	• Convey in plain language the climate change risks associated with status-quo/worst-possible emissions scenarios (through the discussion of emission scenarios such as RCP 8.5) to the owner to enable decision-making. • Address the frequency of reassessment and monitoring required (also includes collection of climate data appropriate for the location to inform future design).
Project documentation	• The findings of the risk assessment and any assumptions made need to be fully documented and clearly communicated to the owner to demonstrate compliance with the intent and objectives of these guidelines. • Identify climate model ensemble used. • Identify vulnerability risk assessment tool (and version), if applicable.

3.3.1 Define Objectives

Specific objectives that must be met by the design with respect to capacity, safety, reliability and longevity should be identified to ensure that appropriate information is included in the climate risk assessment. These are the elements that contribute to the *climate risk tolerance* of the owner.

For example, consider a road that is the only viable route to a given location. It may be that this road cannot be closed for more than two days without causing severe hardship. This forms a reliability objective that should be reflected in the infrastructure components and climate parameters selected for the climate risk assessment.

Or consider a bridge for which the design requires a peak stream flow rate. Historical hydrometric analysis would be adequate for establishing existing design values, but hydrologic modelling would be required to estimate design values based on future climate. Identifying this as an objective ensures that appropriate specific climate parameters are included in the climate risk assessment.

Minimum level of effort

There is little opportunity to reduce effort for this task, except perhaps in the level of documentation detail.

3.3.2 Select Risk Assessment Method

Several risk assessment methods have been developed by various organizations. At their core, however, each climate risk assessment includes:

- a list of infrastructure components
- a list of specific climate parameters
- a matrix showing the combinations of listed infrastructure components and specific climate parameters, and identifying the infrastructure component/climate parameter combinations where there is some potential for the infrastructure component to be negatively impacted by a change in the climate parameter
- assignment of a numerical likelihood that each identified matrix interaction will occur
- assignment of a numerical severity rating to each potential interaction in the matrix, should the interaction occur
- calculation of risk (product of severity rating and likelihood value) for each matrix interaction

Risk assessments can be more detailed than this, but all risk assessment methods include, at a minimum, each of the above-listed elements. Many risk assessment methods include guidance for evaluating the risks once they have been identified, which can be useful.

A well-known climate risk assessment protocol in Canada is Engineers Canada's Public Infrastructure Engineering Vulnerability Committee (PIEVC) *Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment* (Engineers Canada 2011). This is a comprehensive screening-level protocol that covers everything from planning and initiating the process to documenting each step along the way. It is available for use through a licence agreement with Engineers Canada at no financial charge. The PIEVC Engineering Protocol is very specific about how the assessment is conducted, including details such as team composition, information required, how information is gathered and assessed, how results are interpreted, and how the entire process is documented. All of these steps are included as part of the protocol.

Another tool that is especially applicable to assessing climate change risk for transportation infrastructure is the US Department of Transportation Federal Highway Administration's (FHWA) Vulnerability Assessment Scoring Tool (VAST) (FHWA n.d.). It is a "spreadsheet tool that guides the user through conducting a quantitative, indicator-based vulnerability screen." The tool can be downloaded and used without further interaction with FHWA. This ease of access makes the tool attractive—especially for smaller or less complicated design projects. It can also be applied to large or complicated design projects, but lacks some of the elements of the PIEVC Engineering Protocol, such as team development and documentation, that might prove useful.

References for these and other risk assessment tools and methods can be found on the *APEGBC Climate Change Information Portal* (www.apeg.bc.ca/climateportal).

Note that current risk assessment methods and tools were originally developed to assess existing infrastructure. They can, however, be adapted for use in the design process. For example, the capacity of existing infrastructure can be determined because it has physical attributes that are documented or that can be measured. It may have built-in climate change resilience if the load generated by projected climate is less than its capacity. When assessing the vulnerability of infrastructure being designed, it is necessary to first establish capacity or expected performance; it might therefore be useful to size or select components based on current climate values. In this way, infrastructure with high risk scores can be resized using projected climate values to reduce risk.

Also note that most, if not all, of these tools and methods are being further developed and refined with application experience. Therefore, it is the QP's responsibility to remain informed about the status of available tools and methods to ensure that the most current version is applied.

Minimum level of effort

At a minimum, a simple matrix listing the selected climate events and infrastructure components may suffice.

3.3.3 Select Infrastructure Components

The climate risk assessment relies on selecting appropriate infrastructure components. Components may be defined individually, or as a group, or as both if the situation warrants. For example, the QP may choose to group all roadway culverts as a single component, list each culvert as a single component, or group some culverts into a single component while listing others individually. Or a bridge might be listed as a single infrastructure component, or included as individual components (piers, abutments, superstructure and deck).

Listing individual infrastructure components may yield a more detailed risk assessment, but with extra effort and cost. This might not be warranted, and a balance should be established between effort and effectiveness. The ability to select and group infrastructure components likely to be sensitive to climate change comes with experience, but it might be useful to review assessment reports based on the PIEVC Engineering Protocol for examples of how infrastructure components have been defined for similar projects. These are located on the PIEVC website (www.pievc.ca). It is often useful to consider some of the following items to determine if a particular infrastructure component should be assessed individually, as part of a group of components, or not included at all:

- Is there a chance that the component might be affected by climate? If it is obvious that the component is not impacted by climate at all, then there is no reason to include it in the assessment. However, this should still be documented as a part of the assessment.
- What is the functional lifespan of the component? Is it likely to be replaced through routine maintenance in a few years, or will it remain in service for decades? Only include the component if it is likely to be in service in the distant future. Components that are replaced through routine maintenance can be assessed at a later date.

- How critical is the component to the overall performance of the project? Would its failure cause significant impacts in terms of performance and/or safety? Can it be easily replaced or repaired, or would this be costly in terms of money and time?
- Are there many identical or similar components in the project? Is it likely that their response to a specific climate change parameter would also be similar? This is usually a good indicator that the components can be assessed as a group.

The QP should work with team members to create the list of infrastructure components to be assessed. Engineering judgment will be required to determine if a component should be assessed individually, assessed as part of a group, or assessed at all.

Minimum level of effort

At a minimum, it may be adequate to start with the infrastructure as a whole, or with key component groups if the infrastructure is more complex. For example, if the project is a new or upgraded road that includes no major structures, such as bridges, grade-separated intersections, or snowsheds, then the selected infrastructure could simply be "road structure." If the project does include major structures, the list could be expanded to include primary structure groups—culverts, bridges, or snowsheds, for example.

3.3.4 Select and Define Specific Climate Parameters

The QP will need to expand the list of general climate parameters outlined in Section 3.2.3 by adding specific climate parameter definitions. It is useful to list the specific climate parameters that are explicitly and implicitly used in the design process for components. In engineering design, the extreme event is often critical; for example, "rainfall intensity" is a general climate parameter, but "the 1:100 year rainfall intensity for a one-hour duration" is a specific climate parameter. Each of these specific climate parameters should have some interaction with, or affect on the performance of, at least one of the infrastructure components identified in Section 3.3.3 and in Section C-7: A Summary of PIEVC Risk Assessments Conducted by the BC Ministry of Transportation and Infrastructure in Appendix C.

Qualified professionals may have the knowledge and experience to select and interpret projected climate values on their own. However, when this is not the case, and as recommended in Section 3.2.5, the QP should work with climate experts to determine the appropriate parameters and corresponding values to include in the risk assessment. This is especially important for certain climate parameters, such as sub-daily rainfall intensities, since many climate projections are based on annual averages or, at best, daily values.

The QP should also engage climate specialists in discussions of how the climate values will be used to ensure that the information provided is suitable for the intended purpose. Ranges of values should be identified, discussed and documented, since these will have an influence on how the climate values will be applied.

Climate specialists may identify climate parameters that previously have not been considered as a design parameter. For example, temperature might not typically be used in the design of certain infrastructure. However, if increased and sustained temperatures are projected for the future, the corresponding changes in the asphalt mix for road construction might be a secondary variable that could influence the design. In the case where climate projections for a specific climate parameter are not available, climate experts might be able to recommend a different climate parameter to use as a proxy for the desired value.

Some climate parameters are indirectly used for design purposes. For example, design flows for culverts or bridges are a function of rainfall, snowpack and temperature, or both. In such situations, it may be beneficial for the QP to engage climate specialists and other experts, such as hydrologists/water resources experts, to adequately define the climate parameters and values required. For example, to address specific issues of future hydrologic changes (e.g., hydrologic regime shift from snow-dominated to rain-dominated, early snowmelt-driven freshet, rain-on-snow events), input from a scientist or engineer with expertise in or familiarity with that specific area will help.

The key concept to remember is that by working with climate specialists and other experts, the QP is more likely to identify the appropriate specific climate parameters to use for the climate change vulnerability risk assessment, and is also more likely to obtain accurate values that reflect projected climate conditions. Most climate parameter projections provide a range of values. The QP should use their professional judgment and methods such as sensitivity analysis to select the appropriate value going forward, with the selection rationale documented. Note that each vulnerability risk assessment method or tool has its own specific format for documenting the climate parameters. This format should be used by the QP unless there is a compelling reason to do otherwise.

Minimum level of effort

It is not always necessary to have specific numeric values for each of the general climate parameters identified in Section 3.2.3. It may be sufficient to determine if the projected change for each parameter is large, moderate or negligible, and if the change is an increase or decrease from current values. It is likely safe to assume that extreme values will reflect the magnitude and direction of changes to the average values of a given climate parameter. For example, if average precipitation is projected to increase moderately, then extreme precipitation for short duration events can be assumed to increase at least moderately. It may be useful to confer with a climate specialist to confirm these generalized assumptions.

3.3.5 Identify and Characterize Infrastructure/Climate Interactions

For each combination of listed infrastructure component and climate change parameter, the QP and assessment team must determine what type of interactions might occur should the climate event happen. Essentially, the team is to identify "what, if anything, could happen" for each potential interaction. If, for example, the current one-hour rainfall intensity with a 1:100 year return period were to increase by 50%, what might happen to the proposed catch-basins, or culverts, or ditch rip-rap? Could the catch-basins become overwhelmed with increased runoff? Could the road sections with culverts be over-topped and washed-out? Could the rip-rap be washed downstream, causing erosion or damage to downstream structures?

At this point in the climate risk assessment, the only task is to identify potential interactions between each infrastructure component and each climate change parameter. Estimates of likelihood and severity will be made later. Professional judgment is required, however, to ensure that key realistic interactions are identified. It is also important to recognize that there might not be an interaction for every combination of infrastructure component and climate change parameter. This is acceptable and will be part of the result.

Each risk assessment method specifies the format and process for characterizing and documenting the interactions between each infrastructure component and specific climate parameter. These should be followed to ensure consistency across various tasks of the assessment. The climate-infrastructure interaction table used in a *BCMoTI* risk assessment is provided as one of the examples in Appendix C.

Minimum level of effort

There is little opportunity to reduce effort for this task, except perhaps in the level of documentation detail.

3.3.6 Define Risk

As defined previously, and within the context of infrastructure design and climate change, risk is a measure of how vulnerable a design component is to negative impacts of climate change. From a design perspective, a negative impact can be considered a failure of the design component—either physically or in terms of performance criteria. Risk is a function of two attributes:

- the probability, or likelihood, of the failure to occur, and
- the severity of the consequences should the failure occur

Each risk assessment method provides specific guidance on how to define the scoring system. For example, scores could range from 0 to 7 for both "zero to high likelihood" and for "no to high severity." Each value in the range of scores must be defined in a way that is meaningful to the team and to the stakeholders. For example, a likelihood score of 7 could be defined to mean "highly likely to occur" or "100% chance of occurrence" or "approaching certainty." A severity score of 7 could be defined as "catastrophic" or "loss of asset."

The key is that risk be determined using the same definition and calculations for all identified interactions. This provides consistency for the entire assessment process, and will result in a better understanding of how vulnerable each selected infrastructure component is to each identified climate parameter.

Levels of the climate change vulnerability risk assessment include:

- screening of the interaction
- vulnerability analysis or assessment
- engineering analysis

Minimum level of effort

It may be sufficient to define a scoring system where scores would range from 0 to 3 for "zero, low, medium and high" likelihood and "no, low, moderate and high" severity or consequence.

3.3.6.1 Conduct Screening-Level Risk Assessment

A screening-level risk assessment will help the QP determine the level of effort to be expended on conducting a climate change vulnerability risk assessment of the subject infrastructure. A screening-level risk assessment is the first step in a climate change vulnerability risk assessment conducted to help the QP determine if a more comprehensive climate change vulnerability risk assessment is required. Even if it is determined early in the process that a minimal level of effort is not sufficient to conduct a risk assessment, the screening-level risk assessment could provide insight into where additional resources and effort are best applied during a comprehensive risk assessment.

Each of the risk assessment tasks described in Section 3 includes a statement about "minimum level of effort." These statements outline the process for conducting a screening-level risk assessment. If the QP completes each risk assessment task by applying the minimum level of effort, they will essentially complete a screening-level risk assessment.

Screening-Level Risk Assessment contains a yes/no determination if there is an interaction between infrastructure components and climate and thus potential vulnerability. If the screening-level risk assessment indicates that there is insignificant risk due to climate change, then a more comprehensive risk assessment will not be required. When the screening-level risk assessment indicates that risks are moderate or high, it is prudent for the QP to arrange for a more comprehensive risk assessment. This may require expanding the team to provide additional information or expertise, conducting more detailed engineering analysis, defining climate change events in more detail, or any number of other actions. The QP will have to apply professional judgment in order to determine how much effort is required to complete the comprehensive risk assessment.

3.3.6.2 Conduct Risk Assessment

Once the potential interactions between the selected infrastructure components and defined climate change parameters have been determined, the risk assessment is completed by:

- assigning a likelihood of each interaction occurring
- assigning a severity score describing the consequences of the interaction occurring, and
- calculating a risk score as the product of the likelihood and severity score

In mathematical terms,
risk = likelihood x severity.

It is important to determine the likelihood and severity scores independent of each other. The QP cannot allow perceived severity to influence the assigned likelihood for a given interaction. The reciprocal is true for perceived likelihood influencing the assigned severity score. Documenting the reasons for independently selecting both the likelihood and severity for each interaction can be useful when identifying adaptation measures. The design team can reduce risk by:

- reducing the likelihood that the interaction will occur, or
- reducing the severity of the interaction should it occur, or
- both

Determining the likelihood and severity scores for each interaction requires significant expert judgment. This is best accomplished by engaging team members that have experience with the selected infrastructure components when they are subjected to climate events that are similar to the identified climate change parameters.

The QP should also document interactions that require further clarification and thus engage extra risk analysis processes, such as engineering analysis or additional information in order to determine an appropriate likelihood or severity score. This analysis is discussed in Section 3.3.6.4.

Minimum level of effort

While the screening-level risk assessment could technically be completed by a single person, it should be completed by the minimal team identified in Section 3.2.4. It is important that different perspectives and areas of expertise be engaged to increase confidence in the results.

3.3.6.3 Evaluate Climate Risk Assessment

Quantifying risk associated with each of the infrastructure component/climate parameter interactions forms the basis for developing strategies to manage these risks. For example, infrastructure with low risk scores that are the product of low likelihood and low consequence scores can usually be designed without further consideration of climate change. Infrastructure with high risk scores that are the product of high likelihood and severe consequence scores may be candidates for *robust design*.

Infrastructure components that garner "medium" risk scores may be candidates for *flexible design*, or may be evaluated further to determine if additional assessment, such as using engineering analysis, is required to clarify risk and identify appropriate adaptation measures.

Two special cases that can occur are the combination of low likelihood and high severity, or high likelihood and low severity. The corresponding risk for these interactions is typically scored as "low," but further evaluation and engineering judgment should be applied to determine actual risk. These special cases and the risk matrix are shown in Figure 4 (adapted from the PIEVC document 10 October 2011 version).

Figure 4: Sample risk matrix

Severity	7	0	7	14	21	28	35	42	49
	6	0	6	12	18	24	30	36	42
	5	0	5	10	15	20	25	30	35
	4	0	4	8	12	16	20	24	28
	3	0	3	6	9	12	15	18	21
	2	0	2	4	6	8	10	12	14
	1	0	1	2	3	4	5	6	7
	0	0	0	0	0	0	0	0	0
		0	1	2	3	4	5	6	7
		Probability							

Special Case	Low Risk	Medium Risk	High Risk

Note that application of the climate change vulnerability risk assessment results will depend, to a large degree, on the owner's *climate risk tolerance*. If a coastal highway is at risk due to flooding under a future extreme event, the owner of the infrastructure has to assess the importance of the highway to the community or the economy, assess the remaining design life, and assess the adaptive capacity of the highway to determine when upgrades should be considered and what level of upgrades need to be considered. Based on this assessment the owner will establish their level of *climate risk tolerance*, which will define the level of *climate change-resilience* incorporated into the design.

The risk assessment results, and the recommended actions for each of the selected infrastructure components, should be reviewed with the owner and the EOR. Final decisions are documented in the highway infrastructure climate change–resilient design report.

Minimum level of effort

There is little opportunity to reduce effort for this task, except perhaps in the level of documentation detail.

3.3.6.4 Conduct Engineering Analysis

There may be reasons to conduct the additional step of engineering analysis as part of the climate risk assessment. A key reason is to clarify the level of risk associated with a particular infrastructure/climate interaction, particularly when the initial assessment does not yield a clear vulnerability risk score. Typical triggers for an engineering analysis may include a medium risk score that generated significant team debate, interactions that tend to exhibit vulnerability regardless of risk score, or insufficient data to make a definitive assessment. The objective of engineering analysis is to quantify the adaptive capacity to climate change of the proposed design, so it looks in detail at the load and capacity of the subject infrastructure under projected climate conditions.

Details will differ depending on the infrastructure to be analyzed and the risk assessment method selected. However, all engineering analyses will determine total load and total capacity. The total load includes loads due to both climate and non-climate drivers. Total capacity includes design capacity adjusted for aging, normal wear and other factors. When the total load exceeds total capacity, the infrastructure is considered to be vulnerable. If total load is less than total capacity, the infrastructure is considered to have adaptive capacity—resilience. The engineering analysis results can be used to establish climate change safety factors—those factors that will establish the loads required to provide the needed adaptive capacity, increase resilience, and reduce the risks to acceptable levels.

Another reason to conduct engineering analysis is to facilitate the selection of adaptation measures. The contrast between design values generated by both current and projected future climate values can be used to identify ways to reduce risk. For example, the hydraulic capacity required to convey peak flows generated from future climate values could be achieved by increasing conduit diameter, using a material with a lower roughness coefficient, introducing upstream storage to attenuate the peak flow, or a combination of two or more of these options. The analysis can be used to determine which of the options are feasible, and to what extent. These analyses may also provide non-structural options that address vulnerabilities that contribute to the feasibility and cost-effectiveness of the options.

The following three subsections provide additional discussion regarding engineering analysis for each of the three primary engineering fields associated with the design of *highway infrastructure*—hydrotechnical, geotechnical and structural. Engineering analysis may also be required to confirm climate change vulnerability risk associated with avalanches, environmental protection, icing and ice jams, electrical systems, signage systems, and other specialized fields pertinent to the overall infrastructure design. While these engineering fields are not discussed specifically, the risk assessment and adaptation principles presented in these guidelines also apply.

Minimum level of effort

If engineering analysis is to be conducted to help determine whether or not a more comprehensive risk assessment is required, a sensitivity analysis may be sufficient. That is, rather than determining projected design climate values for load analysis, it may be sufficient to calculate capacity required if total load was increased by a specified amount. For example, if total load based on current design climate values were to be increased by 10%, 25%, or even 50%, what would be the impact on the design to provide the corresponding capacities?

3.3.6.4.1 Hydrotechnical Analysis

Hydrotechnical analysis is conducted to support the design of bridges and large culverts for highway projects, as well as piers, jetties and erosion protection for ports. This includes, for example, recommendations for hydraulic design, stream bank and channel erosion protection, scour protection, stream diversions and foreshore erosion protection.

Most, if not all, of the climate data required to conduct hydrotechnical analysis are used indirectly. Design values such as water levels, flow rates, wave action and storm surge heights are the results of climate parameters such as precipitation, wind, snowpack and temperature. In many cases, design values are determined by conducting statistical analyses of historical records—maximum annual flows, for example. However, when considering the impacts of climate change, this approach is not suitable, since future values may change from historical values. This may necessitate modelling and apply non-stationary methods to estimate the impacts of climate change on the required design values.

Modelling climate change impacts for every infrastructure design project may not be necessary, since some of this work is ongoing and potentially available from many sources. Sea level rise, for example, has already been modelled by several organizations, and estimates of future levels are available (e.g., in the BC Ministry of Forests, Lands and Natural Resource Operations *Flood Hazard Area Land Use Management Guidelines*). Hydrologic models that reflect potential climate change have also been completed for selected watersheds in BC. However, the results might be too coarse at this time, both temporally and spatially, to be of use in design projects. Engineering judgment will be required to determine how to best estimate the impacts of climate change on the hydrotechnical design values required for each project.

Since the hydrotechnical analysis usually involves design considerations for a small number of key components (e.g., bridge or culvert) interacting with a small number of climate parameters (e.g., rainfall, freshet peaks), less time may be spent on the risk assessment (i.e., listing components and evaluating interactions). Thus, more time could be spent on an adaptive design approach that considers anticipated effects of climate change on site hydrology and how modified hydrology affects the structure performance.

3.3.6.4.2 Geotechnical Analysis

Geotechnical analysis is conducted to support the design of roads, bridge piers and abutments, retaining walls, and rock-fall protection. Geotechnical design values—such as bearing capacity or slope stability—are dependent on physical properties of the soil, such as texture, moisture, cohesion, groundwater levels and flow, and bedrock presence and composition. None of these are climate parameters, but some can be influenced by climate change.

Permafrost, for example, is highly susceptible to warming trends. Pavements may become more susceptible to failure from a combination of temperature and water impacts—for example, higher, sustained temperatures may soften asphalt surfaces, which can increase rutting; increased freeze/thaw cycles can cause damage from frost heaves or thermal fatigue cracking; higher moisture content in the road base can lead to increased cracking or rutting of the pavement surface due to reduced bearing capacity.

Changes in the average and extreme values of precipitation and temperature, including frequency and duration of events, can have a significant impact on geotechnical design. These should be identified and considered as part of any geotechnical analysis in order to support climate change resilience in infrastructure design.

3.3.6.4.3 Structural Analysis

Structural analysis is conducted to provide design values for a variety of materials and performance objectives. Materials may include concrete, steel, aluminum, plastics, wood, protective coatings, and many composites and combinations thereof. Performance objectives include strength, durability, and sometimes even aesthetics. Climate parameters can directly affect the performance of these materials and the structural components that they comprise.

Loads are at least partially a function of wind, precipitation and temperature (snow and ice). Durability of the structural components, or at least their protective coatings, may be subject to changes in temperature, solar radiation, and moisture. Performance of mechanical systems—both passive and active—may also be impacted by changes in temperature and moisture.

Many of these climate parameters are applied to structural design implicitly rather than directly, because they are embedded in the various codes that are typically used. It is vital that the QP work with the structural team members to identify appropriate climate parameters so that potential changes to the accepted values can be considered and included in any analysis.

3.4 IDENTIFY AND INCORPORATE ADAPTATION OPTIONS

For the purposes of these guidelines, "adaptation" refers to any action that reduces the vulnerability of proposed infrastructure to the impacts of climate change. Infrastructure that is designed and constructed using an adaptation method is considered climate change resilient for specified requirements. It is important to recognize that adaptation is not restricted only to increasing capacity or strength, but may include:

- enhanced maintenance practices
- different construction materials or methods
- different siting
- phasing opportunities triggered by threshold events
- further study or more detailed analysis, and/or
- monitoring, or any number of items that could enhance climate change resilience

It is also important that adaptation reflect the following principles:

- Adaptive actions should not be delayed to wait for a complete understanding of climate change impacts, as there will always be some uncertainty. Plans and actions should be adjusted as understanding of climate impacts increases.
- Adaptation often requires coordination across multiple sectors, geographical scales, and levels of government to build on the existing efforts and knowledge of a wide range of stakeholders. Because impacts, vulnerability and needs vary by region and locale, adaptation will be most effective when driven by local or regional risks and needs.
- Ecosystems provide valuable services that help to build climate change resilience and reduce the vulnerability to climate change impacts. Integrating the protection of biodiversity and ecosystem services into adaptation strategies will increase climate change resilience.
- Adaptation should, where possible, use strategies that complement or directly support other related climate or environmental initiatives, such as efforts to improve disaster preparedness or reduce greenhouse gas emissions.

The principles outlined above are excerpts from the *Progress Report of the Interagency Climate Change Adaptation Task Force: Recommended Actions in Support of a National Climate Change Adaptation Strategy* (White House Council on Environmental Quality 2010).

3.4.1 Exercise Professional Judgment

Professional judgment is required throughout the entire design and risk management process. However, its application is especially important when identifying and implementing adaptation measures to increase climate resilience.

Given the level of public awareness of climate change issues, and by virtue of these guidelines, engineers and geoscientists providing services for BCMoTI projects to which these guidelines apply, cannot maintain that they were unaware that climate change could potentially affect their professional work.

These guidelines should not be interpreted to mean that the professional, specifically the EOR, must become an expert on weather and climate issues. Rather, the expectation is that the professional will, as part of their normal practice, determine where climate information is embedded in codes, standards and assumptions and evaluate how the information is applied in their professional work.

The key concept is that professionals should consider the implications of climate change for their professional work, and create a clear record of the outcomes of those considerations.

The EOR should include documentation of their professional judgment and their team as a means to demonstrate their due diligence obligation that climate was considered. This will help defend against professional liability that is assumed when a design is approved by the EOR.

3.4.2 Identify Adaptation Options

This subsection introduces a range of adaptation measures that could be implemented in order to ensure that the proposed infrastructure is able to withstand the impacts of climate change. Figure 3 shows three categories of adaptation measures that could be applied to the infrastructure design process:

- *status-quo design*
- flexible design
- robust design

Status-quo design recognizes that implementing no explicit adaptation measures is a valid response, provided that the QP documents the reason or reasons that this is done. These may include the following:

- The climate risk assessment shows that the subject infrastructure has low or no vulnerability risk due to projected climate change.
- The service life of the subject infrastructure is relatively short, and adaptation measures can be considered and/or implemented when the infrastructure is replaced or refurbished.

Flexible design is based on the assumption that there will be opportunities to adapt in the future. This option could be selected for a variety of reasons, but the primary one is to reduce up-front capital costs. There are two approaches to this option. One is to initially design the infrastructure using climate values based on climate projections. The other is to initially design the infrastructure based on historical climate values. Both options build in the ability to increase resilience should the climate trend toward more severe conditions.

It is important, therefore, to identify the consequences of the worst-case climate scenario unfolding after the infrastructure is constructed, and to have a plan of action to modify or upgrade the infrastructure accordingly. Within this context, the term "worst-case scenario" refers to the possibility that future design climate values may be best represented by the maximum values in the range of climate projection results. If it is not feasible to develop a response plan to climate conditions that are worse than designed for, the flexible design option should not be used.

With flexible design, some adaptation measures may be implemented as part of the initial design, and others may be implemented when one or more predefined trigger events occur. Trigger events should be defined in a way that ensures continued integrity of the subject infrastructure—no failures —but still signals increasing likelihood that the climate is trending toward conditions more severe than those used for initial design. For example, a trigger may be an event flood level, flow rate or rainfall intensity that reaches or exceeds a threshold.

Flexible design is characterized by the ability to implement one or more of the following measures in the future:

- increase the infrastructure's capacity or capacities
- reduce loads
- reduce consequences of failure

Note that flexible design is more appropriate for gradual changes over time, such as sea level rise or melting permafrost. It may be less appropriate for infrastructure subject to sudden extreme climate events that are not easily predicted based on observed conditions. Successful flexible design also requires monitoring of climate, loads and infrastructure performance, and comparing the data to predefined thresholds. It should be implemented only if the owner has the funds, authority and willingness to maintain the monitoring program and to implement the predetermined upgrades if required.

Robust design has the objective of ensuring that the proposed infrastructure will perform as expected over a range of possible future climate conditions, including the "worst-case" design scenario (as defined above). This option will usually result in higher initial construction costs for the infrastructure, and therefore may be justified for those infrastructure components that are assessed to have high risk of vulnerability to climate change. Other considerations for choosing the robust design approach may be as follows:

- The overall cost of implementing flexible design far exceeds the additional cost of implementing robust design.
- Flexible design is not an option because there are no feasible opportunities to phase in adaptation measures.
- There are social or political issues that are better addressed through robust design.

Robust design may include, but is not limited to, the following:

- use of generous safety factors applied to loads generated using "average" projected climate values, and ensuring that capacities are designed accordingly
- capacities designed to service loads generated using "worst-case" projected design climate values
- redundant features added to the design to protect against failure

It is worth noting that the EOR is responsible for selecting one of the design approaches identified above or an alternative approach based in part on the results of the risk assessment. Regardless of which design approach is selected, essential to include a maintenance program to ensure design integrity over the service life of the infrastructure. All designs assume a level of operations and maintenance that must be maintained to ensure resilience. These assumptions must be clearly documented in the Highway Infrastructure Climate Change–Resilient Design Report.

Minimum level of effort

If the *screening-level risk assessment* indicates that there are no vulnerabilities to climate change, then in consultation with the owner the infrastructure design could proceed without any adaptation measures incorporated. If the screening-level risk assessment indicates only low climate vulnerability risk, simple adaptive or maintenance measures may be appropriate. Whatever adaptive measures, or lack of measures, are implemented into the design, the corresponding assumptions and reasons for doing so must be clearly documented.

3.4.3 Communicate Effectively

In most cases, the EOR does not make all of the decisions with respect to implementing climate change adaptation measures for a design. As presented in Section 3.2.4 a team of professionals, specialists and stakeholders may be involved in the design process. Since the language used to communicate concepts and principles can be interpreted differently by practitioners in different disciplines, it is essential that team members are aware of the potential for misunderstanding, and that they take steps to ensure that what is communicated is understood as intended. In addition, highly technical information must be communicated to decision-makers, some of whom have little or no technical knowledge or experience. BCMoTI, with contributions and support from other organizations, has published a document that addresses this issue within the context of climate and climate projections (BCMoTI *et al*. 2014).

Given the critical importance of these issues, it is the QP's duty to ensure that their communications are understood correctly. Technical terms should be defined and reviewed by team members to ensure a mutual understanding. When using common language, the QP must be aware of how such language is understood by the average person, and must adjust or elaborate communications as necessary.

The EOR may sometimes have to communicate climate issues, risks and proposed adaptation measures to non-receptive decision-makers. In such cases, the EOR must ensure that the consequences of ignoring the issues or rejecting the recommended adaptation measures are clearly understood by the decision-maker. Furthermore, if the EOR believes that public health and safety are at significant risk should the adaptation measures be excluded from the design, it is their duty to communicate such information more broadly—first within APEGBC to seek council and advice, and, if deemed appropriate, with regulators and/or other external agencies.

Although it is the owner that accepts the design recommendations from the EOR, the EOR should be aware that simply recommending actions to decision-makers may be insufficient. Where appropriate, the EOR should communicate any ethical, legal or safety concerns from not implementing the adaptation measures identified by the EOR to the owner.

Minimum level of effort

There is little opportunity to reduce effort for this task, except perhaps in the level of documentation detail.

3.4.4 Finalize Adaptation Plan and Resilient Design Measures

Once the resilient design measures have been identified and organized into options, they must be presented to the owner and other appropriate decision-makers. The goal of this action is to select the adaptive measures that will be incorporated into the final design. Subject to the cautions outlined in Section 3.4.3, the identified adaptation measures should be presented with the following supportive information:

- a list of the infrastructure/climate change interactions that are addressed by the adaptive measure; this should include descriptions of the interactions, the assigned risk scores, and a summary of the likelihood and consequence severity scores that generate the risk scores—information readily available from the climate change vulnerability risk assessment
- a description of how the adaptive measure would be implemented, especially if it is a "flexible design" measure as opposed to a "robust design" measure
- an estimate of the financial impacts of implementing the proposed adaptive measure
- a discussion of any related issues that could impact the implementation of the adaptive measure (e.g., the need for monitoring, land acquisition, product sourcing, schedule impacts)

The selected adaptation measures should be documented, along with any discussions that justify their selection. See Section 3.5 for more detail.

Minimum level of effort

The level of effort for this task will correspond to the number and types of adaptation measures incorporated into the design.

3.5 DOCUMENT PROCESS AND DECISIONS

It is critical to document key information associated with incorporating climate change resilience into the highway infrastructure design process. In addition to fulfilling the quality assurance/quality control requirements of the APEGBC quality management bylaws, such documentation will prove valuable for:

- developing and executing operation and maintenance plans
- maintaining the monitoring programs
- addressing upgrading or refurbishment issues
- demonstrating due diligence, should there be a failure caused by a climate event

For BCMoTI projects, the QP is to complete the assurance statement (Appendix A) and submit it with the report outlining the results of the climate change vulnerability risk assessment as outlined in Section 2.2.3. At minimum, key information from each of the tasks outlined in Sections 3.3 to 3.5 should be clearly documented in this report. This may include, but not be limited to:

- risk assessment and design team members, including their qualifications and roles
- design criteria and associated references
- data sources and corresponding uncertainties, data gaps, and assumptions (each risk assessment method may specify the format for this information)
- reasons for selecting the infrastructure components and climate change parameters used for the climate risk assessment
- scoring methods for likelihood and consequence severity
- engineering analysis objectives, results and conclusions
- design values and adjustments for future climate where appropriate
- adaptation measures other than adjusted design values (e.g., siting changes, monitoring programs, actions to be taken when thresholds are triggered)
- key decisions with respect to the adaptation measures selected for implementation and the corresponding justification for their selection
- the ensemble of climate models used in the risk assessment
- climate projections used in the risk assessment
- emissions scenario(s) considered in the risk assessment
- name and version of climate change vulnerability risk assessment tools used in the risk assessment
- time horizon used for the risk assessment

The EOR is to also ensure that the BCMoTI Design Criteria Sheet for Climate Change Resilience is completed and submitted as required by BCMoTI (Appendix B).

Minimum level of effort

There is little opportunity to reduce effort for this task, except for the level of documentation detail. Assuming that the screening-level risk assessment adequately indicated that the infrastructure has low or no vulnerabilities to climate change, the document may be limited to summary statements of each of the items listed above. However, it is essential that the documentation still clearly indicate the reasons for assumptions and decisions made.

QUALITY ASSURANCE/QUALITY CONTROL

4.1 APEGBC QUALITY MANAGEMENT BYLAWS

At minimum, a quality assurance/quality control (QA/QC) program must satisfy the requirements of APEGBC Quality Management Bylaws 14(b)(1), (2) and (3) with regard to:

- the work being performed under the direct supervision of a QP
- retention of complete project documentation for a minimum of 10 years
- documented checking of engineering and geoscience using a quality control process
- documented internal or external review of report

The APEGBC quality management guidelines state that the project documentation should be retained for a minimum of 10 years; however, given the service life of highway infrastructure, the project documentation should be retained by the owner for the service life of the infrastructure.

These minimum requirements may be supplemented by an independent peer review where appropriate.

4.2 DIRECT SUPERVISION

The Act (Section 1 (1)) states that direct supervision means taking responsibility for the control and conduct of the engineering or geoscience work of a subordinate. With regard to direct supervision, the CEOR, EOR or QP having overall responsibility should consider:

- the complexity and nature of the project
- which aspects of the risk assessment, and how many of those aspects, should be delegated
- training and experience of individuals to whom work is delegated
- amount of instruction, supervision and review required

4.3 RETENTION OF PROJECT DOCUMENTATION

The following documentation related to the incorporation of climate change resilience into the design of highway infrastructure should be retained for a minimum of 10 years, or for the service life of the infrastructure:

- the report detailing the engineering analysis, conclusions and recommendations from the risk assessment
- any documentation related to the risk assessment
- the BCMoTI Design Criteria Sheet for Climate Change Resilience

4.4 INTERNAL AND EXTERNAL PEER REVIEW

An independent peer review is an additional level of review beyond the minimum requirements of Bylaw 14(b)(2) that may be undertaken for a variety of reasons by an independent peer reviewer not previously involved in the project. For example, the independent peer review could be requested by the owner or required as a part of a legal/technical investigation resulting from a complaint or a lawsuit. The peer reviewer will review the risk assessment and the report to determine the accuracy of the findings and the validity of the recommendations.

PROFESSIONAL REGISTRATION; EDUCATION, TRAINING AND EXPERIENCE

5.1 PROFESSIONAL REGISTRATION

A professional engineer who is engaged in work related to public infrastructure is typically registered with APEGBC in the discipline of geotechnical, structural, civil or hydro-technical engineering. Not all professional engineers registered in the disciplines noted above are necessarily appropriately knowledgeable in risk assessments. It is the responsibility of the professional engineer or professional geoscientist to determine whether they are by training or experience able to undertake and accept responsibility for climate change vulnerability risk assessments as a QP or for the climate change–resilient design of highway infrastructure as the EOR (APEGBC Code of Ethics Principle 2).

5.2 EDUCATION, TRAINING AND EXPERIENCE

At minimum, an APEGBC member acting in the capacity of a QP should:

- have worked in a multi-stakeholder team in conjunction with the owner to conduct risk assessments
- be able to work with a climate specialist to acquire the appropriate regional climate data projections
- be able to use regional climate data projections in a risk assessment
- be able to recommend adaptation methods for design of the highway infrastructure based on the risk assessment
- be able to clearly document the results of the risk assessment to communicate the risks due to climate change to the owner

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APPENDIX A: ASSURANCE STATEMENT CLIMATE CHANGE VULNERABILITY RISK ASSESSMENT ASSURANCE STATEMENT

Note: This statement is to be read and completed in conjunction with the *Highway Infrastructure Climate Change–Resilient Design Report outlined in the Professional Practice Guidelines – Developing Climate Change–Resilient Design for Highway Infrastructure in British Columbia* (Climate Change Resilience Guidelines). This assurance statement is to be provided when risk assessment has been completed for the purpose of retrofitting existing infrastructure or informing the design process for new infrastructure, as required by the BC Ministry of Transportation and Infrastructure (BCMoTI). Italicized terms are defined in the Climate Change Resilience Guidelines.

It is important to note that the focus of this assurance statement is on providing assurance that the professional has followed the Climate Change Resilience Guidelines—not on guaranteeing that a specific design will perform without issue under future climate conditions.

To: BC Ministry of Transportation and Infrastructure (or other BC Municipality) Date: ________________________

____

____

Jurisdiction and address

With reference to (check one):

☐ New design
☐ Retrofit
☐ Other (specify) ________________________

For the infrastructure

____

Legal description and GPS coordinates of the infrastructure

The undersigned hereby gives assurance that the attached climate change vulnerability risk assessment report on the above-mentioned infrastructure substantially complies with the intent of the Climate Change Resilience Guidelines. The Highway Infrastructure Climate Change Resilient Design Report and the BCMoTI Design Criteria Sheet for Climate Change Resilience[1] must be read in conjunction with this statement.

In preparing that report I have (check to the left of applicable items):
(The items in **BOLD** indicate the minimum level of effort that needs to be expended by the qualified professional in conducting the climate change vulnerability risk assessment.)

Collected and reviewed appropriate background information, including service life of the infrastructure

____ **1. Collected and reviewed appropriate background information, including service life of the infrastructure**

____ **2. Reviewed the proposed or existing infrastructure development on the project**

[1]The Technical Circular on the BCMoTI website titled "Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design" identifies implications of climate change and extreme weather events for engineering project infrastructure components. The BCMoTI Design Criteria Sheet for Climate Change Resilience, which is part of the Technical Circular, enables the listing of infrastructure components impacted by climate change and extreme weather events and provision of adaptation measures included in the infrastructure design.

____ 3. Conducted field work and reported on the results of the field work on and, if required, beyond the project

____ **4. Assembled a qualified team in collaboration with the *owner***

____ 5. Considered any changed conditions on and, if required, beyond the project

6. For the climate change vulnerability risk assessment, I have:

_____ **6.1 reviewed and characterized, if appropriate, future climate and extreme weather event projections and analyses**

_____ 6.2 worked with a climate data provider to obtain relevant future climate and extreme weather event projections

_____ **6.3 estimated the risk to the infrastructure using a BCMoTI/other owner–acceptable risk screening analysis (such as PIEVC protocol)**

_____ 6.4 included (if appropriate) the effects of climate change and land use change

_____ 6.5 identified existing and anticipated future components at risk on and, if required, beyond the project

_____ 6.6 estimated the potential consequences to those components at risk

7. Where BCMoTI has specified a specific level of *climate risk tolerance* that is different from the standard design criteria, I have:

_____ 7.1 compared the level of *climate risk* tolerance adopted by BCMoTI/other owner with the findings of my investigation

_____ 7.2 made a finding on the level of *climate risk* tolerance on the infrastructure based on the comparison

_____ 7.3 made recommendations to reduce the risk on the infrastructure

8. Where BCMoTI has not specified a level of *climate risk tolerance*, I have:

_____ 8.1 described the method of risk assessment used

_____ 8.2 described the assumptions used in arriving at climate projections

_____ 8.3 (where available) referred to an appropriate and identified provincial or national resource for level of risk

_____ 8.4 compared these guidelines with the findings of my investigation

_____ 8.5 made a finding on the level of *climate risk tolerance* for the infrastructure based on the comparison

_____ 8.6 made recommendations to reduce risks

____ 9. Reported on the requirements for future inspections of the infrastructure and recommended who should conduct those inspections

____ 10. Suggested an operations and maintenance schedule to ensure that climate resilience and operational liability are addressed

Based on my comparison between (check one):

- ☐ the findings from the investigation and the adopted level of climate risk tolerance (item 7 above); or
- ☐ the appropriate and identified provincial or national guideline for level of climate *risk tolerance* (item 8 above)

I hereby give my assurance that the standard of practice established in these guidelines has been applied in conducting the *climate change vulnerability risk assessment*, documenting the results in the *Highway infrastructure Climate Change Resilient Design Report*, and informing the design of the *highway infrastructure*.

I certify that I am a *qualified professional* as defined in the Climate Change Resilience Guidelines.

Name: (print) ______________________________ Date: ______________________________

Signature: ______________________________

Address: ______________________________

____

______________________________ (Affix professional seal here)

Telephone: ______________________________

Email: ______________________________

If the *qualified professional* is a member of a firm, complete the following:

I am a member of the firm ______________________________
(Print name of firm)

and I sign this letter on behalf of the firm.

APPENDIX B: BCMOTI CLIMATE CHANGE DESIGN PROCESS AND PROJECT DESIGN CRITERIA SHEET

Technical Circular T-06/15
Date: June 22, 2015
(Revised August 11, 2016)

To:

Executive Directors	Ministry Traffic & Highway Safety Engineers
Regional Directors	Ministry Environmental Engineers
Directors of Engineering Services	Ministry Electrical Engineers
District Managers, Transportation	Operations, Planning & Major Projects
Ministry Structural Engineers	BCMoTI Maintenance Contractors
Ministry Geotechnical Engineers	BCMoTI Design Consultants
Ministry Highway Design & Survey Engineers	Field Services Branch

Subject: Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design

Purpose:

This Technical Circular outlines climate change adaptation considerations in engineering design for the BC Ministry of Transportation and Infrastructure. It serves as a directive to consider climate change and extreme weather events in infrastructure project design. It thus supports the BC Climate Action Plan in developing strategies to help BC adapt to the effects of climate change and extreme weather events.

The BC Ministry of Transportation and Infrastructure is requiring engineering design work to evaluate and consider vulnerability associated with future climate change and extreme weather events and to include appropriate adaptation measures when feasible, for the design life of infrastructure. Vulnerability assessment methodologies, practice guidance, as well as engineering project examples, can be obtained from other agencies such as professional associations. Climate information can be obtained from climate resource providers.

This directive applies to all new projects, as well as rehabilitation and maintenance projects. In so doing, the Ministry will continue to provide a provincial transportation system that is resilient, reliable and efficient regardless of unfolding climate change and extreme weather events.

Background:

The design life of transportation infrastructure is inherently long, and service requirements for roads, bridges, tunnels, railways, ports and runways may be required for decades, while rights-of-way and specific facilities may continue to be used for transportation purposes for much longer.

In addition to usual deterioration, transportation infrastructure is subject to a range of environmental risks over long time spans, including flood, wildfire, landslide, geologic subsidence, earthquakes, rock falls, avalanche, snow, ice, extreme temperatures and precipitation, and storms of various intensities. When global climate change enters this mix, it can create additional challenges for the transportation system.

Infrastructure designers and operators must consider the magnitude of environmental stress that any particular project will be expected to withstand over its design life. Transportation infrastructure is currently designed to handle a broad range of impacts based on historic climate; therefore, preparing for future climate change and extreme weather events is a relatively new concept. Consequences of climate change and extreme weather events present significant and growing risks to the reliability, effectiveness, and sustainability of the Province's transportation infrastructure and operations. Thus, preparing for implications regarding the design, construction, operation, and maintenance of transportation systems to future conditions is critical to protecting the integrity of the transportation system and the investment of taxpayer dollars.

Given the potential for climate change to impact transportation infrastructure in BC, it is prudent to develop directives and guidance for incorporating climate adaptation into engineering designs provided to the BC Ministry of Transportation and Infrastructure. Climate change adaptation is the practice of implementing actions to address projected climate changes and impacts; thus adapting transportation infrastructure to climate impacts is critical to alleviating potential damage, disruption in service, and other concerns. Responding to potential climate impacts, along with associated economic, social and environmental repercussions, presents additional challenges to the responsibility of developing resilient transportation infrastructure and reliably maintaining operational capacity; however, this will result in wise use of resources to protect current and future investments.

What is the scope and application of this guidance? This directive pertains to transportation infrastructure engineering design work by BCMoTI staff and by engineering design consultants and others working on projects for BCMoTI. Many parameters, such as type, location, traffic volume, and design life of transportation infrastructure, will determine the climate change and extreme weather event analysis required. For example, an infrequently used road may only require a summary analysis, while a major highway with structures having a long design life would require rigorous analysis.

In general, for transportation engineering design projects BCMoTI will require:

- Consideration of climate change and extreme weather events
- Assessment of infrastructure and climate vulnerability for the design life of components, indicating relevant information and sources
- Design that incorporates climate change and extreme weather event information, analyses and projections, where feasible
- Development of practical and affordable project design criteria that take adaptation to climate change into account
- *BCMoTI Design Criteria Sheet for Climate Change Resilience* to summarize engineering design parameter evaluation and modification for adaptation to climate change

What is the timeline? Effective immediately for all new engineering design assignments.

What are the expectations of BCMoTI for engineering design staff and engineering consultants? Consultants and staff of BCMoTI involved in new design, rehabilitation and maintenance projects will integrate consideration of climate change and extreme weather event impacts into design parameters and adaptation responses in the delivery of engineering design for Provincial highway projects by applying the following requirements:

1. Reasonable consideration of climate change and extreme weather events appropriate to the scale of the project
2. Using vulnerability assessment methodologies and climate information for design work from sources such as those providers listed in Appendix 2 (and on the BCMoTI Climate Change and Adaptation website)
3. At the concept stages, the design components most at risk from climate change and extreme weather events over the expected project design life
4. At the concept stages, the project designer will summarize changes in temperature, precipitation and other climatic variables over the expected project design life
5. The project designer will identify the vulnerabilities to project design components from these projected climate changes
6. The project designer will develop adaptation design strategies to address climate change vulnerabilities for the project
7. Based on evaluation of climate change effects, the project designer will develop a project-appropriate set of design criteria for climate change and extreme weather event preparedness and resiliency

8. Engineering design parameter evaluation and modification for adaptation to climate change will be summarized and listed on *BCMoTI Climate Change Design Criteria Sheet for Climate Resilience* (Appendix 1)

9. The design team will implement the developed design criteria into the project

Where can I obtain guidance, climate resources and vulnerability analysis tools? For more information and links to resources and tools related to climate change and extreme weather event adaptation, see Appendix 2 (and the BCMoTI website on climate adaptation). These contain links to climate information providers such as the Pacific Climate Impacts Consortium and vulnerability analysis protocols such as the Public Infrastructure Engineering Vulnerability Committee.

What is the BCMoTI Design Criteria Sheet for Climate Change Resilience (included below)? This sheet documents implications to engineering project infrastructure components from climate change and extreme weather events. This sheet will list infrastructure components most at risk of being impacted by climate change and extreme weather events and detail adaptation measures included in the infrastructure design. One criteria sheet is required per discipline involved in design work.

Appendix 1: BCMoTI Design Criteria Sheet for Climate Change Resilience
Appendix 2: Climate Adaptation and Vulnerability Analysis Sources
Appendix 3: What definitions are used in this directive?

Contact:
Dirk Nyland, P. Eng.
Chief Engineer
BCMoTI Engineering Services Branch
Tel: (250) 356-0723
Dirk.Nyland@gov.bc.ca

____
Dirk Nyland, P. Eng.
Chief Engineer

Design Criteria Sheet for Climate Change Resilience

Highway Infrastructure Design Engineering and Climate Change Adaptation
BC Ministry of Transportation and Infrastructure
(Separate Criteria Sheet per Discipline)

Project: (i.e., project name and number)

Type of Work: (i.e., capital/rehab/reconstruction, bridge structures, culverts, interchange/intersection/access improvement, corridor improvement, etc.)

Location: (i.e., GPS, LKI segment and km reference, road names [major/minor], cardinal directions, municipality, electoral district, etc.)

Discipline:

Design Component	Design Life or Return Period	Design Criteria + (Units)	Design Value Without Climate Change	Change in Design Value from Future Climate	Design Value Including Climate Change	Comments / Notes / Deviations / Variances
e.g., Culvert <3m	50yr	Flow Rate (M^3/S)	20	+10%	22	-See work, including climate projections
e.g., Culvert >3m						
						-

Explanatory Notes/Discussion:

(Provide brief scope statement, purpose of project and what is being achieved. Enter comments for clarification where appropriate and provide justification and evidence of engineering judgment used for items where deviations are noted in the design parameters listed above or any other deviations which are not noted in the table above.)

Recommended by: Engineer of Record: ______________________________

(Print name/Provide seal and signature)

Date: ______________________________

Engineering Firm: ______________________________

Accepted by BCMoTI Consultant Liaison : ______________________________

(For External Design)

Deviations and Variances Approved by the Chief Engineer: ______________________________
Program Contact: Dirk Nyland, Chief Engineer BCMoTI

APPENDIX 2

Climate Adaptation and Vulnerability Analysis Sources

BCMoTI Climate Adaptation site

APEGBC – Climate Change

Pacific Climate Impacts Consortium

Analysis Tools – Plan2Adapt etc.

Pacific Institute for Climate Solutions

Climate Insights 101

Public Infrastructure Engineering Vulnerability Committee

IDF_CC Tool (Western University Ontario)

Ouranos (Quebec)

Intergovernmental Panel on Climate Change (IPCC)

Federal Highway Administration – Climate Adaptation (USA)

AASHTO – Transportation and Climate Change Resource Center (USA

APPENDIX 3

What definitions are used in this directive?

1. **Climate Change** – Climate change refers to any significant change in the measures of climate lasting for an extended period of time. Climate change includes major variations in temperature, precipitation, or wind patterns, among other environmental conditions, that occur over several decades or longer. Changes in climate may manifest as a rise in sea level, as well as increase the frequency and magnitude of extreme weather events now and in the future.
2. **Extreme Weather Events** – Extreme weather events can include significant anomalies in temperature, precipitation and winds and can manifest as heavy precipitation and flooding, heatwaves, drought, wildfires and windstorms. Consequences of extreme weather events can include reliability concerns, damage, destruction, and/or economic loss. Climate change can also cause or influence extreme weather events.
3. **Extreme Events** – For the purposes of this directive, the term "extreme events" refers to risks posed by climate change and extreme weather events. The definition does not apply to other uses of the term or include consideration of risks to the transportation system from other natural hazards, accidents, or other human-induced disruptions.
4. **Preparedness** – Preparedness means actions taken to plan, organize, equip, train, and exercise to build, apply, and sustain the capabilities necessary to prevent, protect against, ameliorate the effects of, respond to, and recover from climate change–related damages to life, health, property, livelihoods, ecosystems, and national security.
5. **Resilience** – Resilience is the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.
6. **Adaptation** – Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects.
7. **PIEVC** – Public Infrastructure Engineering Vulnerability Committee
8. **PCIC** – Pacific Climate Impacts Consortium

APPENDIX C: ADAPTATION EXAMPLES FROM PRACTISING PROFESSIONALS

Climate science as it relates to professional engineering is evolving. These are interim guidelines and as such have not yet been applied to the design of highway infrastructure. The examples in this appendix illustrate methods that can be used to incorporate climate change considerations into design. Feedback received on these guidelines during the interim period will inform updates that are made, and users who have successfully applied these guidelines to the design of highway infrastructure are encouraged to submit their reports to Harshan Radhakrishnan, P.Eng., APEGBC Practice Advisor, at hrad@apeg.bc.ca

Submitted reports may be considered for inclusion in the updates to these guidelines or in APEGBC's Climate Change Information Portal.

C-1 COASTAL FLEXIBLE DESIGN EXAMPLE: CAUSEWAY ELEVATION IN CONSIDERATION OF YEAR 2100 AND 2200 SEA LEVELS

Submitted by Eric Morris, P.Eng., M.A.Sc., Kerr Wood Leidal Associates Ltd. (KWL)

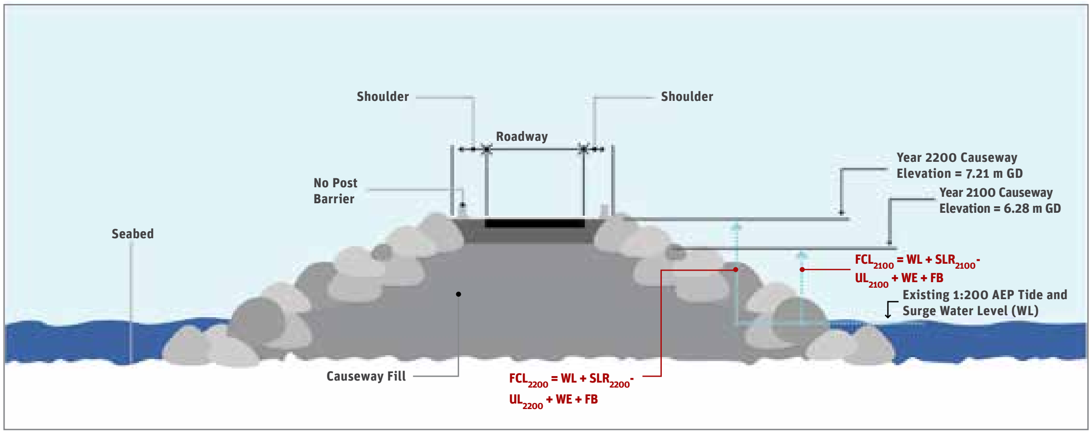
Problem Statement

Determine the minimum elevation for a new two-lane causeway to be constructed adjacent to the sea in an area protected from large waves within the Strait of Georgia. A risk assessment has determined that the causeway is vulnerable to sea level rise and changes in wind and atmospheric pressure conditions. Design elevation to be appropriate for projected sea levels and climate to the year 2100 and to include flexible design to allow for climate adaptation to the year 2200.

Approach

1. Minimum causeway elevation is calculated according to the methodology outlined in the BC Ministry of Forests, Lands and Natural Resource Operations' *Flood Hazard Area Land Use Management Guidelines* (the guidelines) draft amendment. Note that the guidelines are intended as a tool to make *land use* decisions within flood hazard areas, and are not intended as a tool to design roads, but they do specify a risk level for flooding. Only the Flood Construction Level (FCL) provisions have been used to design the causeway; the building setback provisions have not been applied.
2. Obtain the latest provincial policy sea level rise projections from the guidelines.
3. Obtain climate projections from a climate specialist. In this particular example, wind and atmospheric pressure conditions are not projected to change at the project site. Sea level is the only climate parameter that is expected to change.
4. Estimate the existing 1:200 Year Annual Exceedance Probability (AEP) water level through probabilistic analyses of measured water level data and predicted tide data. Adjust data for local effects (e.g., wind set-up) as required.
5. Obtain ground uplift/subsidence data from Natural Resources Canada, Geodetic Survey Division. Note that potential causeway settlement should be considered. In this example, the causeway is expected to rise due to tectonic uplift.
6. Estimate deep water wave conditions though wave hindcasting based on wind data. Determine nearshore wave conditions, considering appropriate wave transformations. Calculate the wave-overtopping rate for the design causeway slope and armouring at various elevations. Note that in this case, the wave run-up/overtopping does not change with water level.
7. Calculate the FCL for the year 2100 and 2200 and determine the required causeway elevation and width to allow the causeway to be raised for sea level rise adaptation to the year 2200.

Figure C-1.1: Causeway cross-section showing year 2100 and 2200 elevations



Design Criteria

Water Level	
1:200 Year Annual Exceedance Probability (AEP) water level as determined through probabilistic analyses of tides and storm surge (WL)	2.74 m Geodetic Datum (GD)
Sea Level Rise	
Allowance for Sea Level Rise to the Year 2100 (SLR_{2100})	1.0 m
Allowance for Sea Level Rise to the Year 2200 (SLR_{2200})	2.0 m
Ground Uplift/Subsidence	
Ground Uplift to the Year 2100 (UL_{2100})	+0.06 m
Ground Uplift to the Year 2200 (UL_{2200})	+0.13 m
Estimated wave effects associated with the Designated Storm with an AEP of 1:200	
Height relative to Still Water Level (SWL) for safe driving at moderate to high speed (0.01 L/s/m overtopping rate) (WE)	2.0 m
Freeboard	
Freeboard allowance (FB)	0.6 m
Notes:	
1. Note that, in general, wave effects may change over time with a changing climate, but in this example, they do not.	

Calculations

Year 2100 FCL and causeway elevation:

$FCL_{2100} = WL + SLR_{2100} - UL_{2100} + WE + FB$

FCL_{2100} = 2.74 m GD + 1.0 m – 0.06 m + 2.0 m + 0.6 m

FCL_{2100} = 6.28 m GD

Year 2200 FCL and causeway elevation:

$FCL_{2200} = WL + SLR_{2200} - UL_{2200} + WE + FB$

FCL_{2200} = 2.74 m GD + 2.0 m – 0.13 m + 2.0 m + 0.6 m

FCL_{2200} = 7.21 m GD

References and Resources

BC Ministry of Forests, Lands and Natural Resource Operations. 2015, Flood Hazard Area Land Use Management Guidelines, Draft amendment to Section 3.5 (The Sea) and 3.6 (Areas Protected by Dikes) of the guidelines (3rd draft, May 7, 2013). Available online at: http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/amendment_to_S35_36_FHALUMG13-05-07.pdf [accessed 20/02/2017].

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C-2 AN APPROACH TO ENGINEERING VULNERABILITY ASSESSMENT OF CLIMATE CHANGE IMPACTS ON FLOOD HAZARDS TO HIGHWAY INFRASTRUCTURE

Submitted by Mariza Costa-Cabral, Piotr Kuraś, and Des Goold, Northwest Hydraulic Consultants Ltd. (NHC)

The BC Ministry of Transportation and Infrastructure (BCMoTI) has been developing vulnerability studies and reports to determine the implications and impacts of future climate change on its infrastructure. Previous studies and reports have been prepared in several parts of the province that follow the PIEVC Engineering Protocol for Infrastructure Vulnerability Assessment and Adaptation to a Changing Climate and that provided guidance through the steps of the vulnerability assessments.

As part of that protocol, and in the wake of consecutive large and damaging floods in 2010 and 2011, BCMoTI retained NHC to conduct an engineering vulnerability assessment of bridge and culvert infrastructure along three BC highway segments: Highway 20 near Bella Coola, Highway 37A near Stewart, and Highway 97 east of the Pine Pass. The Pacific Climate Impacts Consortium (PCIC) provided downscaled climate projections for each of these regions to support NHC's assessment.

Figure C-2.1: Bitter Creek Bridge on Highway 37A, just prior to the washout of its west abutment in September 2011; flow is left to right (September 2011)

NHC's study met the following objectives:

- Improved BCMoTI's understanding of the circumstances that contributed to service interruptions along the highway segments, both climatic and those related to infrastructure design, operation and maintenance
- Evaluated risk outcomes from future climate scenarios based on applying the PIEVC Engineering Analysis process on select bridges and culverts that have been recently impacted by climate events
- Contributed to the development of a best practice document to assist highway infrastructure owners, operators, maintenance personnel and engineering staff address impacts of extreme precipitation

For this project, BCMoTI desired a maximum of three GCM runs. Selection of the three global climate models (GCMs) was based on the recommendations of Trevor Murdock of PCIC. This recommendation was supported by PCIC's work based on GCM performance over western North America, reported in Murdock et al. (2013). PCIC provided NHC with 150 years (1950–2099) of simulated (1950–2000) and projected (2000–2099) daily precipitation and temperature data for the 10x10 km grid cell corresponding to the location of the meteorological station used as historical climate reference for each highway segment. NHC analyzed the PCIC datasets and characterized projected changes in precipitation and temperature for the future mid-century period, 2040–2069, and the late-century period, 2070–2099, as compared to observed and GCM-simulated precipitation and temperature in the historical (reference) period. NHC then modified the historical climate record of each meteorological station in a manner statistically consistent with the GCM-projected changes. The methodology is summarized in Figure C-2.2.

The historic time series and the future scenario time series (Figure C-2.2) were used as input to an existing hydrologic model of Fisher Creek (a stream crossing Highway 97 east of Pine Pass) to predict changes to the 200-year annual maximum hourly flow that occur as a result of the projected climate change. NHC used the results of the Fisher Creek analysis to make inferences regarding climate change impacts on streamflow for the other highway segments, considering the characterization of projected climate changes along those segments.

All three GCM runs predicted large increases in mean annual temperature—for example, along Highway 97, a warming of between 4.5°C and nearly 7°C by the end of the century. In the case of CanESM2, warming is projected to occur rapidly, reaching 4°C by mid-century. All three GCM runs also project increases in mean annual precipitation, in the case of CanESM2 by as much as 40%. Analysis of seasonal changes was outside the scope of this study.

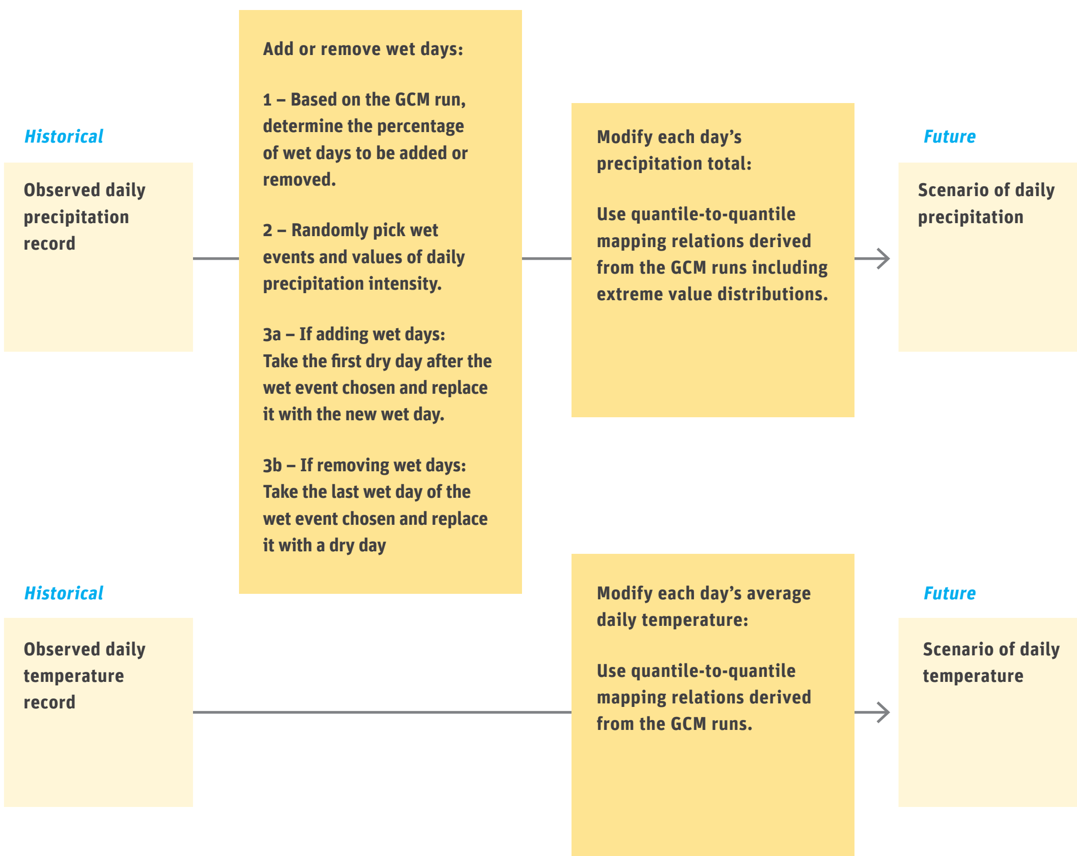
The projected future changes in mean annual precipitation are due in part to changes in the mean intensity of precipitation on wet days, and in part to changes in the mean number of wet days per year. All three GCM runs project rises in mean precipitation intensity on wet days, and two of them project increases in the mean number of wet days per year. The ACCESS1-0 run projects a small decline in wet day occurrence.

Since the simulations have more wet days per year than the station observations, but their wet periods are similar in length, NHC inferred that the dry simulated periods tend to be shorter than the station dry periods. Future projected changes in dry period duration are small.

Important to this study is the occurrence of multiple-day precipitation events. We examined the percentiles of total precipitation accumulated over different periods from 1 day through 30 days. For all three GCMS there appears to be an overall tendency for the projected rate of increase in the 10th percentile to be slightly faster than that of the 50th percentile, and for the rate of increase of the 50th percentile to be slightly faster than that of the 90th percentile, up until mid-century. After mid-century, only the CNRM-CM5 run projects a further increase in the 90th percentile through the late century. CNRM-CM5 does not project increases in the 50th percentile from mid-century to late-century, yet projects increase in the 90th percentile during that same period.

The three downscaled GCM climate simulations provided by PCIC served as the basis for development of future climate scenarios to simulate with the Fisher Creek Hydrologic Model. Figure C-2.2 summarizes our procedure for creating future climate scenario time series. For each climate scenario, the observed precipitation record was modified so that its mean annual number of wet days increased or decreased by the same percentage as simulated by the GCM run (see description of steps in the figure). The resulting daily record was then subjected to daily quantile-to-quantile mapping so as to modify the daily values of precipitation intensity in the same manner as seen in the GCM simulations (i.e., when comparing future projections to the GCM historical simulations). Daily quantile mapping was also used to modify the daily mean temperature to reflect the future changes projected by the GCM simulations.

Figure C-2.2: Summary of the procedure used for creating time series of daily precipitation and temperature for future climate scenarios



C-3 AN APPROACH TO FLOOD HAZARD ASSESSMENT FOR SMALL WATERSHEDS: ASSESSMENT FOR THE CITY OF SURREY ACCOUNTING FOR PROJECTED CLIMATE CHANGE

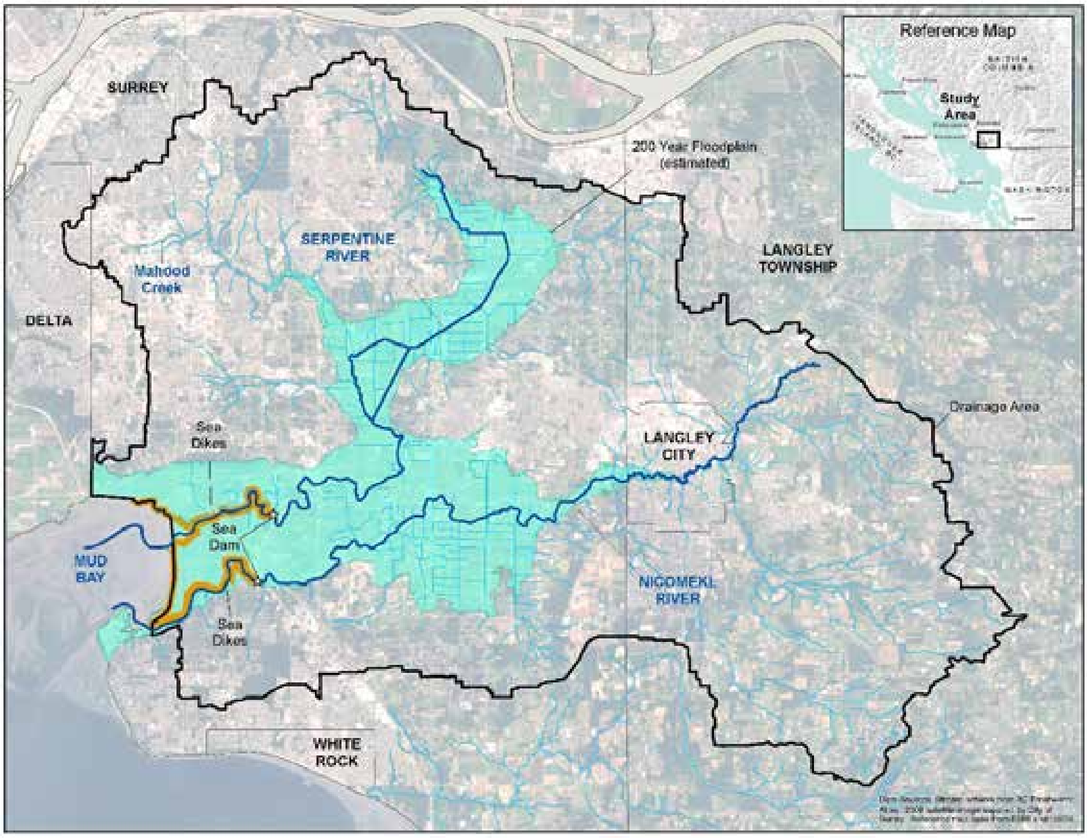
Submitted by Monica Mannerström, Malcolm Leytham, Vanessa O'Connor, and Mariza Costa-Cabral, Northwest Hydraulic Consultants Ltd. (NHC)

The City of Surrey is located on the south coast of British Columbia, just south of the City of Vancouver and north of the Canada/USA border. The greater part of the city is drained by the Serpentine and Nicomekl Rivers. These rivers, with a combined drainage area of about 300 km^2, originate in rolling uplands that have been heavily developed for residential and commercial use. The rivers then flow through flat, low-lying agricultural land to discharge into the Strait of Georgia and the Pacific Ocean. The lowland reaches of both rivers are extensively diked and their flood protection and drainage systems incorporate some 30 pump stations, 170 flap-gated culverts, and a complex network of flow storage areas, canals, ditches and spillways. At their outlets, the rivers drain into the ocean through flap-gated control structures ("sea dams"), with a sea dike protecting the flood plain from ocean flooding (Figure C-3.1).

Flooding of the agricultural lowlands of the two rivers is typically the result of heavy rain or rain-on-snow events, in combination with high ocean tides and storm surge. Sea level rise and increased runoff associated with climate change are expected to have a significant impact on the Serpentine and Nicomekl basins in terms of floodplain extents and the adequacy of the existing flood protection and drainage infrastructure. Of particular concern is the increased risk of flooding at the lowland/upland interface, where relatively modest increases in flood level could have a significant impact on residential and commercial properties.

The City of Surrey developed a scope of work to be conducted in two phases. In the first phase, completed in 2012, analysis of the impacts of climate change focused on the effects of projected sea level rise on flood risk and the infrastructure improvements required to ensure a 200-year level of protection from flooding in the year 2100. The second phase of work, completed in 2014, incorporated projected changes in rainfall regime under climate change scenarios.

Figure C-3.1: Serpentine and Nicomekl watersheds



Inundation of the Serpentine/Nicomekl River floodplain is a function of:

- the volume and temporal distribution of storm rainfall and the watershed's hydrologic response to rainfall
- the time-varying sea level at the river outlets coincident with the storm event
- the hydraulic response of the system (comprising floodplain storage and the various hydraulic infrastructure) to the hydrologic inputs and the sea level boundary condition

This complex system cannot be analyzed directly by statistical means and conventional storm event analysis; that is, it is not possible to state a priori what combination of sea level conditions and storm rainfall event will result in flood depths and inundation extent having an annual exceedance probability (AEP) of 0.5% (return period of 200 years). To avoid the difficulties of a direct statistical joint probability analysis, a continuous simulation approach was adopted whereby long-term (approximately 50-year) simulations of the system's hydraulic performance were conducted, and the simulated annual peak floodplain water levels were subjected to conventional frequency analysis. The approach involved the following steps:

1. An approximately 50-year time series of historic hourly rainfall data was assembled and used as input to an HSPF hydrologic model to produce 50-year time series of simulated hourly runoff under current (nominally year 2010) land use conditions.

2. A hindcasting approach involving reconstruction of historic tide records and numerical modelling of historic storm surge and wind setup was used to develop hourly time series of ocean water levels for the same approximately 50-year time period.

3. The runoff and ocean level time series were then used as boundary conditions for a HEC-RAS hydraulic model of the river and floodplain system, to produce 50-year time series of simulated water levels at selected floodplain locations.

4. Annual maximum water levels at key locations were extracted from the hydraulic model results. These were analyzed through conventional frequency analysis to estimate 200-year (0.5% AEP) floodplain water levels representative of current (year 2010) conditions.

Once simulation of current (year 2010) conditions was complete, floodplain water levels representative of the year 2100 were estimated as follows:

1. Hourly time series of projected precipitation, representing two contrasting future climate scenarios, covering the 21st century, were developed for this study, to be used as input ("forcing") to our calibrated HSPF hydrologic model, in step 6. The projected precipitation time series were developed to be consistent, in a statistical sense, with specific global climate model (GCM) runs, in what concerns daily intensity, storm duration, and the clustering in time of the highest-intensity episodes. The GCM runs of interest were selected from the most recent runs that served as the basis for the recent IPCC (2014) Fifth Assessment Report (i.e., the CMIP5 climate projections). We used GCM precipitation projections downscaled by the Pacific Climate Impacts Consortium (PCIC). Data from 12 GCMs are available from PCIC, and our first step was to analyze their downscaled results. Nearly all of the 12 GCMs project future increases in daily precipitation intensity accompanied by declines in the mean number of precipitation days in a year. The second step consisted in selecting two appropriate GCM runs. It was desired to identify which GCM runs represent, in the context of all PCIC projections, a "severe scenario" and a "moderately high scenario" in terms of flooding risk. The third step consisted in altering the observed historical time series of hourly precipitation at the Surrey Municipal Hall gauge, so as to create the two projected hourly time series. To create each future precipitation time series, the observed historical time series was modified as follows.

2. Precipitation days were removed at random from the observed time series, until the desired number, consistent with the GCM projections, was reached. The daily precipitation totals on the remaining wet days were then increased, so that the distribution of daily precipitation on wet days would be consistent with the GCM projected increases. To this end, the return period of each daily observed precipitation value was estimated, and the value was then replaced by a higher value having that same return period in the future distribution. To estimate return periods for the largest daily precipitation values, a generalized extreme-value distribution (GEV) was fitted to each data set, using a peaks over threshold (POT) methodology (Coles 2001).

3. The HSPF hydrologic model was modified to reflect projected future (year 2100) land use, and produce time series of projected runoff. In the first phase of work, future rainfall input was assumed to be unchanged from the historic record. In the second phase, the projected rainfall time series developed in step 5 were used.

4. A relative sea level time series representative of the year 2100 was developed, considering the effects of absolute sea level rise and land subsidence. Provincial guidelines

(Ausenco Sandwell, 2011) call for an assumed 1 metre absolute sea level rise between 2000 and 2100. The observed sea level rise from 2000 to 2010 was approximately 0.03 m. We therefore assumed a further 0.97 m of absolute sea level rise from 2010 to 2100. Land subsidence was estimated from historic observations at 2.5 mm/year. The net effect of absolute sea level rise and land subsidence results in a relative sea level rise of about 1.2 m from 2010 to 2100. This adjustment was applied to the historic sea level time series from step 2 to represent conditions in 2100.

5. Steps 3 and 4 were repeated using the runoff and ocean level time series for year 2100 to produce revised 200-year floodplain water levels with climate change (sea level rise and rainfall changes).

The following results stem only from the projected rise in mean sea level and changes in land use, but do not yet consider projected changes in precipitation or temperature. Compared to 2010 conditions, the 200-year flood level is expected to increase by 0.9 to 1 m on the approximately 12 km reach of the Nicomekl River upstream from the sea dam. For the approximately 14 km reach of the Serpentine River upstream from its sea dam, the 200-year flood level will increase by about 0.7 m. Further upstream, the flood level increases taper off to 0.1 m, due solely to the impacts of land-use change on peak flows. Floodplain storage cells will see 200-year water level increases ranging from 0.1 to 0.4 m. The modelling assumed that all dikes and the sea dam structures would be raised to prevent overtopping.

In response to the assumed 1-metre sea level rise (per provincial guidelines), the return period for particular flood levels will change greatly. Water levels with a current 72-year return period will on average occur annually by the year 2100. Similarly, the existing 200-year flood level will have an estimated return period of less than two years.

The continuous simulation approach adopted for this work provides a number of significant advantages over traditional event analysis:

- It explicitly captures the joint occurrence of extreme sea levels and severe rainfall events.
- It explicitly accounts for varying duration and amounts of rainfall (and runoff) and the matching of the rainfall with the sea level regime.
- It captures the shift in significance of longer lower-intensity rainfall events under conditions of sea level rise. (Higher sea level implies that longer-duration rainfall events become more important in defining interior flood levels, since the sea dams are closed for longer periods of time.)
- It avoids arbitrary assumptions about the coincidence or lack of coincidence of individual factors that would be required if a direct statistical analysis were attempted.

The information developed provides a necessary first step in understanding the system's response to climate change and the infrastructure improvement that may be necessary to manage future flood risk. The information is, however, subject to large and unquantifiable uncertainty, due to unknown future emissions of greenhouse gases, uncertain response of the global climate system to the atmospheric accumulation of those gases, and incomplete understanding of regional manifestations from such global changes (e.g., Hawkins and Sutton 2010; Kundewicz et al. 2013). Additionally, precipitation processes are very complex and difficult to simulate accurately in models. The downscaling, in space and time, of GCM-projected climate variables, the extrapolation of frequency analyses to long return periods, and the disaggregation of projected daily precipitation to hourly represent additional sources of uncertainty. The sea level and precipitation projections developed in this work should be considered to be plausible representations of future conditions, given the best current scientific information, and do not represent specific predictions. The actual future realizations of precipitation at Surrey will differ from any of these scenarios.

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C-4 CLIMATE CHANGE VULNERABILITY RISK ASSESSMENT OF A SMALL INFRASTRUCTURE PROJECT: STORM SEWER IN CITY X

Introduction

This example prepared by APEGBC serves to illustrate how the principles outlined in the *APEGBC Professional Practice Guidelines – Developing Climate Change–Resilient Designs for Highway Infrastructure in British Columbia* may be applied to small infrastructure projects. The consideration of climate change and extreme weather events in this example is appropriate to the small scale of the project and would allow an EOR to complete the BCMoTI (2015) Design Criteria Sheet for Climate Change Resilience contained in the BCMoTI Technical Circular (T-06/15), *Climate Change and Extreme Weather Event Preparedness and Resilience in Engineering Infrastructure Design.*

Project Description

City X is located in a remote location in British Columbia. The scope of the project was limited to designing a storm water pipe to convey the five-year design flow from a site with the following design parameters:

- Landscaped area (C=0.20) = 1.00 ha (where C is the proportion of impervious area)
- Parking area (C=0.95) = 0.50 ha
- Time of concentration = 10 min for the area, and the pipe is concrete at 2% slope

Given the limited scope of this project, the rainfall intensity was the single climate parameter considered for representative concentration pathway (RCP) 2.6, 4.5 and 8.5 using version 1.0.3892 of the IDF_CC tool developed by the University of Western Ontario (2014).

Climate Change Vulnerability Risk Assessment

Adapting methods used in the City of Barrie's Storm Drainage and Stormwater Management Policies and Design Guidelines (City of Barrie 2009, p. 118), the following equations were applied to calculate flows, pipe diameters from intensity rates generated using the IDF_CC tool:

Composite Runoff Coefficient =

$$\frac{\sum(Area_i)(Coefficient_i)}{Total\ Area}$$

$$i = \frac{A}{(t_d + B)^C}$$

$$Q = \frac{(C)(i)(A)}{360}$$

Using n=0.013, the following equation for pipe flow is used to calculate the pipe diameter:

$$Q = \left[\frac{0.312}{n}\right](D)^{\frac{8}{3}}(S)^{\frac{1}{2}}$$

The full flow velocity was checked using the following equations:

$$V_{full} = \frac{Q_{full}}{A}$$

$$Q_{capcity} = Q_{full}$$

The following climate models were selected in the IDF_CC tool, as they are used by the Pacific Climate Impacts Consortium (2014) in the region of western North America: CanESM2, CCSM4, CNRM-CM5, CSIRO-Mk3-6-0, GFDL-ESM2G, HadGEM2-ES, MIROC5, MRI-CGCM3 and MPI-ESM-LR.

The IDF data were projected under RCP 2.6, 4.5 and 8.5 to the 2080s time period using data from 2070 to 2099. For the future climate scenarios, the intensity, flow and pipe diameter were calculated for each of the mentioned models and then averaged across the models. The values for rainfall intensity, flow and pipe diameter calculated using historical IDF curves and IDF curves under climate change are shown in Table C-4.1.

The IDF data were projected under RCP 2.6, 4.5 and 8.5 to the 2080s time period using data from 2070 to 2099. For the future climate scenarios, the intensity, flow and pipe diameter were calculated for each of the mentioned models and then averaged across the models. The values for rainfall intensity, flow and pipe diameter calculated using historical IDF curves and IDF curves under climate change are shown in Table C-4.1.

Table C-4.1: Rainfall intensity, flows and pipe diameter required under current climate conditions and under Representative Concentration Pathway 2.6, 4.5 and 8.5 scenarios

	Historical IDF Data	IDF_CC RCP 2.6 Data	IDF_CC RCP 4.5 Data	IDF_CC RCP 8.5 Data
Rainfall intensity (mm/hr)	98.1	114.8	119.2	138.1
Flows (m^3/s)	0.184	0.215	0.224	0.259
Pipe diameter required (mm)	335	355	360	380
Nominal pipe diameter (mm)	350	350/375	375	375/425

Recommendation

The actual pipe diameter is 0.381 m and, as shown in Table 1 the pipe diameter required under current rainfall intensities is 0.335 m. It was noted that the actual diameter of the pipe exceeded the pipe diameter required under RCP 2.6, 4.5 and 8.5 scenarios. Therefore, it was concluded that no adjustment in design was required and that the storm sewer pipe is already sufficient to accommodate flows across a range of future projections in rainfall intensities. It should be noted that the pipe diameter required under RCP 8.5 is just 0.001 m smaller than the actual pipe diameter; therefore, the owner of the storm sewer may wish to enhance their monitoring of the storm sewer pipe and revisit the option of upsizing the pipe diameter in the future.

Discussion

There are a number of factors to consider when using the data produced by the IDF_CC tool to inform the design of the storm sewer. It is important to note the inherent uncertainty in statistical downscaling from global climate models. As a result, as global climate models and the tools for calculating IDF curves evolve, it may be appropriate for the owner of the infrastructure to keep the IDF curves and the flood plain maps that could influence the design up to date.

Although the conclusion reached for this small infrastructure project was that no changes should be made to the storm sewer design, it is important that the IDF curves under projected climate change scenarios were considered in the design process in BCMoTI projects. As outlined in a study conducted by the Town of Creston, due to the high cost of overdesigning pipe diameter, alternative approaches that focus on runoff detention, temporary storage, infiltration and runoff may be considered (Paré 2015). Alternative approaches that may be used include redirecting runoff water into swales, sand filters, detention ponds and wetlands. It should be noted that the performance of the design will only be assured with proper inspection and maintenance of the storm sewer during its service life. Regular inspection will detect any debris or vegetation that may block or partially block the conveyance of water through the sewer, thus not allowing it to perform as it was designed.

Engineers may currently face challenges in understanding projected climate data and incorporating it into their design of public infrastructure. To facilitate the use of projected climate data in design, BCMoTI is working with the Pacific Climate Impacts Consortium to develop climate data that engineers can use in their design of public infrastructure.

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C-5 UNIVERSITY OF SASKATCHEWAN ASSESSMENT OF THE ENGINEERING BUILDING'S VULNERABILITY TO CLIMATE CHANGE: A SUMMARY

Introduction

This memo summarizes the methods and findings from *University of Saskatchewan: Assessment of the Engineering Building's Vulnerability to Climate Change* (Associated Engineering 2012). The approach taken to conducting the climate change vulnerability risk assessment as outlined in this study may be applied to highway infrastructure projects. A similar method to the method detailed in this study may be applied to demonstrate that the appropriate standard of practice as outlined in the *Professional Practice Guidelines – Developing Climate Change–Resilient Designs for Highway Infrastructure* (Climate Change Resilience Guidelines) has been applied.

Project Overview

This project was funded by the University of Saskatchewan (the University) and Engineers Canada to assess potential vulnerabilities of the University's engineering building to climate change. Associated Engineering conducted a risk assessment using the PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment (the Protocol) developed by Engineers Canada (2011) and prepared a report on the impacts that future climate change may have on the existing engineering building and on the proposed building expansion. The scope of the project included the current design, construction, operation and management of the infrastructure, in addition to planned upgrades or major rehabilitation projects in the planning stages. This project aimed to provide information that the University can use in its planning and policy development.

The University of Saskatchewan College of Engineering Building was constructed in 1912, and additions and upgrades were made to the building between 1925 and 2000. The building is used by administration, faculty, researchers, students and maintenance and operations staff.

Risk Assessment Process

To conduct the risk assessment, the project used the protocol, which consists of the following steps:

1. Project Definition
2. Data Gathering and Sufficiency
3. Risk Assessment
4. Engineering Analysis
5. Recommendations

As emphasized in the Protocol and in the Climate Change Resilience Guidelines, a multi-stakeholder approach is recommended when conducting a risk assessment. In this study the multidisciplinary project team was composed of individuals from the University of Saskatchewan, Engineers Canada, Associated Engineering, Summit Environmental, MWH Global and a Project Advisory Committee (PAC).

The project team used steps 1 and 2 to set initial boundary conditions for the study by determining the infrastructure components to be assessed and the climate parameters under consideration. For the first step of the Protocol, Project Definition, the team collected general information and identified infrastructure components. Site visits, background reports, drawings and interviews were used to gather data to identify components of the infrastructure for the study. In the second step, Data Gathering and Sufficiency, the team defined infrastructure components and documented the current age, capacities, loads and design basis for each component. Record drawings, condition assessments and anecdotal knowledge provided sufficient information to gain an understanding of the function of the infrastructure components to be investigated.

The proposed building expansion was still in the conceptual stage and infrastructure components had not yet been defined. As the age, capacities, loads and design basis for the expansion was not available, the project team extracted components from the conceptual expansion design and conducted a "risk sensitivity analysis." This approach allowed the University to note and reduce possible negative impacts of the climate on planned installations.

Historical and projected climate data were obtained for temperature and temperature derived parameters, precipitation and precipitation-derived parameters, and other parameters, including wind and extreme weather.

To establish climate conditions for the 1971–2000 baseline period, the team gathered observational weather data from Environment Canada's Canadian Climate Normal and the Canadian Daily Climate Data from the Saskatoon Diefenbaker International Airport station.

Projected climate data were obtained for the 2020s, 2050s and the 2080s from Climate WNA (http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna/), the Canadian Climate Change Scenario Network (CCCSN; http://ccds-dscc.ec.gc.ca/?page=main&lang=en), the Pacific Climate Impacts Consortium (PCIC; www.pacificclimate.org/analysis-tools/regional-analysis-tool) and various literature sources. An ensemble of Global Climate Models (GCMs) for the A2 emissions scenario from the fourth assessment report from the International Panel on Climate Change (IPCC) were used for the engineering analysis.

To conduct the risk assessment, the project team used the PIEVC Worksheet 3 to develop a risk assessment matrix to examine the interactions between the infrastructure components and climate events. This worksheet allowed the project team to assess risk in terms of the likelihood and severity of the climate/infrastructure interactions and responses and to establish risk thresholds in order to determine infrastructure components that required further analysis.

The project team held a group interview with stakeholders at the University to get feedback on the risk assessment process. The results from these interviews informed the development of workshops and the risk assessment process. The project team held a workshop with representatives from various groups of the Facilities Management Division at the University to provide an overview and discuss the risk assessment. The project team compiled the information gathered during the workshops, which was used in completing the finalized risk assessment.

Risk Assessment Findings

The results of the risk assessment indicated how the structural infrastructure, electrical infrastructure and supporting systems would be impacted by the projected climate events. The various infrastructure climate interactions were ranked as low, medium or high risk based on the risk factor developed through the risk assessment process.

Engineering Analysis

In the fourth step of the Protocol, the project team carried out further engineering analysis on the climate-infrastructure interactions that were assessed as "medium risk" during the risk analysis process.

Risk Sensitivity Analysis

The Protocol is designed to assess the vulnerability of existing infrastructure and requires a range of information to conduct the assessment. The expansion of the University's engineering building was in the conceptual stage, so the required information for a PIEVC risk assessment was not available. The project team extracted components from the conceptual expansion design and conducted a "risk sensitivity analysis" to allow the University to minimize possible conflicts between climate effects and planned installations for the new building. Due to the number of common infrastructure components between the existing and propose expansion of the engineering building, the project team focused the risk sensitivity analysis on the components of the expansion that would be significantly different from the existing building.

The team then created a qualitative scale to assess the sensitivity of each of the new infrastructure components to climate change. A simplified scale, where the sensitivity of the components to climate change was ranked as low, medium or high, was used due to a lack of available information on the construction of the infrastructure components. The project team made recommendations to address sensitivity where there was medium or high sensitivity of the infrastructure component to climate change.

Recommendations

The findings of this report are limited to the availability of data, the technology available for analysis and the time available to the team. The project team identified the following limitations of the report:

- The engineering building functions as part of the University of Saskatchewan's campus, which functions as a system.
- In consideration of the time frame and the scope of the project, infrastructure components were grouped together.
- There are a number of assumptions and uncertainties associated with using GCMs.
- The model technology is evolving.
- Further research is needed to develop predictions of extreme weather events.
- There were limitations of analysis team knowledge of existing infrastructure.
- There were limitations due to the difficulty of completing a risk assessment for a building that has not yet been designed.

As a result of the risk assessment, the project team made a number of recommendations to the University of Saskatchewan Facilities Management Division. The recommendations arising from the study were grouped into remedial actions, management actions and additional study required. The project team identified a number of high-priority building components that they recommended the University address immediately. The highest-priority building components included walkways; roofing; heating, ventilation and cooling adequacy; and reliability of the power supply to the building.

Additionally, as a result of the risk sensitivity analysis, the project team made a number of design recommendations concerning the proposed engineering building expansion. These included recommendations to ensure that the structure is designed to account for the additional loading that will occur due to large increases in wind gusts and to ensure that the building drainage is adequately sized to handle large storm events.

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C-6 DEVELOPMENT OF IDF CURVES UNDER A CHANGING CLIMATE IN THE TOWN OF CRESTON: EXECUTIVE SUMMARY

Columbia Basin Trust, through its former Communities Adapting to Climate Change Initiative (CACCI), has supported the Town of Creston in this project.

This report presents the results of an update to the Intensity-Duration-Frequency (IDF) curves for the Town of Creston considering a range of climate change projections over three future time horizons. A comparative analysis of the effect on stormwater infrastructure design was then performed using the historical, current and future IDF curves for the 2020s, 2050s and 2080s.

IDF curves are an essential engineering design tool for all stormwater systems. Currently the practice of updating IDF curves is based on historical climate events and assumes that extreme events will not vary significantly over time. But the climate is changing. Extreme weather events such as high-intensity rainfall are occurring more frequently and with increased severity, resulting in challenges for designing infrastructure that will be in place well into the future. If stormwater infrastructure continues to be designed based on historical climate events, there is an increased risk of infrastructure failure and flooding. Hence, adaptation measures for mitigation of the potential impacts of the climate change to the municipal infrastructure are extremely important for municipal governments. Consequently, municipalities should consider developing the IDF curves under a changing climate as initial steps in minimizing municipal risk issues to the municipal stormwater infrastructure.

The projected IDF curves were generated with the web-based Intensity-Duration-Frequency under a Changing Climate (IDF_CC) tool by inputting local historical climate station data for Creston. Outputs from the tool for all three representative concentration pathways, low (2.6), medium (4.5) and high (8.5), were generated, but as the current global emissions trajectory is tracking higher than the worst-case scenario, all subsequent infrastructure analysis was limited to the results from the RCP 8.5 output. Without substantive socio-political action in support of emissions reduction, it is very unlikely that the current emissions pathway could be redirected to the low or even medium trajectory within the next 35 years. The risk of overdesign by choosing the RCP 8.5 over the RCP 2.6, would result in a 30% increase in intensity in the 2080s time period.

Rainfall intensity increases above historical values associated with RCP 8.5 (all return periods and all durations) were developed using the model ensemble. The average increases are 16%, 26% and 42%, respectively, for the 2020s, 2050s and 2080s.

The Town of Creston chose a culvert on Dodd's Creek crossing under 5th Avenue to test the effects of applying the results of the three future IDF curves in comparison to the historical and current design IDF curves. The flow at the culvert resulting from the projected 5-year storm in the 2080s is only 13% lower than flow from the 1983 100-year-design storm. From the current IDF curve data to the 2020s, 2050s and 2080s, the flows generated by the 5-year return period increases in range from 15% to 36% and the 100-year return period increases in range from 16% to 29%.

The impact on infrastructure design will vary depending on specific situations and the type of infrastructure being assessed. The increase in 5-year and 100-year flows due to the future climate change predictions will result in increased frequency and magnitude of flooding.

There is an inevitable level of uncertainty to consider in using climate modelling, as it relies in part on our understanding of future greenhouse gas (GHG) emissions and in part on our understanding of how the earth's climate system will respond to the changes in GHG concentrations in the atmosphere. Additional uncertainty in the results presented in this work includes assumptions related to how projections of sub-daily extreme precipitation are extrapolated from daily information, and the uncertainty associated with these assumptions is not adequately defined. These assumptions can result in underestimating the sub-hourly intensities and therefore flows. The revised IDF curves will provide Town of Creston staff with advanced decision-making capacities with respect to stormwater infrastructure design and flood control projects.

However, discretion should be used by designers where infrastructure must quickly handle peak flow events.

Source

Paré, E. (WSP Canada). 2015. Development of IDF Curves under a Changing Climate, Town of Creston.

C-7 A SUMMARY OF PIEVC RISK ASSESSMENTS CONDUCTED BY THE BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

To date the BC Ministry of Transportation and Infrastructure (BCMoTI) has applied the PIEVC Engineering Protocol to conduct a climate risk assessment of a number of highways and highway segments. This memo summarizes the climate parameters and infrastructure components assessed for the following highways and highway segments:

- Coquihalla Highway – Hope to Merritt section
- Yellowhead Highway 16
- Highway 20 in the Bella Coola Region
- Highway 37A in the Stewart (Bear Pass) Region
- Highway 97 in the Pine Pass Region

In 2010, the BCMoTI applied the PIEVC Engineering Protocol to identify components of the Coquihalla Highway Merritt South Road Section that were at risk of failure, loss of service, damage or deterioration due to the impacts of climate change (BCMoTI and Nodelcorp 2010).

In 2011, the BCMoTI conducted a similar study for the Yellowhead Highway. In this study the BCMoTI applied the PIEVC Engineering Protocol to develop future climate risk profiles of transportation and infrastructure on a section of the Yellowhead Highway and analyzed components with high risk elements (BCMoTI and Nodelcorp 2011)

The BCMoTI applied the lessons learns from the Coquihalla and Yellowhead highway studies in 2014 to conduct an engineering vulnerability assessment of three highway segments. Using the PIEVC Engineering Protocol, the BCMoTI identified components at risk of failure, loss of service or damage in two coastal highway segments—Highway 20 in the Bella Coola region and Highway 37A in the Stewart (Bear Pass) region—and one interior highway segment—Highway 97 in the Pine Pass region (BCMoTI et al. 2014).

As illustrated by Table 1, there is variation in the infrastructure component–climate parameter interactions that each study examined. The table serves as a quick summary of the PIEVC Engineering Protocol risk assessments conducted by BCMoTI. The full reports can be accessed through the links in the list of references below or in the “Adaptation Case Studies” section of APEGBC’s Climate Change Information Portal, which can be accessed at www.apeg.bc.ca/climateportal.

References

BC Ministry of Transportation and Infrastructure (BCMoTI); Nodelcorp Consulting Inc. 2010. Climate Change Engineering Vulnerability Assessment: Coquihalla Highway (B.C. Highway 5) Between Nicolum River and Dry Gulch. Available online at: http://pievc.ca/sites/default/files/coquihalla_highway_nicolum_river_and_dry_gulch_final_report_web.pdf [accessed: 20/02/2017].

BCMoTI; Nodelcorp Consulting Inc. 2011. Climate Change Engineering Vulnerability Assessment: B.C. Yellowhead Highway 16 Between Vanderhoof and Priestly Hill. Available online at: http://pievc.ca/sites/default/files/bcmoti_yellowhead_highway_-_vulnerabuility_report_web.pdf [accessed: 20/02/2017].

BCMoTI; Nodelcorp Consulting Inc.; Pacific Climate Impacts Consortium. 2014. Climate Change Engineering Vulnerability Assessment of Three British Columbia Highway Segments. Available online at: www.th.gov.bc.ca/climate_action/documents/hwy20_bella_coola-hwy37A_Stewart-hwy97_Pine Pass.pdf [accessed: 20/02/2017].

Table 1: Summary of Infrastructure Component-Climate Parameter Interactions Examined in BCMoTI Studies

This table summarizes the infrastructure component–climate parameter interactions that have been examined in BCMoTI PIEVC Engineering Protocol risk assessment studies. Interactions marked with a "C" were examined in the Coquihalla Highway study, interactions marked with a "Y" were examined in the Yellowhead Highway study, interactions marked with a "BC" were examined in the Bella Coola study, interactions marked with an "S" were examined in the Stewart study, and interactions marked with a "PP" were examined in the Pine Pass study. Interactions marked with "All" were examined in all of the studies listed.

Infrastructure Components	High Temperature	Low Temperature	Average Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Total Annual Rainfall	Extreme High Rainfall	Light Substantial Rainfall	Heavier Substantial Rainfall	Sustained Rainfall	Snow (Frequency)	Snow Accumulation	Rain on Snow	Freezing Rain	Rain on Frozen Ground	Snow Storm/Blizzard	Rapid Snow Melt	Snowmelt Driven Peak Flow Events	Magnitude of Storm Driven Peak Flow Events	Frequency of Storm Driven Peak Flow Events	High Wind/Downburst	Hail/Sleet	Ground Freezing	Ice/Ice Jams
Surface – Asphalt	C, Y	C, Y		C	C, Y	C	C		C				C	C		C		C			C	C			Y	
Pavement Marking	C, Y	C, Y		C	C, Y								C	C		C		C								
Shoulders (including gravel)	Y				Y				All	BC, S, PP	BC, S, PP	Y	BC, S, PP, C	BC, S, PP, C		C		C		PP	BC, S, PP, C	S, PP, C				
Barriers					C				Y				C	C				C								
Curb	C, Y	Y			C, Y				Y				BC, PP, C	C												
Luminaires													C	C		C	Y	C					Y			
Poles						Y							C	C		C	Y						Y			
Signage						C, Y							C	C		C	Y	C					Y			
Ditches				C	C, Y			Y	All	BC, S, PP	BC, S, PP	Y	BC, SS, PP, C	BC, SS, PP, C	All		S	C	BC, S, PP, Y	BC, S, PP,	BC, S, PP, C	BC, S, PP, C				S
Embankments/ cuts	Y			C	C, Y	C	C	BC, S, PP, Y	All	BC, S, PP	BC, S, PP	Y	C	BC, S, PP, C	BC, S, PP, Y		S	C	BC, S, PP, Y	BC, S, PP	BC, S, PP, C	BC, S, PP, C				S

Hillsides	Y			C	C, Y			BC, S, PP, Y	All	BC, S, PP	BC, S, PP	Y	C	BC, S, PP, C	All		S		BC, S, PP, Y	BC, S, PP	BC, S, PP, C	BC, S, PP, C				S
Protection Works/Armoring								BC, SS, PP	BC, S, PP	BC, S, PP	BC, S, PP			BC, S, PP	BC, S, PP		S		BC, S, PP	BC, S, PP	BC, S, PP	BC, S, PP				BC, S, PP
Engineered Stabilization Works					C	C	C	BC, S, PP	S, C					BC, S, PP	S		S		BC, S, PP	BC, S, PP	BC, S, PP, C	BC, S, PP, C				S
Avalanche (Inc Protections Works)		C		C	C	C	C		C				C	C	C	C		C			C	C				
Debris Torrents (Inc Protection Works)	C			C	C	C	C		C				C	C	C						C	C				
Structures that Cross Streams	C, Y	C, Y		C	C, Y	C, Y	C	Y	All		PP	Y			BC, S, PP, Y	C	S, Y		BC, S, PP, Y	BC, S, PP, Y	BC, S, PP, C	BC, S, PP, C	Y			BC, S, PP, Y
Structures that Cross Roads	C, Y	C, Y		C	C, Y	C, Y	C,		C, Y			Y			Y	C	Y				C	C	Y			
MSE Walls/Retaining Walls					C				S						S		S		S	S	C	C				S
Road Sub-Base											PP										BC, PP	BC, PP				
River Training Works (Rip Rap)		C		C				Y	C, Y			Y							Y	Y	C	C				Y
Pavement Structure		C		C, Y	C, Y	C, Y	C	Y				Y													Y	
Detail Drainage																					S	S				

Drainage Appliances					C, Y	C		Y	PP, C, Y		PP	Y		C	PP, C, Y	C	Y		Y	PP	C			Y		
Sub Drains		C, Y			C, Y	C	C	Y	C, Y			Y			Y						C					
Catch Basins				Y	C	C		Y	PP, C, Y		PP	Y		C	PP, C, Y	C	Y		Y		C	C		Y		
Grates																										
Culverts > 3 meters		C, Y		C	C, Y			Y	All	BC, S, PP	BC, S, PP	Y			BC, S, PP, Y		BC, S, PP		BC, S, PP, Y	BC, S, PP, Y	BC, S, PP, C	BC, S, PP, C		Y		BC, S, PP, Y
Culverts > 3 meters		C, Y		C	C, Y			Y	All	BC, S, PP	BC, S, PP	Y			BC, S, PP, Y		BC, S, PP		BC, S, PP, Y	BC, S, PP, Y	BC, S, PP, C	BC, S, PP, C				BC, S, PP, Y
Asphalt Spillway and Associated Piping/ Culvert	C, Y	C			C, Y			Y	C, Y			Y		C	C	C	Y		Y		C			Y		
Bridge End Fill									BC, S, PP		BC, S, PP				BC, S, PP				BC, PP	BC, S, PP	BC, S, PP	BC, S, PP				
3rd Party Utilities									PP, C, Y		PP					C	Y			PP	PP, C	PP				
Railway								Y	PP, Y		PP	Y			Y		Y		Y	PP, Y	PP	PP				

APPENDIX D: OVERVIEW OF CLIMATE CHANGE

D-1 BACKGROUND: HISTORICAL CLIMATE VARIABILITY AND CLIMATE CHANGE IN BC

To provide context for future climate change effects in British Columbia, this section considers the degree of climate variability that has been experienced historically, in comparison with projected climate change. The data presented in this section serve to show trends in projected climate change. As the field of climate science as it relates to professional practice is evolving continuously, this section should be used only as a primer and should 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 produced by the combined factors of:

- 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)

Of these factors, topography and geography can be considered as stationary. However, the 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 months' duration, though longer phases have been recorded, and occur on a frequency of 2 to 7 years (National Ocean Service 2016).Typical El Niño effects are likely to 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 n.d.).

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 normals. 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 1°C, and approaching 2°C in northern regions of the province, are 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 2015).

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 province-wide basis, climate change projections generally indicate warmer and shorter winters, with longer summer periods. Total precipitation will increase, with a greater proportion concentrated in the shorter winter periods. During the summer, precipitation will decrease. However, the magnitude of these changes is not uniform over the province, and can vary significantly even within a given region due to topographic or orographic effects and local influences. Table D-1 summarizes the average projected temperature change by region, and the range in the projections. Table D-2 summarizes the projected changes in key temperature/heat indices (growing and heating degree days, and frost-free days), while Table D-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 2.5, 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 D-1: 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 2015

Table D-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 2015

"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 and the first frost in the fall (Natural Resources Canada 1981c).

Table D-3: Projected % 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 2015

D-1.1 Temperature

Overall projections indicate there will be higher average temperatures throughout the province, with a greater likelihood of extreme warm periods than was historically experienced or occurs currently. Increased fire risk is expected, especially when combined with the effects of reduced summer precipitation and reduced summer soil moisture (see D-1.2). Extreme high temperatures may place a 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 precipitation as snow. A greater proportion of winter precipitation will run off and will not be retained in watersheds for release during the spring melt (freshet) or contribute to soil moisture during the summer. Freezing elevations will be higher. 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.

Due to warmer winter temperatures, a significant decrease in heating degree days is expected, representing a decreased use of energy to heat structures and a beneficial effect. Similarly, an increase in frost-free days is expected, accompanied by an increase in growing degree days, representing longer growing seasons and the possibility of greater agricultural yields and utilization of farmland. However, this benefit to agriculture may be negated by changes in summer precipitation and reduced winter snowpack, as discussed below (PCIC 2015).

D-1.2 Precipitation

Average annual precipitation is generally projected to increase throughout British Columbia. Extreme precipitation events will increase in magnitude and frequency. Accordingly, 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 as snowpack. Increased soil moisture may increase the potential for slope instability in poor draining soils. Increased loading on engineered soil retaining structures may result.

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 2015).

D-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 a greater stress on drainage systems in low-lying coastal areas.

During extreme storm conditions, wave run-up and storm-surge effects, which are secondary effects relative to temperature and rainfall and that cannot be predicted with certainty at this point, will be magnified, increasing the risk of overtopping of sea dykes, damage to coastal infrastructure and flooding of low-lying areas.

D-1.4 Other Climate Impacts

Other potential changes in climatic conditions are not as readily quantified. However, more extreme storm events, as represented by increases in the magnitude and frequency of precipitation, will likely be accompanied by an increase in extreme winds. 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.

D-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 C.

D-3 CLIMATE PROJECTIONS

Incorporating climate change effects into infrastructure design and management requires that suitable data and information on potential future climate conditions be identified, and the required parameters extracted in a form useful to the design professional. In order to responsibly undertake such an effort, a basic understanding of the process of climate modelling is essential. 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.

D-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 are used to 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. Recently, more comprehensive earth system models (ESMs) have become established. 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 CO2 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 D-4, in terms of being most applicable to western North America (i.e., British Columbia). Each model is generally run with a number of emissions scenarios (See D-3.3) and over multiple runs. 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 D-4: Projected change in temperature indices by 2050s, from 1961 to 1990 baseline, by region

	Model Name	Institute ID	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	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 2015

D-3.2 Downscaling

Most highway infrastructure projects are local or regional in scope, and are carried out at spatial scales far smaller than the resolution of GCMs. Also, most GCM output has temporal resolution on the order of days. For infrastructure design or assessment purposes, finer-resolution (both spatial and temporal) data are required. Accordingly, a valid process for extracting relevant data from the coarse-scale GCM results is required.

The process of producing higher-resolution data suitable for analysis and design at a local scale is referred to as "downscaling." Two techniques are used to downscale from large-scale GCM output: statistical downscaling and dynamic downscaling, using regional climate models.

Statistical downscaling makes use of historical climate data at both the global and local scale and output data produced at a coarse scale by a GCM for the same period.

Typically, the downscaling technique attempts to adjust for any biases evident 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 (which has been 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 parameters, 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, they are potentially subject to inaccuracy due to large-scale errors in the future condition GCM output data that provide the boundary conditions for the RCMs. These issues are generally addressed by additional correction using statistical processes.

D-3.3 Greenhouse Gas Emissions Scenarios

Climate projections require that a forcing effect 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 are used to 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 have been used in climate change projections. Developed in 2000 by the IPCC for the Third Assessment Report on climate change, the Special Report on Emissions Scenarios (SRES) scenarios were employed until 2010. The SRES scenarios were then superseded by the representative concentration pathway (RCP) scenarios. Each set is described briefly below.

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.

Representative Concentration Pathway Scenarios

Representative concentration pathway scenarios are based on GHG concentration pathways, which could result from 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/m^2), 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 D-5.

Table D-5: 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).

D-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. From a simple perspective, projected climate data can be divided into three categories on the basis of their characteristics, detail, complexity and ease of application (Charron 2014):

- 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 expert will likely be required with the higher categories.

The category of a required dataset can be 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 (2014), 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 is presented is also an important consideration in making the climate projection data suitable for use. Climate data can be provided in a variety of formats that may contain the same information, but that may ease or hinder its use. A range of formats are possible, including 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 discussed briefly 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 are needed, 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.

D-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).

D-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).

D-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 APEGBC'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.

D-4.1 Pacific Climate Impacts Consortium (PCIC)

The Pacific Climate Impacts Consortium (PCIC; www.pacificclimate.org/) is a not-for-profit corporation at the University of Victoria and is a centre 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. It serves as a primary resource for climate change information for British Columbia.

D-4.2 Intensity–Duration–Frequency Climate Change (IDF_CC) Tool

The IDF_CC (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 makes use of the most recent Environment Canada IDF datasets, which were revised in December 2014. 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.

D-4.3. Environment Canada – Engineering Climate Datasets

Environment 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

D-4.4 Natural Resources Canada – Climate Adaptation Website

The Impacts and Adaptation website of Natural Resources Canada (www.nrcan.gc.ca/environment/impacts-adaptation/10761) 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.

D-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

D-4.6 CLIMDEX

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 (www.climdex.org/overview.html). 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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APPENDIX E: TOOLS AND RESOURCES FOR CLIMATE CHANGE ADAPTATION

For an up-to-date list of tools and resources for climate change adaptation, visit the APEGBC Climate Change Information Portal, at www.apeg.bc.ca/climateportal

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